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Review

The Framework of the Principles of Sustainable Urban Ecosystems Development and Functioning

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Abstract: Nowadays, the increasing rate of human population in urban areas and the importance of urban functions pose a number of ecological cross-boundary challenges. The scientific research of the twentieth and twenty-first centuries revealed dramatic consequences of human intervention into natural ecosystems. The outcome of inadequate consumerism, which promotes industrial growth, and the pursuit of a better life is not only damaging to the natural ecosystems, but will eventually lead the World to dramatic climate change outcomes. Therefore, scientists are looking for ways for sustainable urban transformation without endangering the human population and the environment. According to the identified assumptions, the article investigates the principles of sustainable urban ecosystems. The authors consistently seek to explain the concept of sustainable urban ecosystems in both a broad and narrow sense, focusing on the individual constructs of this term—sustainability, city and ecosystems. The theories and approaches of urbanization and ecosystems are also analyzed in the article in order to highlight the opportunities and specific features of the application. The principles of sustainable urban ecosystems are provided in the modeled system which exposes the interfaces of identified principles and can be used for future studies.

Keywords: ecosystem; sustainability; sustainable ecosystems; sustainable city; sustainable urban ecosystems

1. Introduction

Sustainable ecosystems are considered to be the goal of today's society, smoothly linked to the values and culture of sustainability. The sustainable ecosystem is characterized by its' durable, autonomous (independent) and dynamic features. Sustainable ecosystems are the ones that, despite environmental disturbances, retain a characteristic diversity of functional groups, productivity, soil fertility and the rate of the biogeochemical cycle [1]. In the studies of ecosystems and its' management, fundamental elements of environmental sustainability are the biosphere, hydrosphere, geosphere, atmosphere and their interrelationship. In contrast, the perspective of urban ecosystems research focuses on the ecological structure and functions containing biophysical aspects and ecological regulation of system dynamics.

The city, as a complex and open system, performs a variety of nationally important functions, such as social, political and economic. Natural resources, including water, food, energy and fertile land are the basis for populations' existence and prosperity in the World, which, however, is dependent on humanity's consumption rates [2]. It means that humans are fully addicted to ecosystem services and environmental conditions. Recently, more than half of the human population lives in urban territories. According to the statistics provided by the United Nations, today, 3.5 billion people live in cities [3] and the number is projected to reach 5 billion by 2030 and 6 billion by 2045 [4]. This means that the population of urban areas will grow 1.5 times in the coming decades. However,

this would determine even bigger demand for various natural resources located in the urban area in the future. According to Giljum et al., today, the human population extract and use around 50% more natural resources than when compared to 30 years ago and use approximately 60 billion tons of raw materials annually [2]. It is already proved that deforestation, water shortage and climate change are the consequences of the consumption of natural resources in the developed world and emerging countries [5]. Current studies predict, complement and elaborate on the growth of population and demand for agricultural products to be 70–100% until 2050 [6], while causing a negative impact on food security and environment issues such as the growth of Green House Gases (GHG) emissions, degradation of ecosystems, biodiversity loss and etc. [7]. The study of Chen et al. also focuses on the issue of energy shortages [8]. The globalization of the problems of sustainable urban ecosystems has led to the fact that the current shared goals are being implemented in different continents, states and cities around the World. The growth of the human population is only a part of the problem. Despite the fact that the total urban area of the World occupies only 3% of a whole Earth surface, it accounts for 60–80% of energy consumption, 75% of CO_2 generation and 90% of total air pollution all over the World [3]. It also has a negative impact on freshwater supply, wastewater, the living environment and public health. It has been observed that resource efficiency is much lower in urban systems when compared to the natural ones, while production is still based on a linear system, with large amounts of waste generation and air pollution [9,10]. In a response to these processes, it is necessary to set the principles and recommendations for sustainable urban ecosystems, which would lead to positive changes in the quality of urban ecosystems, environmental condition and minimization of climate change.

Sustainable urban ecosystems research is widespread throughout the World and is gaining importance in recent times. The definition of sustainability has been developed constantly. Nowadays it is applied to different areas, such as economics, social, health, demography and etc. In this case, the research does not focus on a specific aspect. The urban ecosystem is understood as a set of various interrelated ecosystems within the urban area. The analysis concentrates on research over the last decade [11–19], but inevitably integrates the primary [1,20–22] results of the analysis of sustainable urban ecosystems. The theories and approaches for the sustainable urban ecosystem are discussed by Tian et al. [23], who modeled the existing framework of analyzing urban and ecological systems. In accordance with the insights of Harris [24], Capra [25], Shrivastava and Berger [26], Lindsey [27] and Emas [28] into the principles of sustainability; the insights of Chaudhuri and Chaudhuri [12], Hannover [29] and Melbourne [30] into the principles of the sustainable city; and the insights of Holmberg et al. [31], Van Roon and Van Roon [32], Gibson [33,34], Luederitz and John [35] and Shaw and Allen [36] works on sustainable ecosystems, the purpose of the article is to investigate the principles of sustainable urban ecosystems. Accordingly, the objectives are set: (1) to analyze the concept of sustainable urban ecosystems; (2) to highlight the opportunities and specific features of the theories and approaches of sustainable urban ecosystems; (3) to model the framework of the principles of sustainable urban ecosystems.

