The Integrated Urban Ecosystem and Urban Sustainability

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1 Introduction

Since the industrial revolution, the world has experienced an accelerated urbanization process. At the same time cities have become the seedbeds of social crisis, and urban studies have focused its attention to the extensive regional competition and collaboration as well as the complex links between cities and the natural environment. While cities manifest more abundant content and features, they are also confronted with more complex issues.

2 Urban Issues and Solutions

2.1 The Internal Issues of the Cities

The first issues that confront urban planning were problems such as urban poverty, congested housing, deteriorated environment and unauthorized development. As a response, urban planning used to focus more on the physical and spatial elements in the cities, hoping to resolve urban problems through optimizing spatial structures and patterns by generating rational blue prints.

Under this context, Howard's (1902) "Garden City" theory attempted to establish a standardized urban morphology to control urban development and tackle congestion and hygiene problems in the cities. However, due to the complexity and individuality of the urban issues, spatial planning alone was never effective and sufficient for resolving urban issues.

As the cities developed, more attention was paid to its social elements. The single physical and spatial approach in urban planning was harshly criticized (Jacobs, 1961). More issues were then included in urban planning such as those of industrial development, employment, education and healthcare, etc. Issues like social equity and equality were given higher regards (Harvey, 1973), such as the protection and empowerment of vulnerable groups (Friedmann, 1996), and the revitalization of communities. The importance of public participation was also highlighted. (Davidoff, 1965; Healey, 1997)

2.2 The Inter-city and Regional Issues

The complexity and interactivity of the cities have been spurred by globalization and the development of information technology. In *Megalopolis: The urbanized northeastern seaboard of the United States*, Gottmann (1961) pointed out that, rather than urbanization, megalopolitanization is taking place.

Peter Hall (1966), in his book *The World Cities*, regarded world cities as the highest level of

status in the economic system of European industrial capitalism that led to the later growth of Japan and North America. They were defined as the concentrative centers of human resource in politics, trade and finance. Since then, more literatures were added to the world city research. Based on the world city hypothesis, John Friedmann (1986) attempted to contribute to the theory of spatial organization from the perspective of international division of labor. He asserted that a world city should be a connection point in the global economic system to allow various regional economies to be integrated through the network of the world cities, and thus cities were attributed with regional or even global controlling power. Meanwhile, some other theories related to world cities also argued that the world cities had a complex network through which the global and regional controlling power was formed (Sassen, 1991; Castells, 1996).

2.3 The External Issues of Cities

After World War II, the low energy costs and the hidden environmental costs resulted a golden era for the world economy, but followed with severe environmental and energy crisis. In the 1970s, people began to pay attention to how long-tern development could be achieved with limited resource availability (Meadows et al., 1972; Commoner, 1971). Brown's (1981) *Building a Sustainable Society* made systematic elaboration for the first time on the idea of sustainable development with an analysis of a series of habitat and environmental issues encountered in economic development, and proposed three major ways of sustainable development - to control population growth, to protect natural environment, and to develop renewable resources. In 1987, the World Commission on Environment and Development wrote to United Nations a report *Our Common Future,* in which sustainable development is defined and elaborated in detail, advocating for a balance between resource use and economic growth for future generations. (WCED, 1987) Later, other literatures also provided analyses for upgrading urban sustainability through various means such as optimizing urban spatial layout or improving roads and infrastructures, and thus putting forward exemplary planning modes and methods for sustainable urban development (Barton et al., 1995).

