

# Sustainable Development Planning of Protected Areas near Cities: Case Study in China

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**Abstract:** The regional level is believed to be an important platform to carry out sustainable development (SD) strategies. In China, the rapid urbanization process causes city expansions. To protect environmentally sensitive areas between cities, some protected areas (PAs) have been established. This paper proposes a framework of translating general SD principles into specific practices at the regional level, particularly for the PAs. The framework is based on and illustrated by a detailed case study of the comprehensive SD planning of an environmentally sensitive area in China. A multicriteria decision-making (MCDM) technique, the analytic network process (ANP), was used to weigh the evaluation criteria and rank the proposed capital and social development projects. It was found that the framework was helpful in guiding the SD planning process and the ANP method provided insights on the interaction of various aspects of sustainability. DOI: 10.1061/(ASCE)UP.1943-5444.0000133. © 2013 American Society of Civil Engineers.

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## Introduction

Sustainable development (SD) as a concept has gained wide acceptance around the globe [e.g., Harris and Goodwin (2001), Sohail et al. (2005), and Wallbaum et al. (2011)], but the question remains how to effectively achieve it (Carley and Christie 2000). Over the past decades, sustainability has been approached at different levels by various players. At the international level, the international communities have strived to reach a mutual understanding of what constitutes sustainability and developed criteria and metrics to measure progress toward it [e.g., Parris and Kates (2003), United Nations (UN) (2007), and EUROSTAT (2009)]. At the national level, some countries have developed comprehensive SD strategies or sustainability policies in specific areas [e.g., Hřebík et al. (2006) and UK Department for Environment, Food and Rural Affairs (2010)]. At the industry level, certain industries have developed guidance and rating systems to promote sustainability pertinent to the particular industries, such as the Leadership in Energy and Environmental Design (LEED) in the United States and the Building Research Establishment Environmental Assessment Method (BREEAM) in United Kingdom. Nongovernmental organizations

(NGOs) have also played important roles in advocating SD, especially at places where intuitional capacity to carry out SD is lacking (Handfield et al. 2001; Gemmill and Bamidele-Izu 2002). In addition, sustainability initiatives have been performed at the grassroots or community levels (Uvin 1995; Fraser et al. 2006).

All these efforts seemingly benefit SD in the world; however, it is criticized that the actual progress achieved toward the goals of sustainability can be best described as limited (Wallbaum et al. 2011; Lafferty 2006; Loorbach and Rotmans 2006). To make fundamental changes, the general principles of sustainability have to be translated into organized and concerted actions, and spontaneous actions need to be guided by well thought out SD principles and strategies. It is argued that sustainability performs poorly at the practical level because of a vague definition of priorities, inadequate attention to connections between the different dimensions of sustainability, and lack of consideration of financial costs and administrative requirements (Hřebík et al. 2006). To facilitate the translation of SD concepts into practices, more attention needs to be paid to the interfaces at which the two connect.

One of the most important interfaces between the general SD principles and specific actions is thought to be at the regional development level [e.g., Hřebík et al. (2006), Von Zeijl-Rozema and Marten (2010), and Márton (2010)]. A region is a territory within which there exists a high degree of homogeneity in demographics, culture, economic characteristics, and ecology. It is a place in which sustainability meets the local specificities and circumstances (World Summit on Sustainable Development 2002) and where SD policies and practices can potentially make a significant impact. However, there are two particular challenges to conducting regional planning under SD principles: (1) how to identify the appropriate sustainability criteria that are aligned with general sustainability principles yet relevant to the local context, and (2) how to prioritize actions under the constraints of resources.

This paper reflects on the process and methodology the authors used in carrying out SD planning for a special region, a protected area (PA) between two cities in China. The PA is located in the

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Hebei Province and was recently established as a national nature reserve named as the Hengshui Lake Nature Reserve (subsequently, the Reserve). Due to the mass migration of people from countries to cities, China is currently experiencing large-scale urban development and expansion. In some densely populated regions, cities start to lose their traditional boundaries and merge into connected mega metropolitan areas. The urban sprawl squeezes the rural spaces and threatens the natural environment and the ecological system. In response to such concerns, PAs are established or proposed in some environmentally sensitive areas. These PAs are often claimed as the back gardens of the adjacent large cities and their developments are constrained by government policies. However, conservation of natural resources and protection of ecological systems need to be balanced with the desire of the local communities for improving their economic status. Otherwise, conflict may arise between environmental conservation and economic development, and the latter may eventually prevail due to the lack of strong institutional and social supports for environmental protection at the current moment in China.