2. Definition of Sustainable Urban Ecosystems

The definition of sustainable urban ecosystems is complex, therefore, it is important to analyze it consistently focusing on separate components of the concept. In the discourse of ecology, the ecosystem is described as a complex of living organisms, their physical environment and interconnection in a particular space. The concept emphasizes that the ecosystem is characterized by a distinctive system of individual elements and functions which combine structural components. Cities are complicated complex systems and the human factor, its dominance and impact have led to various changes in the concept of the ecosystem in terms of climate, soil, water circulation, species composition, dynamics of population, energy and material flows, and formed a unique urban ecosystem phenomenon [23,37–39].

In comparison with natural ecosystem, the definitions of urban ecosystems form two attitudes: in the senso largo (broad) sense it is a greater ecological system (ecology of cities), and in the meaning of senso stricto (narrow) describes it as any ecosystem located in an urban or another densely settled

area (ecology in cities) [40]. Pickett et al. [19] state that urban ecosystems have a high density of people and land area, most of which is a techno-sphere (infrastructure and buildings). According to Lawrence's [41] system of human ecology, it can be argued that abiotic (atmosphere, temperature, water, minerals and waste), biotic (materials, food, energy and waste), cultural (law, economics, technology, politics, ideology, values and lifestyle) and human factors interact with each other in the city area. The latter system highlights the ability of humans to dispose and transform natural resources which are dependent on legal regulation, consumption and production processes, technological development, values and ideology. In addition, from Gómez-Baggethun et al. [42] point of view, urban ecosystems include blue and green spaces, such as parks, cemeteries, yards, gardens, forests, swamps, rivers, lakes and ponds. Therefore, in the context of urban planning, the urban ecosystem is represented as a synthesis of green and built infrastructure. In length of time, the components of the urban ecosystems have been expanded assigning a biological complex by human population and its' demographic characteristics, institutional structures, social and economic tools and physical complex by buildings, networks of transport, modified surfaces, environmental changes, energy consumption and the import of materials, transformation and export of waste, pollution and excess heat. Consequently, transdisciplinary and interdisciplinary accesses are used to analyze the interactions and mechanisms of urban ecosystems, whose theoretical system formula can be defined as EE + SES + HES (ecological-economics, socioecological system, human-environmental systems).

A city as an ecosystem does not operate under vacuum conditions—it is a dynamic and wide process. Urbanization and ecological urban environment are analyzed in various levels—global, national, subnational and local [23,43]. Wolman [22], one of the first scientists working on urban ecosystems, noted that the urban transformation of natural resources and the generation of waste and emissions have affected more extensive local and regional levels and that the problem of fresh water supply to cities has had a broader impact in its geographical boundaries. Regarding these issues, Pincetl et al. [43] propose to study urban ecosystems from a global perspective, including economics, migration and climate change aspects. In order to manage ecological problems properly, environmental policy is implemented internationally, establishing supranational institutions that have the prerogative of shaping and implementing the principles of sustainable cities and circular economy [23]. The national level focuses on the implementation of environmental policy which involves the development of new and smart technologies. The energy sector, water, regulation of buildings, transport policy, financing of programs, business structures and their capabilities at lower levels are analyzed at the subnational level. At the local (city) level, the functional zoning of the area and land use, transport system planning, business interests, fiscal opportunities, climate, resources, population and political economy must be taken into consideration. It is understandable that international institutions (the United Nations, the European Union) set the broad principles and goals for sustainable development which are specifically adapted to countries.

Sustainable cities, as the object of this scientific research, are not selected accidentally. Scientific research of the 20th and 21st centuries revealed dramatic consequences of human intervention into natural ecosystems regarding the increasing rate of urbanization and demand for various natural resources in urban territories. According to the United Nations [3], a number of cities are already struggling with environmental degradation, traffic congestion, lack of urban infrastructure and basic services, such as water supply, sanitation and waste management. Inadequate consumerism, which promotes industrial growth, the pursuit of a better life and its' results are not only damaging to the natural ecosystem, but also pose a threat to human health/safety and determine climate change. It could be assumed that the public's perception of the problem of conservation of natural ecosystems could lead to catastrophic consequences in the long term and visible effects of climate change have resulted in searching for measures to improve the quality of human life while preserving natural resources for future generations strategically.

The assumptions discussed previously determined the emergence of sustainable urban ecosystems phenomenon. In order to define a sustainable urban ecosystem, the analysis of sustainable development,

sustainable city and sustainable ecosystems should be carried out. The concepts of sustainability are understood differently among the countries considering the particularities between developed market economies, transition economies and developing countries. Sustainability is a normative and socially designed concept that indicates the state or trajectory of development and is analyzed using a deductive approach [15]. The essence of the definition is focused on the ability to use resources, not by consuming them completely or totally destroying them. International Council for Research and Innovation (CIB) has developed the model which reflects the features of sustainability and shows, how attitudes towards traditional engineering change containing environmental (sustainability) requirements (Figure 1). The competitive factors identified in the model show that the integration of sustainable ideas is determined by time (T), cost (C) and quality (Q). Taking into account environmental requirements, a new paradigm is formed to maintain the balance of resources (R), emissions (E) and biodiversity (B). In addition, the global context covers social, economic and environmental pillars and requirements [44].