Being aware of the conflicts between the built environment and the natural environment, the concept of ecological footprint was introduced to measure human activities against the carrying capacity of the natural environment. The academic world also expected to solve urban problems by building a model of an ideal city, such as ecocity, ecopolis or low-carbon city, etc. An US ecologist, Richard Register (1987), put forward the ecocity concept for the first time, defining an ecocity as a healthy city with ecological significance. However, his initial definition was only limited to the harmony between human and nature, still lacking consideration of the social ecology, i.e. the harmony among human being themselves. Recently, Shmelev and Shmeleva (2009) in *Sustainable cities: problems of integrated interdisciplinary research*, emphasized a methodology of interdisciplinary analysis on various aspects of urban sustainability. Besides the traditional aspects of natural environment and ecology, it also included quality of life, preservation of the heritage and democratic participation, etc. That means the ecocity definition has been substantially enriched from the initial stage of stressing harmony between human and nature to a higher level, including synthesizing more means and methods. It demonstrates a more systematic and

multidisciplinary approach of understanding the ideal city model that is more complex today.

3 The Ecosystem Theories and Its Impact on Urban Studies

The application of the ecological principle in urban studies is not a simple imitation of natural ecology, but rather an explanation of the operational mechanisms and principles of cities so that urban development can be appropriately guided.

3.1 The Ecosystem Theories

Tansley first put forward the word ecosystem to express an organizational model of the mutual impact between man and nature (Yang, 2005). Its significance is the emphasis of the mutual impact between everything and its external factors, rather than the narrow thing in-itself. But Tansley's ecosystem concept was confined to certain functional units. For instance he regarded the world as to be formed by a series of ecosystems which connect to each other.

In 1971, UNESCO took the lead in linking the cities with ecosystems. It proposed that the city, the suburb and the countryside should be regarded as an integrated system. It also looked at urban issues and the distribution of urban space from a regional perspective. Urban ecosystem was then written into UNESCO's *Man and the Biosphere* Program (MAB) (Huang & Chen, 2007). This means that a city itself is not only a system but also part of a larger-scale system, and that the cost and the value of a city must be appropriately displayed in a wider spatial scale.

Since the 1950s, the development of the systems science has enabled itself to become an effective means for undertaking integrated urban study. Due to the systems character of the urban areas and the close connectivity and similarity of the built environment and the natural environment, some Chinese scholars tried to combine the two together and put forward a concept of the integrated ecosystem.

3.2 The Development of the Concept of the Complex Ecosystem

Ma Shijun and Wang Rusong (1984) were the first ones to put forward the concept of a complex ecosyetem. They regarded that a complex ecosystem is composed of three subsystems, i.e. the social subsystem, the economic subsystem and the natural subsystem, which have mutually restrictive and supplementary impacts. In addition, they further subdivided and refined the three subsystems to construct a model of a complex ecosystem (see Figure 1). Unfortunately, the model only points out the three subsystems and factors in these subsystems, but neglects the interrelationship among them. The model is more tree-shape rather than network-shape and thus is unable to thoroughly display the integrated ecosystem. The model also focuses more on the internal factors of a city, lacking attention on intercity connectivity and the connection between the city and the larger natural environment.

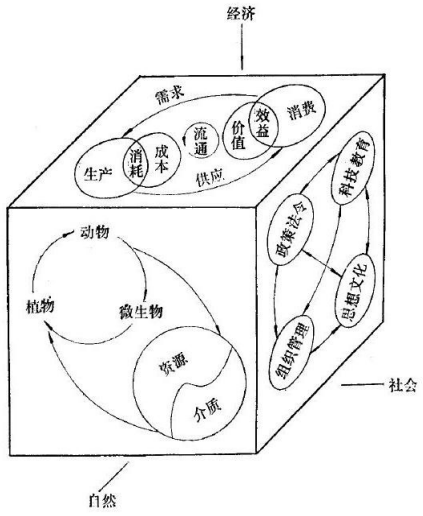

Figure 1: Social-Economic-Natural Complex Ecosystem

Source: Ma, Shijun & Wang, Rusong (1984) "The Social-Economic-Natural Complex Ecosystem", *Acta Ecologica Sinica*, Vol.4, No.1