This paper is a combination of results from two studies. In the first study, detailed analysis of the Reserve in various aspects of sustainability was performed based on desktop studies of documents related on the region, interviews with the government officials, and several participatory surveys of the local residents. The result of the study was a SD plan for the Reserve (Deng et al. 2011), including strategies and a list of approximately 80 capital development projects and a few social development projects that would cost approximately 2.8 billion yuan (approximately US \$42 million). However, the government did not have the necessary financial means to implement all these projects. Therefore, it requires a mechanism to rank the projects based on their values of promoting SD. The second study, which forms the main content of this paper, aimed to identify and rank the relevant sustainability criteria for the Reserve and evaluate the contributions of each project to those criteria. In the following discussion, the general framework of performing SD planning at the regional level is proposed in “General Framework of SD Planning at the Regional Level,” while the application of the general framework in this particular case is introduced in “Sustainable Development Planning of the Hengshui Lake Natural Reserve.”

## General Framework of SD Planning at the Regional Level

There have been many studies on the application of sustainability principles in planning, e.g., improvement of pedestrian connectivity in an urban environment (Randall and Baetz 2001), transportation planning [e.g., Jeon et al. (2006) and El-Gafy et al. (2011)], urban human settlements (Mani et al. 2005), and urban images (Sepe 2010). Wallbaum et al. (2011) provides a summary of more than 30 methods and tools for promoting sustainability in construction-related fields. SD planning at the regional level, however, receives little attention and academic inquiry (Haughton and Counsell 2004). Moreover, a number of existing studies [e.g., Haughton and Counsell (2004) and Birkmann and Gleisenstein (2002)] on this topic mainly focus on conceptual and political issues without discussing the methodological aspects of implementing SD in regional planning. A region is a complex system that involves numerous components, stakeholders, and their interactions. In China, there is an increasing awareness of SD as well as a political system that favors regional planning, but there lacks a systematic approach that incorporates the SD principles into the development plans. Based on the authors’ involvement

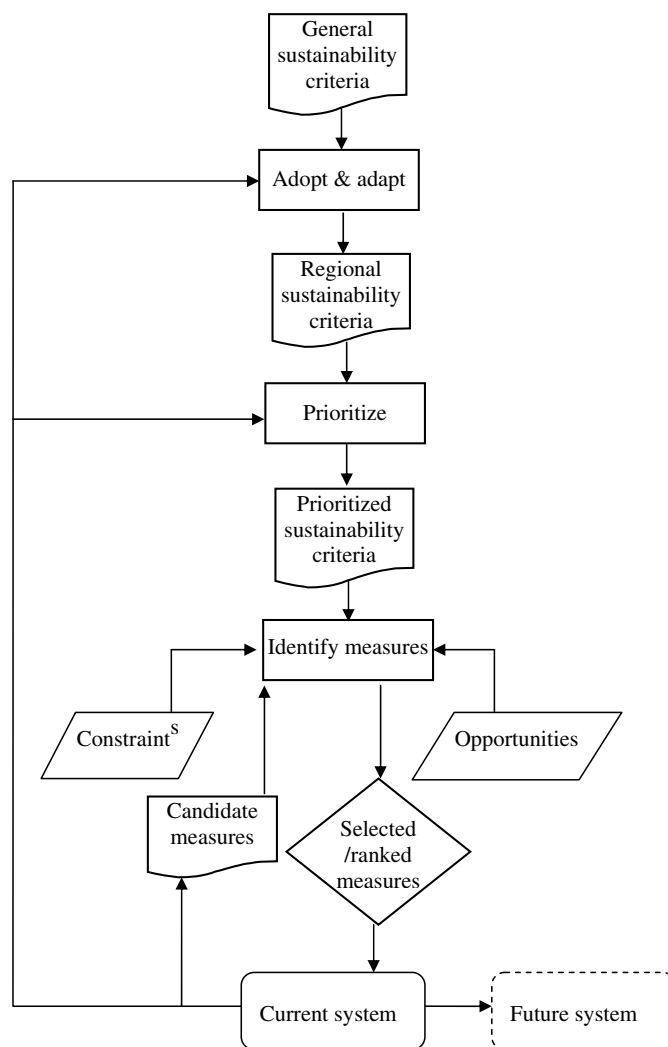


Fig. 1. Proposed framework of SD planning at the regional level

in the SD planning for the Reserve, a framework of SD planning at the regional level is proposed, as shown in Fig. 1. The elements and connections of the framework are explained as follows.