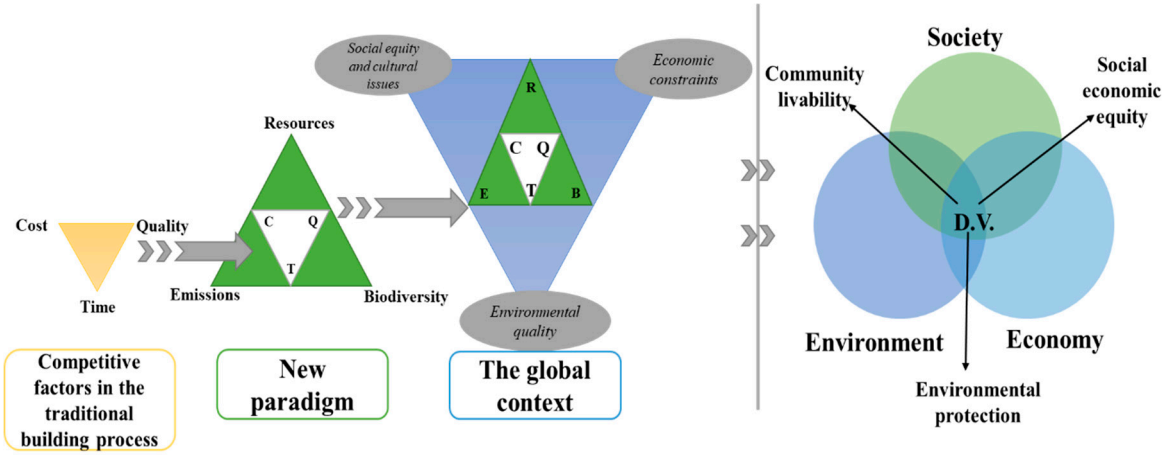

Figure 1. Requirements and pillars for sustainability, from the micro-level to the global level [14,44].

According to the fact that the problems of sustainability reflect the bottom-up model, it can be assumed that the latter principles are applied not only at the global level but can be used for the local level analysis as well. As economic, socio-cultural and environmental issues form the basis of a global level, one of the criteria of sustainability is the balance between all of these systems. Figure 1 illustrates that all three systems must be sustainable, otherwise, this definition cannot be applied. For an explanation, the case of Shanghai is used. The city is ranked the top economic city among all Chinese cities but due to the fragmentation and unbalanced social-ecological factors, it cannot be called sustainable [16]. Hassan and Lee [14] improved this model and set the basic requirements. Sustainability occurs when communities are viable, social and economic equality prevails and environmental protection is ensured. However, recently, research highlights the growing influence of policy and public administration in the areas of regulation and strategic planning [14,23], so the pillars presented by the authors could be extended with the pillar of governance. Development of strategic plans with long-term goals, draft or modification of legislation, proper coordination and control point to the direction of developing sustainability principles in states, regions or cities, and contributes to the achievement of targeted goals.

There is an important aspect of development in the implementation of sustainability principles. The definition of development, in the context of sustainability, means the process or state moving to a better state and making progress [38]. Thus, the concept of sustainable development has been formulated. The United Nations [45] defines sustainable development as a development that meets the needs of the present human population without compromising the ability of future generations to meet their needs. It is a long-term economic and environmental stability that can be reached while integrating each of the social, economic and environmental elements into the decision-making process [28]. Accordingly, sustainable development includes demand management and constraints.

In the context of humans, natural and artificial capital, sustainable development, as Emas states [28], can be defined as strong and weak. The weak definition explains that artificial or produced capital is an appropriate alternative to natural capital. On the contrary, strong sustainability recognizes the unique features of natural resources that cannot be replaced by alternatives, in this case, artificial capital. For these reasons, sustainability cannot be reached without the basis of development.

In the view of demographic, urbanization, economic and environmental indicators, cities play a crucial role in the perspective of sustainable development. A sustainable city is one where social, cultural, environmental and political needs are met with economic and physical goals, ensuring equal access to all services, without wasting the resources of other cities or regions [21]. The transformation of the traditional city to a sustainable one is based on the societal dependency on the surrounding environment and the focus on renewable and nonrenewable energy sources [12]. Moreover, the concept of sustainable city questions the dilemma of personal choice because in the territory of the city, according to urban planning structure, individuals have a right to choose and set the results of their everyday life but not at the expense of other citizens [18]. This idea must be based on social development, economic growth, environmental management and urban governance [46]. In general, a sustainable city is a city where citizens minimize the usage of natural resources and generate less waste, taking environmental impact into consideration.

In the scientific discourse, there are several opinions due to the impact of urbanization on ecosystems. Economic, social and environmental factors result positively and negatively in the urban environment. According to the primary attitude of Camagni, Capello and Nijkamp [20] a city is considered to be sustainable, if positive factors exceed the negative ones. However, in the case of Shanghai and later insights, formed by the authors [14,16,47], cities cannot be considered as sustainable if at least one of the economic, social or economic environments are not filled. For this reason, Hassan and Lee [14] created a system of positive and negative external effects in the interaction between the different environments in a city. From a positive perspective, efficient energy use, rational use of nonrenewable natural resources, economies of scale in the use of urban environmental amenities lead to saving funds for access to adequate housing, meeting the social facilities, satisfying health services and providing educational amenities. In addition, financial aids promote access to urban environmental amenities, create green areas among residential lots and secure greeneries for social activities. In contrast, the negative aspects appear in the interconnection of the economy and environment. For example, health problems, deterioration of historic buildings, loss of cultural heritage, an increase of suburbs, social frictions in the labor market and exacerbation of poverty which inevitably result in noise, traffic congestion, depletion of greeneries and natural resources, air pollution and intensive energy use. This synthesis of environmental impacts deepens the perception of how the interaction of economic, social and environmental factors affect the urban system.