Ma Shijun has subsequently adjusted the complex ecosystem structure, and shaped it into a pyramid-shape model. Its core is the "human society", including the organizations, agencies, management, culture, science, education, policy and law, etc., which is the control section of the complex ecosystem. The mid-circle is the direct environment to human activities, including physical geography, artificial and biological environment, which is the base of human activities and the foundation of a complex ecosystem and has a certain boundary and spatial location. The outer layer is taken as the "pool" (external environment of the complex ecosystem, including material, energy, and information), the "source" (to provide the fund and the manpower), the "store" (to get the outputs of the complex system), and the "sink" (to deposit the material, energy, and information). The "pool" does not have a certain boundary which only represents the influence range. (see Figure 2) (Qin & Zhang, 1998) This system model makes the urban complex ecosystem much more solid, points to the different states of the urban complex system, and tries to display the interaction between the different factors. However, this system model fails to clearly explain the connectivity of "human society" to the cities and urban environment.

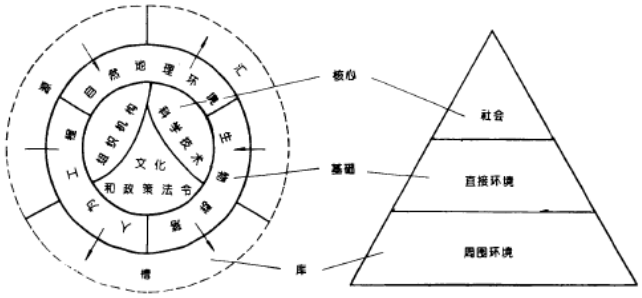

Figure 2: Urban Complex Ecosystem

Source: Qin, Pei & Zhang, Shengtu (1998) "Research Progression of Ecological Engineering", Chinese Journal of Nature, Vol.20, No.1

Wang Rusong has further improved the analysis of a complex ecosystem. He indicated that city is a social-economic-natural complex ecosystem driven by both human activities and ecology processes. The natural subsystem is composed of Chinese traditional five elements, such as water, fire (energy), earth (nutrition nature and land), wood (life organism) and gold (minerals). Economic subsystem includes the production, consumption, revivification, circulation and regulation. Social subsystem includes technology, institution, and culture. The significance of urban sustainability is to identify the coupling relationship of temporal, spatial, procedural, structural and functional levels of the three systems. (see Figure 3) (Guo, 2006) The model has been improved in according to the model proposed by Ma Shijun, and pays more attention to the internal ecological process of each factor in the system. However, there is insufficient research on the internal process of the factors involved.

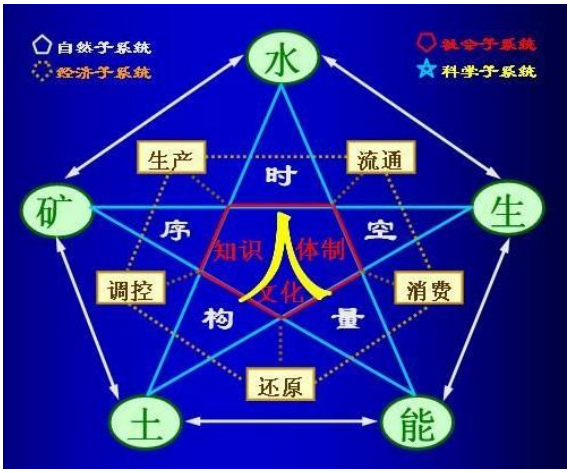

Figure 3: Urban Complex Ecosystem
Source: Wang, Rusong (2002) Fifth International Ecocity Conference

The complex ecosystem research conducted by Ma Shijun and Wang Rusong has greatly facilitated the theory of complex ecosystem. The social, economic and natural division in accordance with the characteristics of human activities is theoretically meaningful to attract the attention of ecological civilization. Moreover, the development of the model in a broader context has stayed at the basic level without considering the analyzing a multi-layer complex ecosystem. In addition, the social, economic, and natural factors do not play an equal role in the multi-level system. There is an overlapping area in the three systems, especially in the area of social and economic areas. Therefore, there are limitations of the application of this theory in the traditional disciplinary division.

