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Dynamic analysis and assessment for sustainable development

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Abstract: The assessment of sustainable development is crucial for constituting sustainable development strategies. Assessment methods that exist so far usually only use an indicator system for making sustainable judgement. These indicators rarely reflect dynamic characteristics. However, sustainable development is influenced by changes in the social-economic system and in the eco-environmental system at different times. Besides the spatial character, sustainable development has a temporal character that can not be neglected; therefore the research system should also be dynamic. This paper focuses on this dynamic trait, so that the assessment results obtained provide more information for judgements in decision-making processes. Firstly the dynamic characteristics of sustainable development are analyzed, which point to a track of sustainable development that is an upward undulating curve. According to the dynamic character and the development rules of a social, economic and ecological system, a flexible assessment approach that is based on tendency analysis, restrictive conditions and a feedback system is then proposed for sustainable development.

Keywords: sustainable development; assessment; dynamic analysis

Introduction

Since the United Nations Conference on Environment and Development (1992), many countries have a common view that human society should go along a sustainable development path. Every country needs to be better informed about sustainable development to achieve economic, social and environmental objectives in a manner that balances peoples needs and aspirations with ecosystem constrains. As an aid to this task, the assessment of sustainable development is vital to making the sustainable strategies. Some efforts have been made for the assessment of sustainable development.

For the assessment of sustainable development, sustainability or unsustainability is the key issue. UN (United Nations) and many countries have suggested some methods to indicate to what extent development is sustainable development, but most of the methods so far have focused on the state of development rather than on the process of development. Some indicators systems have been suggested for measuring the state of development. There are two main categories: social-economic indicators and aggregate indicators. The social-economic indicators, e.g., World Bank indicator system (World Bank, 1997), mainly give a warning signal for the capital saving. The substitutability problem between each capital is the main obstacle for application. The aggregate indicator systems, e.g., United Nations indicator system (UN, 1996) and England's indicator system (Department of the Environment, 1996), etc, usually include three categories: society, economy and nature. These indicator systems directly reflect the state of development. But there are still some shortcomings, for example, indicators based on the environmental state may give a warning too late, or the complexity of the ecosystems makes it impossible to predict all possible effects of a certain social activity (Azar, 1996).

Existing indicator systems give a relative quantitative concept of the state of development at one point in time. However, sustainable development is a dynamic process. Through out the whole development process, the development level at different phases is distinct, only using one of the above indicator systems for assessing sustainable development can not reflect the dynamic aspects. Besides the spatial dimension (Niu, 1996), the time dimension is another important aspect for assessing sustainable development.

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Therefore, the assessment of sustainable development should focus on either the state or the process of development. In a discussion of the processes of development, the length of the time period is a critical point (Georgescu, 1976). The assessment should include trend analysis. Furthermore, as "unsustainable" can express either a gradual change or a sudden collapse, some restrictions should be considered for the assessment of sustainable development, also a feedback system can help to decrease some uncertainty during the assessment.

This paper proceeds with the definition of sustainable development in section 2. Section 3 analyzes the dynamic trait of sustainable development on social, economic and ecological aspects. Section 4 proposes a flexible assessment framework and approach including tendency analysis and restrictive conditions as well as a feedback system. In section 5, the results and the future works are presented.

1 Definition of sustainable development

The World Commission on Environment and Development offered the first scientific definition of sustainable development. It defines sustainable development as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED, 1987). This definition stress the intergenerational equality of development, and implies a dynamic balance between maintenance (sustainability) and transformation (development), as well as the harmony among society, economy and nature. The definition includes the following aspects (David, 1997): (1) the future is not compromised by the present (the temporal dimension); (2) geographic area(s) are not compromised by other geographic area(s) (the spatial dimension); (3) human needs and aspirations are met within biological limits, and natural capital is maintained and enhanced; (4) a proactive effort is made to maintain and enhance the sustainable and to eliminate the unsustainable development; (5) sustainability is recognized as a dynamic concept, taking many forms and can not be judged by a unified value.

For promoting this paradigm in decision making, many operational interpretations of the concept of sustainable development are proposed. These interpretations can be classified as two predominant categories: the statement from a wealth viewpoint and the statement from a system viewpoint. From the viewpoint of wealth, sustainable development stated that if development is to be sustainable, people must fully appreciate the value of nature and built capital so that the next generation can inherit a stock of assets no less than those we inherited ourselves (Pearce, 1989). From a system viewpoint, sustainable development is a perfect combination of social sustainability, economic sustainability and ecological sustainability. Social sustainability requires that society is stable and thriving (prosperous). Economic sustainability requires a good economic level and structure. Ecological sustainability requires keeping ecological balance and providing a sustainable support for human society. The system viewpoint provides a basis for the following discussion on the assessment of sustainable development.