In order to form the definition of sustainable urban ecosystems, it is necessary to understand the importance of sustainable ecosystems alongside the definition of a sustainable city. Sustainable ecosystems are considered to be the goal of today's society, smoothly linked to the values and culture of sustainability [17]. A sustainable ecosystem is characterized by its longevity and autonomy, furthermore, it is dynamic. Chapin III et al. [1] argue that sustainable ecosystems are those which, despite environmental disturbances, retain the characteristic diversity of functional groups, productivity, soil fertility and the rate of the biogeochemical cycle. The biosphere, hydrosphere, geosphere and atmosphere, as well as their interrelations, are the fundamentals of environmental sustainability in ecosystem research and management. From the perspective of urban ecosystems, the main focus is on the ecological structure and functions, including biophysical aspects and eco-regulation of system dynamics. However, it is noticeable that a sustainable city and sustainable urban ecosystems are often identified and perceived in the work of scientists as equals.

The formation and development of a sustainable city is a complicated process that depends on local conditions. In this case, the method of urban metabolism is applied to allow quantification of relevant characteristics (Figure 2).

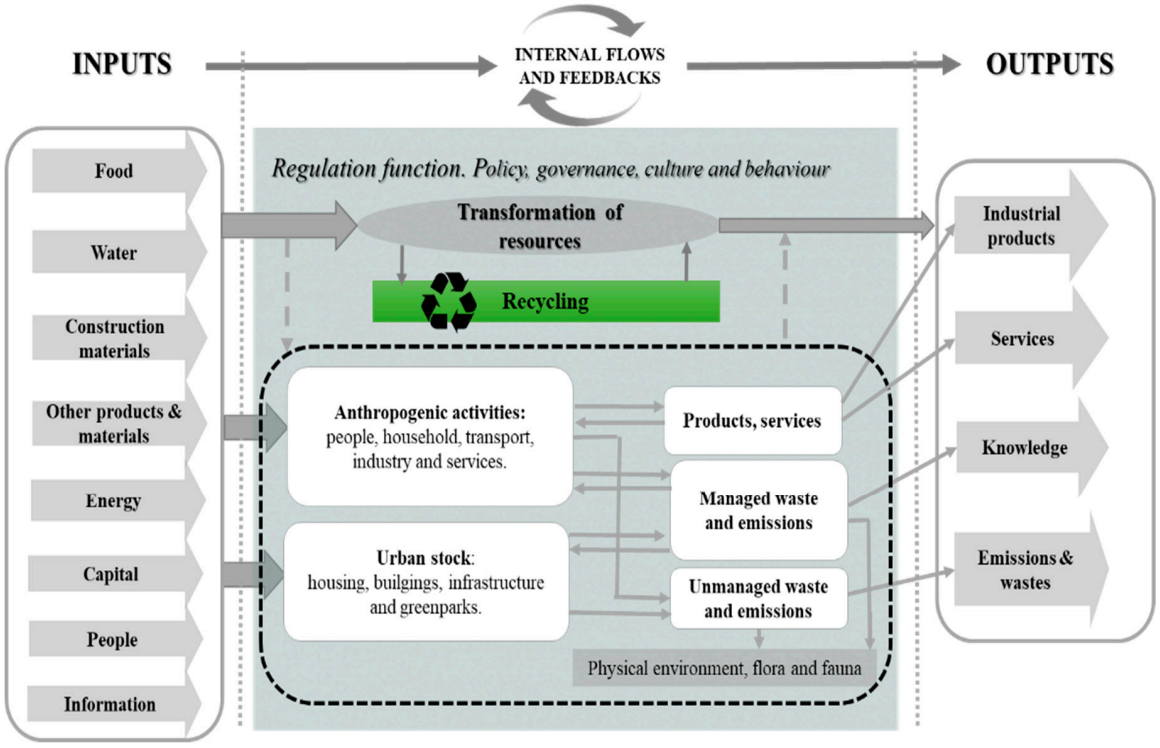

Figure 2. The system of urban metabolism [11] (modified by authors).

Since the first of the research of the urban metabolism process, most scientists divide this process into two important stages-inputs and outputs [11,13,22]. The system, illustrated in Figure 2, has a strong theoretical background, which is seen not only in the work of environmentalists, but also sociologists and economists. Urban metabolism has deep roots since the concern Marx and Engels had about human and nature relationships in sociology. Later, it was used for the empirical description of societal metabolism on an economic scale. Leontiev was the first economist, who expressed concern about the impact of economic activity on environmental quality. The model of input–output refers to the global environment and highlights air as a separate sector in the model [48]. Wolman, in his study of the Metabolism of Cities, finally developed the definition of urban metabolism, analyzed the limitations of natural resources and projected a problem of waste compilation with the integration of waste output in the model. These theoretical aspects prove the fact that, in order to reach a balance of the three pillars of sustainability, similar models can be adopted in different scientific fields. Figure 2 shows that inputs consist of not only natural (food, water and energy), but also demographic, social, informational resources, construction and other materials and products. Currently, the analysis of urban metabolism focuses on internal flows and feedbacks more than ever. Gasparatos [13] argues that transformation is characterized by transformed materials that are absorbed in the city and outside the city. Bai [11] states that the components of inputs are needed for anthropogenic activities and functions whose transformations, on the one hand, contribute to urban resource formation, product manufacturing and service delivery, and, on the other hand, generate uncontrolled wastes and emissions. Moreover, outputs include products and services, knowledge, various waste and emissions. According to the factors affecting the urban ecosystem, the concept of Bai highlights the importance of politics, public administration institutions, culture, the individual and collective urban system behavior for internal interactions and feedback. It can be observed that recent research in urban metabolism reflects the principles of the circular system. The concept of linear system-based metabolism is essentially transformed into a circular system, in order to reduce the output of waste, pollution and noise, thus forming a prototype for a sustainable city.