### Selection of General Sustainability Criteria

SD planning at the regional level starts with the selection of general sustainability criteria. It is commonly agreed that sustainability consists of three pillars: environment, society, and economy (United Nations 2005). Out of these three dimensions, more detailed sustainability indicators and metrics have been developed. The UN Commission on Sustainability Development (CSD) has developed a set of sustainability indicators (United Nations 2007), which are widely known around the globe. The European Union (EU) has developed a set of sustainable development indicators and uses the indicators to monitor the progress toward sustainable development in the European Union (EUROSTAT 2009). Sustainability indicators have also been developed at the national level. For example, the United Kingdom has developed its own 68 sustainability indicators that are organized in four themes: sustainable consumption and production, climate change and energy, protecting natural resources and enhancing the environment, and creating sustainable communities (UK Department for Environment, Food and Rural Affairs 2010). The general sustainability

principles are the basis for more specialized SD indicators at the regional level.

### **Analysis of the Current System**

A region is a complex social-ecological system that entails a systems approach for analysis (Gallopri'n 2003; Clayton and Radcliffe 1996). Before performing SD planning, the planners perhaps already have general ideas about the basic attributes of the region and the main concerns it faces. For example, a major concern for the Reserve in this study is to protect the migratory birds and their habitats. However, a systems approach is not to focus on one component alone, but to "look at a problem in its entirety, taking into account all the facets, all the intertwined parameters" (Ramo and Clair 1998). The multiple dimensions of SD and the complex social-ecological systems make it necessary to thoroughly study the characteristics of the system components, their connections, and how the components and connections are related to SD goals. Various approaches can be used to analyze the current system, including but not limited to desktop studies, laboratory and field tests, and questionnaire or participatory surveys. Based on the system analysis, the status quo of the system as well as the constraints and opportunities for SD can be identified.

### **Development of Regional Sustainability Criteria**

At this step, the general sustainability criteria are combined with the information obtained from the system analysis to create specialized regional sustainability criteria. During the process, some general sustainability criteria can be directly used, others may need to be modified and then used, and new sustainability criteria may be created.

### **Prioritizing Sustainability Criteria**

It should be recognized that not all the criteria are equally important for the system. One advantage of carrying out SD planning at the regional level is that it allows planners to highlight the main needs and concerns of the system. For instance, water quality is more of a concern in the Reserve than the air quality. There are a variety of methods that can be used to rate the relative importance of the criteria, such as the multiattribute utility technique (MAUT); simple multiattribute rating technique (SMART); analytic hierarchy process (AHP) and its general form, analytic network process (ANP); and many others (Kiker et al. 2005; Figueira et al. 2005). All of these techniques have their advantages and disadvantages. In this study, the ANP technique was used because it enabled capturing the interdependency of sustainability subcriteria.

### **Identification of Constraints, Opportunities, and Measures**

Measures represent what alternatives are available or what actions can be taken to move the current system toward sustainability. As shown in Fig. 1, the selection of measures is a repetitive process. Initially, based on the system analysis, a list of measures can be developed, perhaps out of a brainstorming process. This list, along with the constraints and opportunities, enters the selection process in which the measures are further refined and ranked. The constraints and opportunities are as important as the system components in the identification of possible measures. For example, one critical constraint for the Reserve in this study is the lack of water resources, which mainly rely on water diversion programs paid by the local government and a local factory. However, one imminent opportunity is the South-to-North Water Diversion

Project initiated by the central government that diverts water from the Yangtze River to Beijing. The project will pass the border of the Reserve and potentially provide water for the lake, but hydraulic facilities need to be built to connect to the project. The proposed measures will also be subject to financial constraint, which requires prioritizing these measures.

### **Sustainable Development Planning of the Hengshui Lake Natural Reserve**

The Reserve (Fig. 2), covering an area of 268.08 km<sup>2</sup>, is bordered by the Jizhou city, China, on the southwest and the Hengshui city, China, on the northeast. The uniqueness of the Reserve is that it hosts the largest wetland in the dry North China Plain, which forms a rest place for hundreds of species of migratory birds, some of which belong to the highly endangered wildlife in China. However, urban development has been continuously encroaching on the wetlands: the border of the Jizhou city is already at the south bank of the main lake and the Hengshui city is less than 10 km away from the north bank. In the first study that forms this paper, the Reserve and its peripheral suburban areas were treated as a region for analysis and different aspects of sustainability were analyzed. However, it remained a question how to prioritize the different dimensions of sustainability, assess the sustainability values of proposed alternatives, and allocate resources.