2 The dynamic analysis of sustainable development

Sustainable development herein refers to the development and sustainability of a mega and complex system, which usually consists of three subsystems: society, economy and nature (environment and resource). The integrative system is affected by many factors during its development. All of these factors can be classified into two categories: promotional factors and restrictive factors. Its development process is the interaction process between the promotional and restrictive factors. When the function of promotional factors is stronger than that of restrictive factors, the complex system shows development, otherwise the complex system shows stagnation or even breakdown (Fig.1).

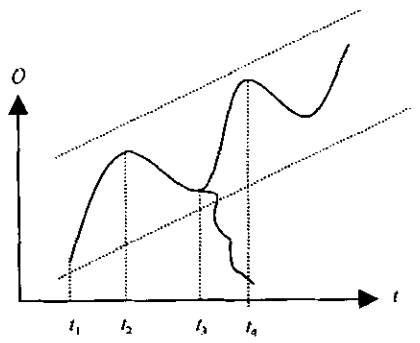

Fig. 1 Sustainable development track

The three subsystems are also interacted. In the society subsystem, stable society order, healthy economy and comfortable environments are the promotional factors, which can promote the development of society. Economic crisis and environmental pollution are the restrictive factors that hamper the development of society. In the economy subsystem, rational economy structure, stable society and sufficient resources as well as good technology support are the promotional factors. They are the conditions for a well-run economy. Upheavals in society and resource shortages as well as low technological support are the restrictive factors. They are obstacles to the development of the economy. In the nature subsystem, good consciousness of environmental protection and sufficient funds are the promotional factors, for they are beneficial to the development of the nature subsystem. Exhausted exploits and utilization as well as natural disaster (calamity) are the restrictive factors, leading the nature system to become unbalanced. Thus the nature subsystem is the basis for the healthy development of the economy subsystem and the social subsystem.

People's development strategies could affect the power balance (contrast) between the promotional factors and restrictive factors to some degrees, thereby deciding the development pattern of the complex system. The main distinct aspect of sustainable development is changing the development of society from exhaustible utilization of resources to sustainable utilization of resources. During the period of industrial revolution in the 19 century, limited by knowledge, people only emphasized the development of the economy and neglected environment protection. The development strategies give priority to economic benefit, which finally becomes unsustainable. Sustainable development focuses on the harmony of development among society, economy and nature. It requires that such strategies try to make the complex system develop a pattern that meet the needs of current generations without compromising the ability of future generations to meet their own needs.

According to the discussion above, the development is affected by many factors, and the power of these factors is different at different times. The degree of development is determined by the interaction of these factors. This causes the distinct development level at different periods, and therefore decides the dynamic character of the development. For example, society develops from low class to high class; economy development has its cyclical fluctuations; ecosystem is easy changed when it suffers an outside force. Therefore, the development track of the integrative system constituted by the three subsystems is an undulating curve. Sometimes the development is good, sometimes it is stagnating or even going backwards.

The process of development covers three periods: (1) the development period (t_1 to t_2 in Fig. 1), when the power of "promotional factors" are stronger than that of "restrictive factors". (2) the stagnation or backward period (t_2 to t_3 in Fig. 1), when the power of "promotional factors" is equal to the power of "restrictive factors" in this period or the power of "promotional factors" is weaker than that of "restrictive factors". (3) innovation and leap period (t_3 to t_4 in Fig. 1), in this period, through the innovation, the power of "promotional factors" gradually become the main factors and the system develops to higher level, otherwise, the system will collapse. Therefore, sustainable development should shorten period 2, avoiding the collapse in the third period, helping the system develop to a higher level by innovation. The track of sustainable development is not only an undulating curve but also the overall trend is upward (shown the curve between the two dotted lines in Fig. 1).

3 Assessment approach

3.1 Assessment framework

As sustainable development is affected by many factors, the assessment of sustainable development involves large quantities of data. A framework can provide a means to organize the data and to integrate it in a meaningful way. Frameworks can also give us a clear outline for assessment. According to the analysis in section 1 to section 3, the framework for the assessment should include some of the following points: (1) Sustainability assessment should integrate society, economy and ecology concerns. (2) Dynamic characteristics should be reflected in the assessment. Temporal dimension and spatial dimension are the two main aspects. Research scale and time period should be determined at the beginning of the assessment. Tendency analysis should be the main basis for assessment. (3) Identifying unsustainability. As there is no exact watershed between sustainability and unsustainability at a time point, the border between them is not very sharp. Unsustainability may go through a gradual change or appear as a sudden collapse. Restriction conditions are required for the assessment. (4) The assessment should provide a guide for decision-making so that remedial actions can be targeted.