3. The Theories of Urbanization and Ecosystems

Research of the last decades on the interaction between urbanization and natural environment has laid the background for the emergence of different theoretical systems that allow the analysis of the relationship between these two elements from different perspectives. There are three major types of prevailing approaches that define the city as a single special type of ecosystem (broadly), as a coupled system (narrow sense) and as a system of interconnections (City as a nexus system) [23]. City as a special type of ecosystem is analyzed in urban biodiversity and ecosystem, urban metabolism and ecosystem services theories. The purpose of urban biodiversity and ecosystem theory is to evaluate the effect of urbanization on the ecological system and is applied to urban forest and landscape management. The urban metabolism approach is applied to material and energy cycle assessment and environmental footprint analysis. The ecosystem service concept can be defined as environmental contributions provided to humans. The purpose of this theory is directly related to the provision of ecological, environmental, economic, social and cultural benefits for mankind. Due to this reason, a single tool for ecosystem services assessment is insufficient and only a combination of methods is practically efficient. As the term is also based on socio-economic background, 24 case studies have shown a variety of methods and approaches, which can be used for ecosystem services assessment such as biophysical, integrated mapping–modeling, land-use scoring, participatory, socio-cultural, monetary and integrative [49]. However, the theory is criticized by other authors in two ways. On the one hand, it enhances the value of biodiversity priority areas, supports sustainable ecosystem management beyond protected areas and raises awareness of decision-making processes, on the other hand, the theory does not include critical species, it prioritizes processes, which benefit humanity, and the optimization of one service, which is harmful to biodiversity or ecological functions under the risk [50]. Consequently, there are theories investigating the city as a special type of ecosystem.

Ecological economics (EE), socio-ecological system (SES) and driving forces–pressures–states–impacts–responses (DPSIR) theories analyze the city as a coupled system. Ecological economics itself is based on two different components. The urban and regional planning approach is applied to model a balanced eco-system of built, manufactured, human, social and natural capital. Therefore, the component of strategic planning, including intermediate and ultimate measures, sets clear metrics for implementing sustainable development goals. Economic growth is one of the most important goals of states, but the economy as a subsystem cannot grow indefinitely because of a dependency on natural resources. For this reason, the theory focuses on the extent of sustainability and fair distribution. A complex SES system is composed of core subsystems, such as resource systems and units, governance systems and users. SES is applied to the analysis of urban environmental stewardship, urban-ecological network structure and dynamics within urban SES. However, in the scientific literature, this theory is criticized for the corresponding gaps and depoliticization of the situation under investigation, its anti-naturalistic position, inadequate perception of social and ecological complexes, lack of clear power and biased explanations generated by previous assumptions [51]. The purpose of DPSIR theory is to create a better perception of, indicators for and appropriate responses to impact of human activities on the environment [23] integrating key elements: Acting forces as the key social processes, specific human actions affecting the environment, state as an environmental condition reflecting current environmental trends, impacts and responses, as a state effort to make changes depending on impacts [52]. In the background of these theories, urban ecosystems are understood and investigated as a coupled system composed of several ecosystems.

The city as a nexus system is analyzed using the nexus model, smart city domains and E-LAUD framework. The exploration of the city's systems has shown a valid impact of governance structures and innovations on urban ecosystems. Accordingly, Jacobs' [53] modeled nexus model covers a wide range of areas and presents an interdisciplinary approach that combines state, market, social and geographic contexts, based on the fact that cities are shaped by a multitude of political–governmental, market, civil–societal and geographic–natural activities and events taking place at all spatial levels [53]. The rapid development of technological innovations, along with human and institutional factors,

requires the implementation of sustainable development ideas a comprehensive understanding of the complex social–technical services and the physical environment in the urban area to create a smart mind theory [54]. Integrating technologies, separate systems, infrastructure, services and capabilities, the ecological network is created in parallel to identifying technologies as a significant tool for addressing urban ecological issues. Smart cities are based on matching the needs of existing residents, reducing the risk to other people or future generations while meeting their needs, within local or planetary environmental constraints and ICT integration [15]. Although a smart city is characterized by flexible management of urban areas and is considered as one of the most important future models, Klimovsky, Pinterič and Sapariene's [55] conducted study revealed that integration of technological principles, such as ICT, in the cities of post-communist countries remains challenging due to low awareness of the technological potential.

In response to the low awareness of the role of urban ecology in urban infrastructure, the perception of ecosystem functioning and ecological resilience, a substantially reduced effectiveness of urban planning, E-LAUD theory has been developed, combining ecological–land-use–architecture–urban spheres. The core of this system is focused on strategic ecosystem management increasing the potential for urban ecosystem services and ecological resilience integrating ecosystems, transport systems, waterways, urban assets and innovations together in order to conserve wild habitats and biological resources, filter pollutants, develop tools and technologies increasing a decision-making efficiency in urban areas [56]. In conclusion, by reviewing the theories and methods discussed, it can be argued that each of them highlights specific aspects of urbanization and ecosystems for sustainable urban development research.