Subsequently, based on these, some scholars developed and improved the structure of the complex ecosystem model. Song, You & Wang (2000) adopted Ma and Wang's social–economic–natural system structures. Within the regional ecological frame, they subdivided each subsystem and their factors, and attempted to strengthen the relationship among various factors. (See Figure 4) But this model has not been able to sufficiently express the relationship between cities and their regions. The simple subdivision of the three

subsystems weakens the relationship among various factors.

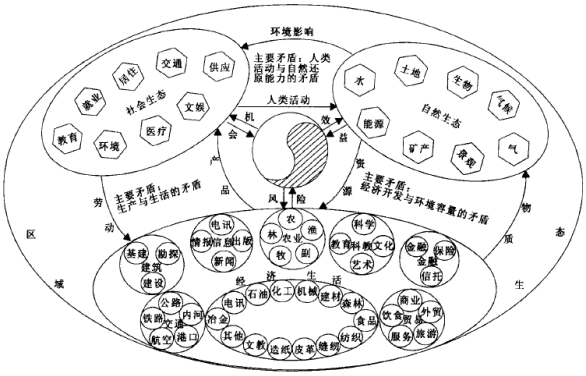

Figure 4: Social-Economic-Natural Complex Ecosystem

Source: Song, Yongchang You, Wenhui & Wang, Xiangrong (2000) Urban Ecology, Shanghai: East China Normal University Press

Jiang and Zhu (2000) tried to explain the characteristics of urban ecosystem and its connection with natural ecosystem by comparing comparison of them, and this has improved the research on the openness of the complex ecosystem (See Figure 5). However, they still mainly emphasize the consumption to the exterior producers, as well as the destruction to the exterior natural environment done by an artificial environment. They lack the focus on the relationship between different artificial environments. The expression of the model is also not clear. In addition, the model lacks analysis of urban internal operation, therefore, it has not been able to comprehensively show the complex relationship between urban ecosystem and natural ecosystem.

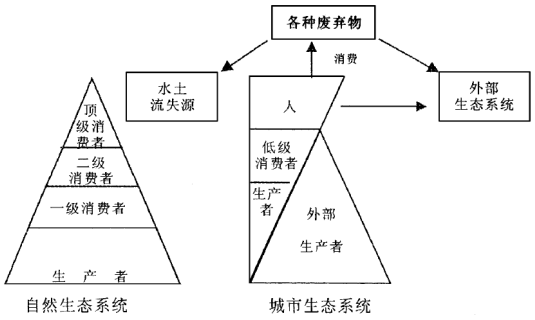

Figure 5: Natural Ecosystem and Urban Ecosystem

Source: Jiang, Ailin & Zhu, Guoyong (2000) “Formation and Characteristics of Soil Erosion in Cities and Prevention Strategy”, Urban Studies, Vol.7, No.3

4 The Integrated Urban Ecosystem (IUE)

4.1 The IUE Model

As pointed out earlier in the paper, despite the theoretical rationality, the society-economy-nature model fails to meet the practical requirements in urban studies and city planning. By applying ecological principles and systems theory, and by studying and reviewing the concept of ecosystem, we attempt to construct a simple and clear theoretical model of IUE from the urban-study and urban-planning perspective to echo the key society-economy-nature factors. Our effort is to bridge the gaps between different disciplines and to renew the views on the nature of integrated urban ecosystem and eco-city.

The IUE is subdivided into eight subsystems (see Figure 6).