The proposed flexible framework for assessing sustainable development shown in Fig.2 includes five parts. (1) Define a period of temporal and a spatial region. This defines the level and direction of the research objective. (2) Select the indicator system. This indicator system includes three kinds of indicators: society indicators, economy indicators and nature indicators. It has a tiered structure. (3) Analyze the trend for each subsystem. The complex system consists of society, economy and nature subsystems. Each subsystem has its own development track. For the sustainable society subsystem, it focuses on improving the cultural degree of whole society, its track is an upward undulating curve. The sustainable economy subsystem focuses on increasing the financial resources of society with an upward undulating curve. The sustainable ecology subsystem focuses on maintaining diversity and the balance of the system. Nature resources have to be consumed as long as society requires development. Fortunately, nature regeneration and substitute resources produced by technical innovation can compensate for the consumption of nature resources. The rectified track should be an up-down undulate curve around a

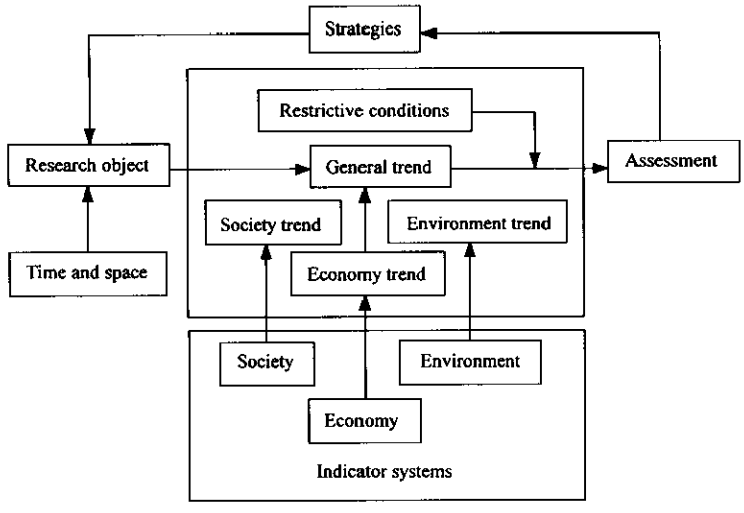

Fig.2 Framework of assessment

balance curve. Assessment of sustainable development should be based on the assessment of each subsystem. (4) Restrictive condition analysis is the limitation for the utilization of the nature resources. (5) Feedback, when the results of assessment are fed back as references for decision making, thereby

helping to avoid unsustainable features in future development period.

3.2 Assessment principles

Most of the sustainability indicators are formulated with respect to known effects in three subsystems (i.e., society, economy and nature), and the complexity of ecosystems makes it impossible to predict all possible effects of human societal activity. Some causes of damages are well known, but the others have not yet been identified. Some effects change with time. A set of indicators is not enough for the assessment, so general principles of sustainable development are required.

According to the definition of sustainable development (WCED, 1987), four principles are proposed as follows:

Principle 1. The extractive amount of natural resources should be within the carrying capacity of nature resources. Natural resources can be divided into two main categories, one is renewable resources and the other is non-renewable resources. Renewable resources should be exploited in a sustainable manner by limiting their rate of depletion to the rate of regeneration. That is to say, the available amount of renewable resources is limited within a period of time, in which the utilization amount by people should not be exceeded. Non-renewable resources should be exploited in a quasi-sustainable manner by limiting their rate of depletion to the rate of creation of substitutable resources. The substitutable resources should be created while the renewable resources are being utilized. When the non-renewable resources are depleted, the substitutable resources will be available. It also implies that the utilization of resources is equitable among different regions and generations.

Principle 2. Waste emissions should not exceed the relevant assimilative capacities of ecosystems. The capacity of every substance existing in nature system is limited, above which damage occurs to the environment. For example, extra amounts of sulphur dioxide lead to acid rain, and extra amounts of phosphorus lead to eutrophication. Oxygen organic contaminant leads to water pollution, likewise heavy metals and toxic chemical materials lead to soil pollution. This principle implies restrictions on waste emissions with increased recycling of material and decreased dissipative use of resources, especially, strong restrictions on the use of persistent substances foreign to nature.

Principle 3. Improve the utilization efficiency of nature resources. The assimilative capacity as well as the available resource flow is limited. In order to fulfil people needs for a growing global economy, the resources and services obtained from the nature should be utilized efficiently. Efficiency means that resources should only be used where they are needed most. This also leads to the requirement of a just distribution of resources among society and people (Smith, 1998).

Principle 4. Fair development between different regions and generations. Sustainable development emphasizes the equitable development of regions and generations. All people, across and within generations have the same right to share the services provided by the nature system and to be developed. Therefore, any region should not meet its own benefits by compromising others ability to meet their own needs. This principle is one of the necessary conditions for sustainable development.