4. The Principles of Sustainable Urban Ecosystems

Sustainable urban ecosystems are based on certain principles. For a better perception of the principles, on the basis of logical analysis and synthesis, the authors separately investigate the principles and interrelations between sustainability, sustainable city and sustainable urban ecosystems completing and modeling the framework at the end. The principles of sustainability have been established in accordance with the insights of Harris [24], Capra [25], Shrivastava and Berger [26], Lindsey [27] and Emas [28]. Accordingly, the principles of a sustainable city are formed considering the principles of Hannover [29], Melbourne [30], Chaudhuri and Chaudhuri [12], Gibson [33,34] and Luederitz and John [35]. The principles of sustainable urban ecosystems were adapted from Van Roonir and Van Roon's [32] low impact urban design and development (LIUDD) model and Holmberg, Lundqvist, Robèrt and Wackernagel [31] and Show and Allen's [36] analysis. Figure 3 illustrates the identified, structured and mutually combined system of principles of sustainability, sustainable city and sustainable urban ecosystems.

The principles of sustainability are identified differently in the scientific literature. They are relevant as the background for sustainable initiatives applied in various objects and areas. One of the key principles of sustainability is to ensure equal rights for humans and the natural environment. This principle consists of a number of fundamental sub-principles: ensuring equality between current and future generations, human rights, quality of life and preserving natural capital as well [26,28,34]. The principle of integration between environmental, social and economic aspects is perhaps the most important. It is mentioned in the works of Shrivastava and Berger [26], Emas [28] and Harris [24] noting that the concept of sustainable development must correct social inequalities and environmental damage while maintaining a reliable economic basis. The principle incorporates several additional principles analyzed by Capra [25], such as networks, nested systems, interdependence, diversity, cycles, flows, development and dynamic balance. It is worth understanding that sustainable development is not a static process. It consists of various (environmental, social and economic) systems that interact with each other and are interdependent.

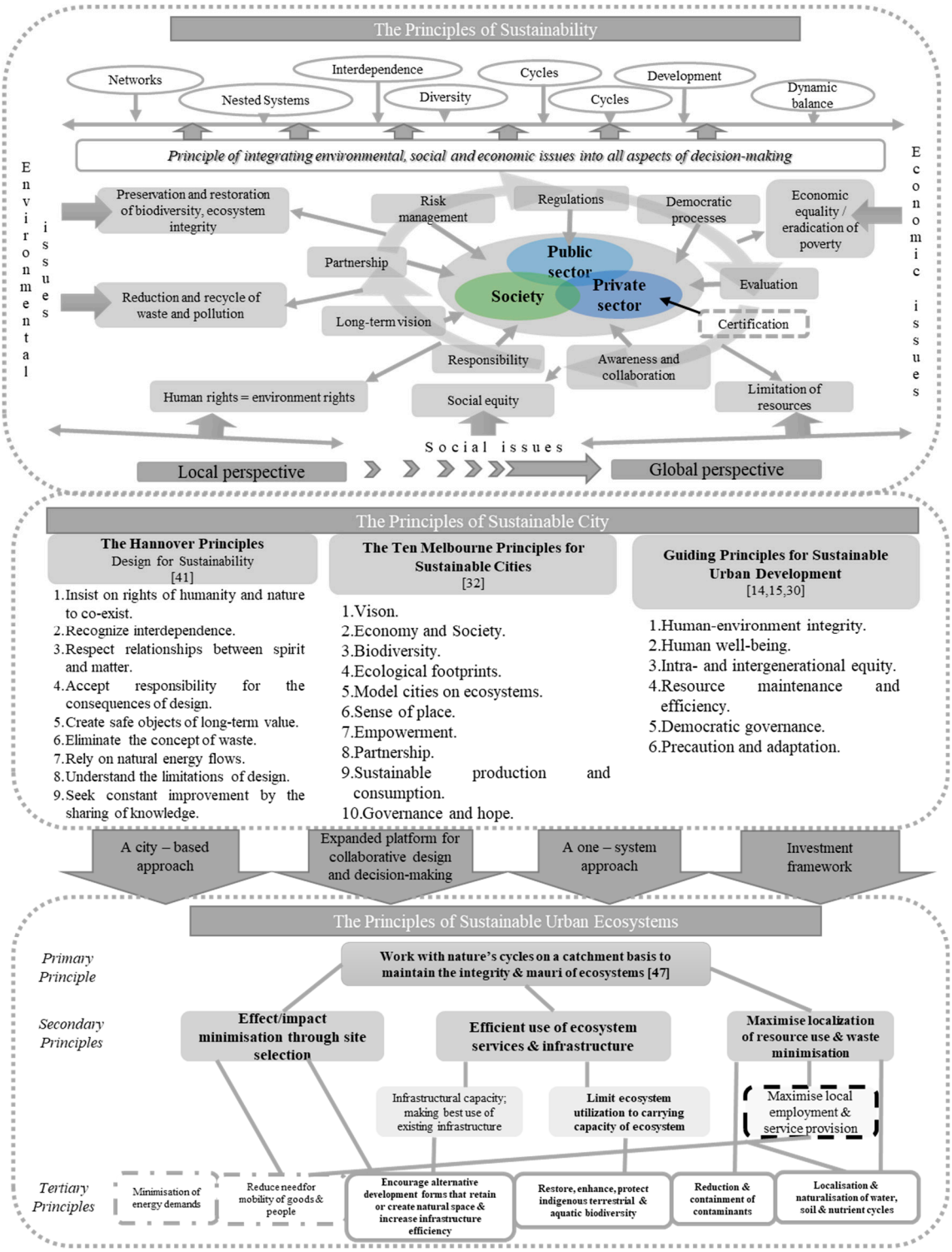

Figure 3. The system of the principles of sustainability, sustainable city and sustainable urban ecosystems.