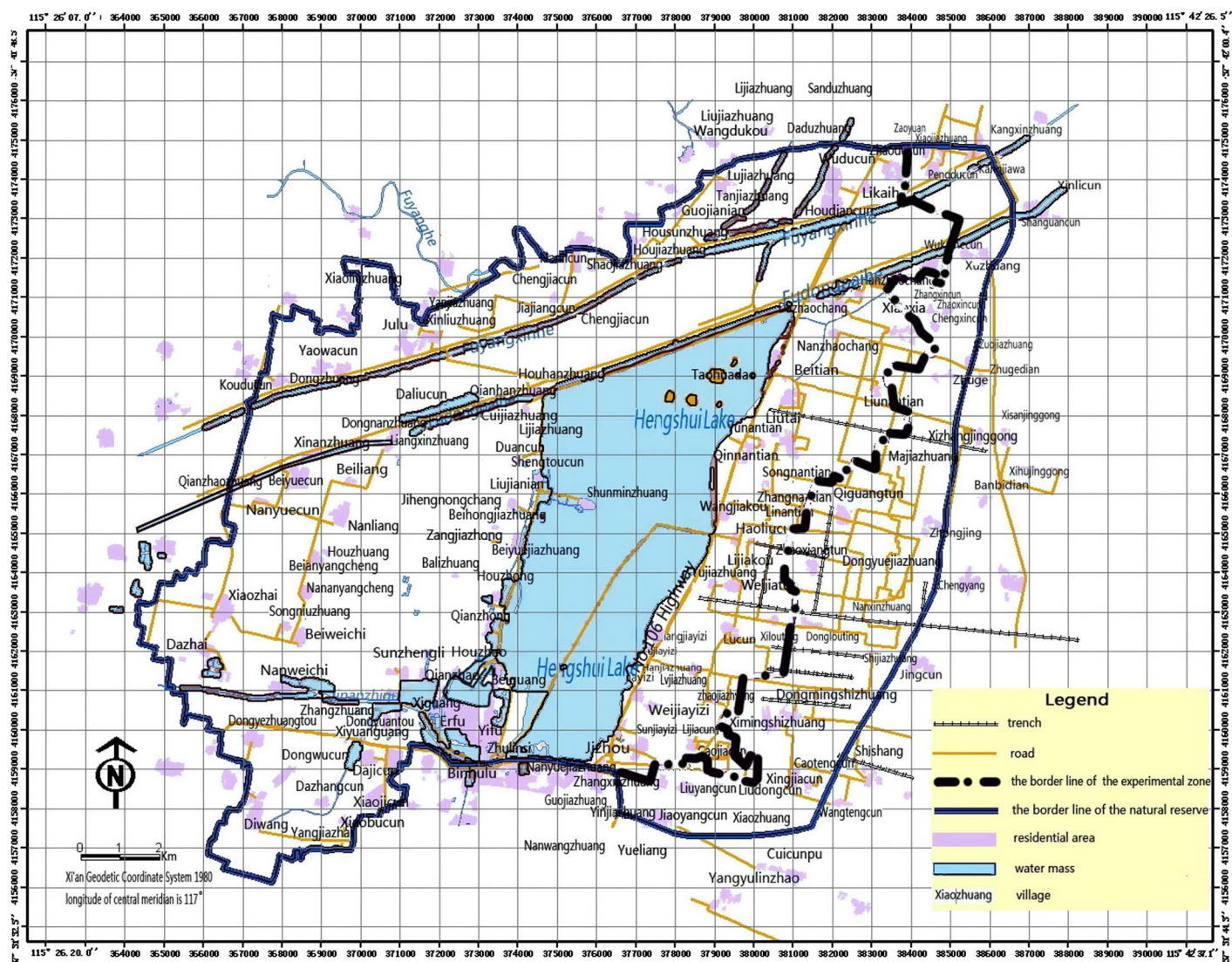
### **Analysis of the Current System: the Reserve and its Environmental Significance**