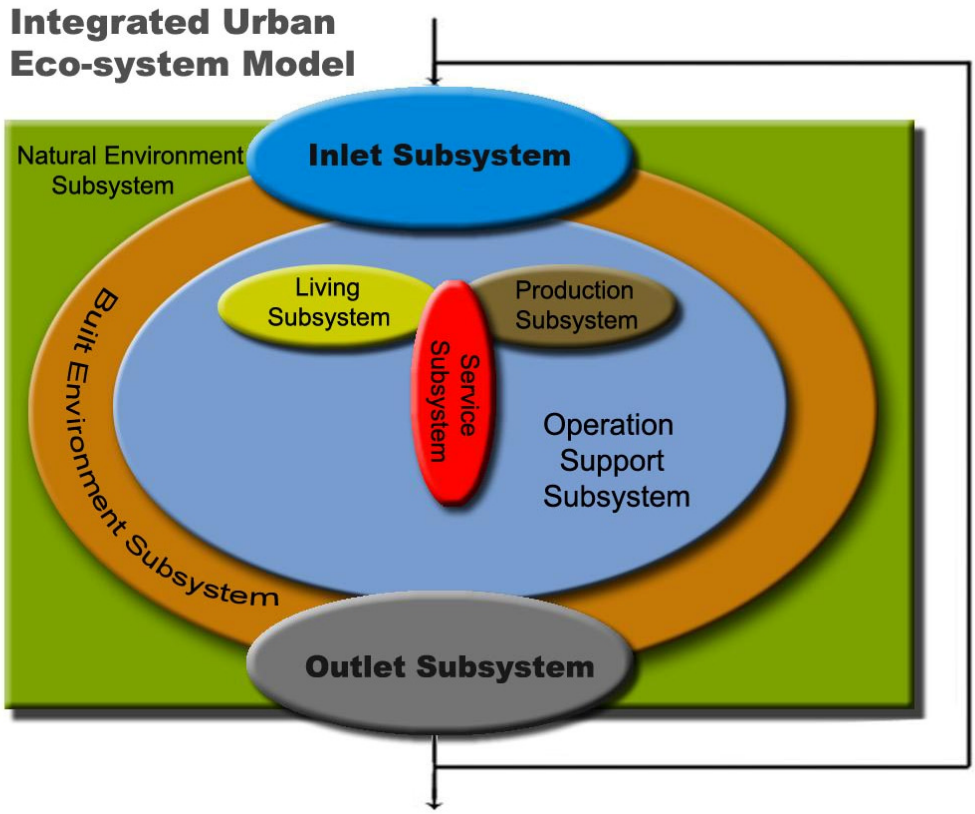

Figure 6: Integrated Urban Ecosystem Model
Source: Authors

The Natural Environment Subsystem is the natural space and the carrier of physical resources on which cities and all humans depend for survival. The Built Environment Subsystem is the man-made space and carrier of physical resources that sustain functional operation of a city. The Operation Support Subsystem serves as the pillar underpinning the three fundamental functional systems - the Living Subsystem, the Production Subsystem and

the Service Subsystem. The Inlet Subsystem and the Outlet Subsystem act as the two "valves" that impact all the above subsystems from the two extreme ends of IUE. These subsystems, rather than simply inclusive or exclusive, are in fact differentiated but interrelated with each other. A single change in one subsystem will also trigger changes in all other subsystems.

What is particularly worth noting is that the Inlet Subsystem and Outlet Subsystem imply a concept of massive regional flow, including materials, energies and information. Inlet Subsystem encompasses positive "nutrient" and "energy" in the city or channeled to the city from its surrounding regions or other regions – as well as the negative ones such as acid rain or pollution. All of these elements will inevitably be absorbed, filtered, used, changed and restructured in the city before they are outputted to other regions and cities through the outlet system or fed back to the city to make it grow, develop and change. Apart from serving to output "nutrients" and "energy", the outlet system in the city will also discharge "waste" – household rubbish and some toxic, harmful substances, which will unavoidably expand outwards if they fail to be properly dealt with locally, and thus may become the source of "negative input" for other cities. Hence, the relation between urban complex ecosystem and outside complex ecosystem, in which the importance of regional coordination is highlighted, is of paramount importance to urban planning.