In the system, each of the essential pillars includes specific principles of a particular area. The preservation and restoration of biodiversity, ecosystem integrity [24,26] and reduction and recycling of waste and pollution [26,27] are derivative principles representing environmental issues. The reduction of wastes and pollution is implemented through control and reduction of public consumerism/degradation, which in the long term should ensure that the use of the biodiversity components of the private sector and other stakeholders does not suffer from its long-term decline.

This also reflects the precautionary principle which means that developed countries share greater responsibility in light of the resources they require and the pressures they exert on the environment [28]. Harris [24] argues the principle of social equity is one of the key elements of development and is linked to environmental sustainability. From an economic perspective, it is necessary to ensure the principle of economic inequality and the eradication of poverty [26] and understand that the public's demand for natural resources must be balanced due to its' limitation [24].

This external cycle of principles is determined by an internal one and both of them interact with each other. The main actors of the internal cycle are society, public and private sectors. In accordance with the principle of responsibility [26], individuals, business and governance are responsible for developing and implementing sustainability principles. The internal cycle is created by integrating the principles set by Shrivastava and Berger [26]. In the author's opinion, sustainability requires the development of democratic processes, the establishment of a long-term vision, partnership between different sectors, awareness and cooperation, risk management and evaluation. The implementation of the regulatory principle is attributed to the public sector and specifically applies to legislative and executive authorities who have the prerogative to adopt legal documents for sustainable development. The principle of certification is applied to the private sector, which determines whether a product, process or service meets the requirements. Given the extent to which sustainability issues are resolved, all of these principles are applied locally and globally.

Principles for sustainable city development are formed according to the guidelines of two cities—Hannover and Melbourne. A number of principles are also integrated from the works of Gibson [33,34], which were later systematized by Luederitz and John [35]. The Hannover principles represent the interdependency between humanity and nature. This core principle is also found in the further works [33,34,53]. For its implementation, vision with a long-time value, elimination of waste and resource efficiency is necessary for the production and consumption phases. The long-term vision of sustainability includes generational, social, economic and political equity and individuality. The principle of long-term economic and social security implies the co-ordination of both pillars regarding environmental protection and a fair allocation of resources. The principle of biodiversity and ecosystem protection and restoration emphasizes increasing sense of responsibility for natural environment, biodiversity, effective protection and management. The Hannover and Melbourne principles are socio-environmental, representing different social actions for sustainability. Humans' responsibility for city design and its consequences and limitations are emphasized in the Hannover principles, when social forms of contribution and collaboration (society empowerment, partnership and governance), economic aspects for sustainability are highlighted in ten principles of Melbourne. The community's engagement in sustainable development processes promotes civic participation, the empowerment of citizens and the public's inclusion in decision-making processes. Luederitz and John give the examples of successful neighborhood collaboration such as BedZED in London, Vauban in Freiburg, Bo01 in Malmo [35].

The principle of sustainable production and consumption particularly is important. The aim of this principle is focused on raising awareness of production and industry, supporting and motivating business representatives to use new, environmentally friendly, anti-pollution technologies, and promoting recycling and productive use of energy and resources.

In order to transform the city into a sustainable one, Chaudhuri and Chaudhuri [12] suggest several additional principles for Eco2 cities. A city-based approach means that local authorities lead the development process and identify specific circumstances. Sustainable urban ecosystems require an expanded platform for collaborative design and decision-making, ensuring synergies through mutual coordination of stakeholders. It is necessary to apply a one-system approach to realize the benefits of integration and to implement an investment framework that values sustainability and resiliency. The application of discussed principles into practice could release linear cities transform to a circular and, at the same time implement, the ideas sustainable development.

The Melbourne Principles describe cities as ecosystems, they can be specified and detailed. Cities are opened, multi-planar, heterogeneous composites of ecosystems [57]. Holmberg et al. [31] state that people are dependent on the ecosystem and cannot resist systematic changes in their physical condition, for example, the systematic increase of carbon dioxide (CO_2) emissions into the atmosphere, the decline in the concentration of metals and chemicals or yield, pH, fresh water and etc. The authors distinguish four principles for sustainable urban ecosystems. The societal influence on the ecosphere due to accumulation of lithospheric material is covered by the first principle which means that the balance of flows between the ecosphere and the lithosphere must be such that concentrations of substances from the lithosphere do not systematically increase in the whole ecosphere, or in parts of it [31]. The second principle covers the societal influence on the ecosphere due to the accumulation of substances produced in society. For this reason, the flows of publicly produced molecules and nuclides cannot integrate into the natural cycles in the ecosphere or settle in the lithosphere. The third principle manifests itself through the social influence of the ecosystem on the manipulation and harvesting of funds and flows within the ecosphere and the fourth one is concentrated on the internal societal metabolism and the provision of services. To meet these needs, society needs to respect the limitations of natural resources and integrate the three primary principles in order to use resources efficiently and meet the needs as well [31]. Efficiency can arise not only through reduced resource flows but also through better tools for dealing with social issues, such as justice, equality and population growth.