The Reserve is surrounded by urban areas. Besides the two cities adjacent to the Reserve, it is 250 km away from Beijing and Tianjin, China, and 100 km away from Shijiazhuang, China, the capital city of Hebei province. In 2005, it hosted 65,180 people from 19,046 households. This region has been historically known for its large lake and wetlands; but ironically, many attempts were made to drain the lake to create farmlands. Today, complicated hydraulic infrastructures are built in the Reserve and the river basin, and natural rivers are disconnected from the lake in the upper streams by dams. In the recent half-century, frequent droughts and occasional floods brought tremendous hardship to the local people. To meet the agricultural and industrial demands on water, the local government restored a small portion of the dried lake through water diversion projects and gradually expanded the lake area in recent years. The restored lake incidentally provides a rare rest place for thousands of migratory birds in the middle of their migrating routes: 51 species of the birds found in the Reserve belong to either category I or category II of endangered wildlife in China, 151 species are listed in the "Agreement to Protect Migratory Birds and Their Habitats between China and Japan" (a total of 227 species) (Wu 2009), and 40 species are listed in the "China-Australia Migratory Bird Agreement" (a total of 81 species) (Department of Foreign Affairs and Trade, Australia 1988). Therefore, the Reserve has a great ecological and environmental value with worldwide significance. However, the economic interests of the local people need to be considered in carrying out environmental conservation activities, particularly in the densely populated PA in which people heavily depend on natural resources (Altrichter 2006; Robbins et al. 2007).

### **Identification of Sustainable Development Criteria for the Reserve**

China currently does not have a set of official sustainability indicators. The UN sustainability indicators (United Nations 2007),





**Fig. 2.** Scope of the reserve (adapted from 2002 village survey maps by Jizhou Land Bureau, 1979 village survey maps by Hebei Province Survey Service, and satellite photo by China Remote Sense Earth Station taken on July 1, 2001)

which represent the widest consensus on what constitutes sustainability by the international community, were chosen as the general sustainability criteria. The CSD indicators, consisting of 50 core indicators, are categorized into 14 themes and 44 subthemes. Three principals were followed in selecting the regional SD criteria based on these indicators: First, the criteria need to be comprehensive enough to reflect different facets of sustainability, yet not be too refined to make it difficult to compare their relative importance; second, the chosen criteria should be applicable to the particular regional problem; and third, the criteria should be under the influence of the planners and decision makers. Based on these principles and the planning documents generated in the first study (Deng et al. 2011), the following CSD themes were excluded: demographics; oceans, seas, and coasts; and global economic partnership. The remaining CSD themes and the subthemes were adopted or adapted as the evaluation criteria and subcriteria, respectively, in addition to a few created in this study. The evaluation criteria and subcriteria are shown in Table 1 and the reasons for choosing them are explained subsequently.

- **Poverty:** The CSD sustainability theme under poverty consists of five subthemes: income poverty, income inequity, sanitation, drinking water, and living conditions. Based on the analysis of

the social and economic conditions of people living in the Reserve, all of these subthemes were chosen as sustainability subcriteria. In 2006, the poverty rate in the Reserve was 0.4% of the total population based on the local poverty line (Deng et al. 2011). There also existed income inequity problems: the average per capita net income of the poor families was only approximately one-tenth of the average in the region. The suburban areas and the villages in the Reserve had poor sanitation conditions and facilities, which posed health threats to local residents and degraded the water quality of the lake and wetlands. Because the water from the lake was unsafe to drink, people had to obtain their drinking water from deep wells, causing the water table in this region being lowered every year. The CSD indicator for “living conditions” refers to the “proportion of urban population living in slums.” Because the Reserve still mainly covers the rural area, the CSD indicator was modified to “housing conditions.” There were two particular housing issues in the Reserve. First, several villages needed to be relocated from the lake area for future water restoration projects, which required the government to build resettlement housing and facilities for those affected residents. Another issue was that many houses of the poor families were in dilapidated conditions and