3.3 Assessment approach

3.3.1 Indicator systems

The quantitative analysis of the sustainable development of the complex system required building a set of indicator systems. According to the system definition discussed above, sustainable development of complex systems herein covers two main contents: one is the development of society and economy, the other is the sustainability of nature (environment and resource). The indicator system including society, economy and nature can be formulated by means of AHP (analytic hierarchy process) approach. This indicator system has an appraisal index structure with three layers. The first top layer consists of development and sustainability; the medium layer consists of society, economy, resource and environment;

the bottom layer consists of many single indicator values relevant to each indicator of medium layer. Last, the development degree can be evaluated by a synthetic index (Shi, 1998). According to the synthetic index, the track of development could be got.

3.3.2 Trend analysis

According to the framework, sustainability assessment is made in terms of the direction and degree of measurable changes in a certain development period. Sustainable development is a development's ability to continue when the development level of each period is different. The slope of the trend line provides a quantitative index, so that trend analysis is consistent with the requirement of the assessment. Trend analysis assumes that the future tendency of a system's development can be approximated from the present tendency. For a certain period, a system is considered sustainable if the total trend of development and the curve is upward. However, unsustainability expresses itself as either a gradual change or sudden collapse. So, some restrictive conditions are also required for the assessment (UCSD, 1995). Certainly, the subsystems also should be considered, because trend of society and economy subsystem should not be negative, and the rectified level of the ecology subsystem should not be low down the restrictive conditions.

3.3.3 Restrictive conditions

The following four conditions should also be satisfied according to the four principles presented in section 2.

(1) The extraction rates of resources should be lower than the regeneration or the substitution rates of resources. Otherwise, the depletion of resources will occur in the future. Other generations will loose their basic level of support. This kind of development is unsustainable. Let R_{ex} is the extraction rates of resources, R_{re} is the regeneration or substitution rates of resources, β is the rate between R_{ex} and R_{re}, i.e., $\beta = R_{ex}/R_{re}$, and if the tendency of development tends to sustainability, then $\beta \in (0, 1)$.

(2) The amount of waste emissions should not excess the threshold for the environment. The nature environment has its own capacities for most substances, and these capacities are limited. If the emissions exceed these capacities, the environment will be damaged, and ecosystem will tend to imbalance. Therefore, people's development should focus on the recycling utilization of the resource, reduce the waste of production, and avoid discharging more manmade products foreign to nature. Let Q is the environment capacity, E is the amount of waste emission, we have $N = Q - E$, and $N > 0$ is a necessary condition of sustainable trend of development.

(3) Improve the efficiency of resource utilization and promote the just distribution of resources. With the growth of the globe population and the increase of the globe economy, the supply of biomass for food, material and energy is becoming stressed. Limited resources should be maintained, and thus the productivity of lands and the biodiversity of ecosystem should not be worsened. Another important aspect is that people should do their best to improve the utilization efficiency of resources using them in a time of greatest need. Let η_e represents the efficiency of resources in a research year, η_s represents the efficiency of resources with the best available technology (BAT), then $H = \eta_e/\eta_s$. H should approach to 1, if the development trend to sustainable.

(4) Equity development. This covers two aspects: intragenerational and intergenerational equity. Nature resources belong to people. All people, in any region and in generation have the same right to use the resources and to share the environment for development. That is to say, no one should damage the others benefits for his own development. Condition (1) to condition (3) provides a kind of equity for the usage of resources and the sharing of environment. This condition will focus on population control and regional capacity. It is well known that extra growth in population will stress the supply resources, therefore, the population of any country should be control within that permitted by the support of resources

and environment belonging to his own country. Moreover, every region has its own resources; so no country should occupy the resources belonging to another country for their own development. The exchange of resources should correspond the benefits for each side. Therefore, population control and the equitable utilization of resources are two necessary conditions of sustainable development.

Based on these conditions, we can design proper specific computing models for the assessment of sustainable development of specific application fields.

4 Conclusion

This paper presents a dynamic assessment approach to assessing whether sustainable development is approached or not. The main work covers three aspects. Firstly, we analyze the dynamic character of sustainable development. Secondly, we suggest a dynamic assessment framework. Thirdly, we provide a flexible assessment method based on trend analysis, restrictive conditions as well as utilizing feedback system for the assessment of sustainable development. The proposed approach is a necessary complement to traditional methods. This approach has two characteristics: it reflects the dynamic characteristic of sustainable development; it is also a flexible assessment based on trend analysis with a set of conditions for sustainable development and a feedback system.

The ongoing work is to apply the presented approach to the assessment of the sustainable development of a county in China, and to establish a computer-assisted system that can help the assessment of regional sustainable development.

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