Principles of natural ecosystems recently dominate and form the background for a sustainable, circular waste city. Nature does not produce trash or waste—it is the reason why these principles are applied for the explanation of the other types of human-dominated ecosystems. For example, Shaw and Allen [36] created a toolset of six lenses (ecosystem, organism, population, community, landscape and biome) with concrete principles in order to find the similarities between natural and innovational ecosystems. In the research authors separate recycling flows of nutrients along pathways made up of living subsystems, which are organized into process-orientated roles; living and nonliving subsystems connection; energy gradients power recycling of scarce nutrients. According to the authors, the importance of ecosystems is hidden in the recircularity and the roles of individual organisms and species play in the flows of resources along pathways.

The principles of sustainable urban ecosystems are still not formed in the scientific literature yet, but this three-word combination presents the idea of integrating natural principles into urban systems. LIUDD system (sustainable urban ecosystems part in Figure 3), formed by Van Roon and Van Roon in 2005, simply illustrates the main ideas of sustainability—reduction of natural resources consumption, waste and mobility [32]. It promotes a life circle approach in infrastructure for a continuity of existing buildings, facilities and functions in order to save resources. The formed principles are the result of the six-year work of Centre for Urban Ecosystem Sustainability (CUES), applicable throughout the territory of New Zealand, implementing sustainability goals in urban ecosystems. The layout of principles allows them to be detailed and categorized because of an appropriate distribution of principles, subprinciples (primary, secondary and tertiary) and the implementation program. The basic principle is working with nature's cycles on a catchment basis to maintain the integrity and mauri of ecosystems. It includes the minimization of effects and impacts through site selection, efficient use of ecosystem services and infrastructure, maximized localization of resource use and waste minimization. Accordingly, tertiary principles cover minimization of energy demands; reduction of the need for mobility of goods and people; promotion of alternative development forms; restoration and protection of indigenous terrestrial and aquatic biodiversity; reduction and containment of contaminants; localization and naturalization of water, soil and nutrient cycles. It should be noted that one measure can contribute to the implementation of a number of principles, for example, increasing the use of local goods and sustainable transport opportunities reduce the need for energy and mobility for goods and people, enhance the promotion of alternative forms of development, reduce and limit the amount of emissions.

To sum up the results of the analysis of the principles of sustainability, sustainable city and sustainable urban ecosystems, it can be stated that these principles have a distinctive hierarchy and

are interdependent (analyzing from general to specific, in this case from sustainability to sustainable urban ecosystems). The principles of sustainability form the basis of sustainable urban ecosystems and are used to explore specific areas. Accordingly, the principles of a sustainable city and sustainable urban ecosystems, especially subprinciples, are more specific and reveal more detailed possibilities for the application. It is worth emphasizing that the model of identified principles and subprinciples is not exhaustive and can be expanded in further research.

5. Discussion

In a theoretical discourse sustainable urban ecosystems are described in different ways and are characterized by specific features. Considering the results and impact of anthropogenic activity, sustainability aims to meet the needs of the existing population by properly managed consumerism and limited use of natural resources, without compromising the interests of future generations. Sustainable development of the urban ecosystem is a complicated process dependable on local conditions. A sustainable ecosystem is characterized by persistence, autonomy and dynamics, maintains the characteristic diversity of functional groups, productivity, soil fertility and the rate of biogeochemical cycle. The perspective of sustainable urban ecosystems highlights ecological structure and functions, including biophysical aspects and eco-regulation of system dynamics. Different theories and approaches can be used for the analysis of sustainable urban ecosystem. Therefore, three basic types of urbanization and ecological systems are distinguished which define a city as a special type of system (broad sense), as a coupled system (narrow sense) and as a nexus system. However, not all of the theories, discussed in the article, are widely used. A framework of the principles of sustainable urban ecosystems illustrates, how different principles of each construct of the definition interact with each other and form general principles of sustainable urban ecosystems. It is necessary to highlight the point that working with nature's cycles on a catchment basis to maintain the integrity and mauri of ecosystems is the primary principle of sustainable urban ecosystems eventually is detailed into subprinciples covering reduction of impact and effect on natural ecosystems, efficient use of infrastructure and ecosystem services, proper management of wastes and pollution and etc. Each principle supports the essence of sustainable urban ecosystems—the preservation of natural resources and equal rights of nature and humanity. The study provides an overview of the current situation and is evidence of the difficult integration of sustainability in today's social and economic policies. The theories, analyzed in the article, explain a long scientific process, which is performed in order to combine different aspects of sustainability in urban areas. However, case studies prove the fact that it is still hard to reach. Moreover, the hierarchy of the principles, which is formed by scientific works from different disciplines, leads to a broader discussion and further research of, how the term "principles" can be generally applied to sustainability from different scientific disciplines. Accordingly, significant theoretical research in depth should be done including all principles of sustainability to indicate contradictions, synergies and contrarieties for the improvement of the methods of urbanization and ecosystems analysis, finding out the obstacles for sustainable development in urban ecosystems and providing solutions.

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