The subsystems in the IUE are not entirely paratactic to each other. As there are some overlapping parts, it should not analyze a subsystem in an isolated or segregated way. When overlapping happens, the attributes of the related subsystems also encounter complex changes (as indicated in the change of color of the cross-sectional diagram) and thus more parameters would be required to carry out comprehensive analysis during the planning process. (see Figure 7)

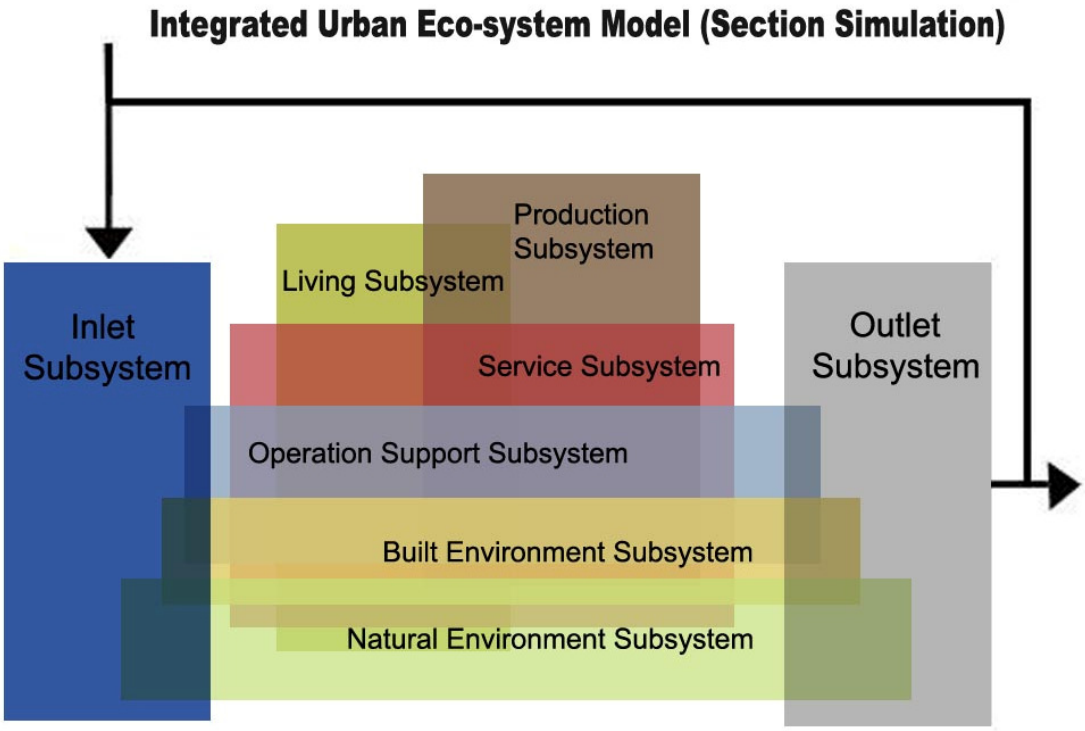

Figure 7: Integrated Urban Ecosystem Model (Section Simulation)
Source: Authors

In fact, overlapping of the subsystems is involved in majority cases of urban planning, which requires a more comprehensive and integrative planning process.

4.2 China's Current Rapid Development Analysis through the IUE

The rapid development of many cities in China is benefited from the increase of capital Input in the Inlet Subsystem through economic globalization. It accelerates the operation of various urban subsystems so that cities have more opportunities to accumulate more positive outputs such as material and non-material products that are represented by GDP. The increased positive outputs then feed back to the functional subsystems and contribute to their development and growth. Cities and regions can therefore exchange their positive outputs with other cities and regions to gain more positive inputs. This is why they never stop pursuing GDP growth.

However, this process also greatly increases the burden on the Inlet Subsystem of a city, often exceeding the carrying capacity of both the Inlet Subsystem and the Natural Environment Subsystem in order to import certain positive "nutrition" and "energy" (resources and energy). At the same time, many cities in this process ignore or even indulge the large amount of negative outputs generated by the functional subsystems and then released by the Outlet Subsystem. These negative outputs then feed back to their own Inlet Subsystem and transform into Negative Inputs, going beyond the self-purification capacity of the Natural

Environment Subsystem, resulting in environmental pollution, ecological degradation and malfunction of other affected subsystems. This is quite similar to a broken biological chain that the cities are in danger of losing their sustainability.

While there is a substantial increase of Inputs and Outputs, the functional subsystems as well as the Operation Support Subsystem are overloaded. They then require more positive inputs (such as labor, capital, raw materials, and other material and non-material products) and the expansion of their own scale to maintain their functional operation. It explains, under such circumstances, the phenomena of increasing influx of rural population to urban areas, mounting pressure on regional logistics and transport, and the aggravation of urban safety problems.

All this has also posed much burden on the existing Built Environment Subsystem. Many cities choose to supply more land for development in order to relieve the burden. This leads to horizontal expansion of the Built Environment Subsystem and its encroachment into the Natural Environment Subsystem, with a consequence of disordered urban sprawl and brutal redevelopment of the old towns, leading to rapid consumption of land resource and large-scale demolition in the Built Environment Subsystem, which in turn causes a chain reaction in the Living Subsystem, damaging urban fabric, cultural heritage and social network, and thus aggravating social conflict and disorder.

With the increase of the capital input in the Inlet Subsystem, seven of the eight subsystems other than the Natural Environment Subsystem will be expanded. The greater the contrast of the high capital input against the low capacity of the subsystems, the more violent and brutal the subsequent expansion of these seven systems, which in turn poses higher demand on capital input. This cyclic expansion once begins to accelerate, is difficult to slow down if capital supply is adequate and external intervention (such as public policies) is inadequate. As most of the available resources are limited and non-renewable, also taking into consideration of the accumulating negative outputs in the Outlet Subsystem, the Natural Environment Subsystem is therefore eroded, being the only shrinking and declining system in the process.

Therefore, unless the resource availability in the Natural Environment Subsystem has a significant increase or the functional subsystems' dependency on the Natural Environment Subsystem is significantly reduced, the two "valves", i.e. the Inlet Subsystem and the Outlet Subsystem, have to be restrained to prevent from excessive demand on resources and energy, and to reduce negative output to direct capital investment towards environmentally friendly endeavors. In the Inlet Subsystem for example, it is important to restrict use of non-renewable and inadequate resources such as fossil fuel. In the Outlet Subsystem for another example, it is also important to restrict over pursuit of positive outputs such as material and non-material products represented by GDP, and control negative outputs that will pollute and damage the Natural Environment Subsystem as well as other subsystems. This is probably the only key for the Chinese cities to achieve sustainable development and to pursue the eco-city vision.

4.3 IUE Indicators Selection

At present, the majority indicator systems regarding urban development are based on various factors of urban subsystems. The level of urban development is often measured through describing the status of each factor. This kind of indicator system is largely a static and isolated system in which the level of urban development but not that of urban sustainability can be measured.

Therefore, it is necessary to choose more indicators which can show relationship between different subsystems, for example, energy consumption and waste discharge per GDP unit, energy consumption per capita, utilization ratio of public utilities, etc.

5 Conclusion

This paper attempts to look at the dynamic mechanisms and systems of urban development from a new "ecological" perspective. It analyzes the concepts of eco-city and integrated urban ecosystem and uses a new theoretical model of integrated urban ecosystem (IUE) to reveal the nature of urban growth process as well as to lay down a new platform for studying urban sustainability. Different from the previous framework on IUE study which looks at the social, economic and natural systems from a macro perspective, the new IUE model illustrates more the relationships between various urban subsystems, including those of the internal urban functions and the external linkages. It is simple and clear for understanding the dynamics of urban development, more connected to the traditional urban study and the planning process, and more informative to planners and policy makers when they touch upon urban sustainability issues. We sincerely hope that in-depth research on IUE model would be further developed in the future.

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