**Table 1.** UN Sustainability Themes and Subthemes and those Chosen and Adapted for this Study

CSD themes	CSD subthemes	Evaluation subcriteria for this study
Poverty	Income poverty Income inequality Sanitation Drinking water Living conditions	Poverty rate Income inequality Sanitation Drinking water Housing conditions
Governance	Crime	Illicit fishing and hunting
Health	Health care delivery	Health care facilities Health care subsidies
Education		Education facilities Education subsidies
Natural hazards	Vulnerability to natural hazards Disaster preparedness and response	Habitant in hazard prone areas Disaster preparedness and response
Atmosphere	Climate change Ozone layer depletion Air quality	Air pollution
Land	Agriculture	Farmland protection Chemical fertilizer and pesticide use Crop loss subsidies
Freshwater	Water quantity Water quality	Water quantity Water quality
Biodiversity	Ecosystem Species	Biodiversity
Economic development	Macroeconomic performance Employment Information and communication technology (ICT) Research and development	Gross domestic product (GDP) Employment ICT Research
Consumption and production patterns	Tourism Material consumption Energy use Waste generation and management Transportation	Green industries Nonrenewable material and energy Waste Transportation

needed to be improved. For example, 35.7% of houses owned by poor families were made of earth bricks (Deng et al. 2011).

- **Governance:** The CSD theme governance contains two subthemes: corruption and crime. Although both subthemes were concerns for the Reserve, corruption is more related to institutional measures by the government than project selection and thus was not selected as an evaluation subcriteria. In addition, the subtheme crime was modified to “illicit fishing and hunting,” which were the main illegal activities concerning environmental protection.
- **Health:** The primary concern under the theme health was health care delivery. The rural and suburban areas lacked high-quality health care facilities. In a 2007 survey, 19 out of 21 interviewed villagers who had major illness had to go to the hospitals in the nearby cities for treatments (Deng et al. 2011). In addition, many families could not afford high health care costs and some slipped into debt due to medical expenses.
- **Education:** High education cost was another heavy burden for some families. Due to the lack of quality education in the region, many families sent their children to boarding schools in the nearby cities. Before 2007, all students from the rural families had to pay tuition and educational fees, plus expensive boarding

fees. After 2007, based on the amended Compulsory Education Law of China, the education expenses were covered by different levels of government. This reform shifted part of the financial responsibility from families to governments. In addition, the governments needed to build new schools for the resettlement families.

- **Natural hazards:** The major natural hazards in this region were earthquakes and floods. In the history, several powerful earthquakes struck Hebei Province with heavy death tolls, including the Great Tangshan Earthquake, which occurred in 1976 (Spignesi 2005). In the most recent 500 years, 10 major earthquakes had been recorded in this region. From 16 BCE to 1979 CE, this area had 931 recorded floods (Deng et al. 2011). The most devastating flood occurred in 1968, which inundated all the villages in the Reserve with a death toll of 43 (Deng et al. 2011). Unfortunately, rural houses today are still poorly built to withstand any major earthquake or flood. Some villages remain located in the dried lake, which was another reason to relocate these villages to a higher ground.
- **Atmosphere:** Although the CSD theme atmosphere consists of three subthemes, they are difficult to evaluate separately for a region. Therefore, air pollution was used as a subcriteria to assess the impacts of different project alternatives on atmosphere. In China, the currently used indicator on air pollution is the air pollution index (API), which is a composite index including three types of pollutants: particulate matter (PM), sulfur dioxide (SO<sub>2</sub>), and nitrogen oxides (NO<sub>x</sub>) (Hao and Wang 2005). If the API value falls in the range of 0–50, the air quality is categorized as grade 1; if API is in the range of 51–100, the air quality is grade 2. In the Reserve, the air quality is grade 2 most of the time, which is better than many cities [e.g., Chen et al. (2008)] but not good for a nature reserve. The annual average concentration of SO<sub>2</sub> ranges from 0.002 to 0.355 mg/m<sup>3</sup>, exceeding the grade 1 limit by 4.1%; the annual average concentration of PM ranges from 0.024 to 0.785 mg/m<sup>3</sup>, exceeding the grade 1 limit by 26.2% (Deng et al. 2011). The NO<sub>x</sub> is not a concern in the Reserve. The main air pollutants in the Reserve are some small rubber processing factories, heating radiator manufacturers, and a power plant.
- **Land:** The CSD theme land includes four subthemes and 10 indicators. The only applicable subtheme to the Reserve was agriculture, under which the indicators cropland protection and reduction of chemical fertilizers and pesticides were chosen as the evaluation subcriteria. Another subcriteria was also created—crop loss subsidies, to compensate the crop loss of the villagers to the increased bird population.
- **Fresh water:** Water is essential to the ecological system as well as to the economic development of the Reserve. Water in Hengshui Lake is replenished by annual water diversions from distant reservoirs and the Yellow River. It was planned to use water from the South-to-North Water Diversion Project in the future. On the other hand, local rivers were disconnected from the lake because of heavy pollution. To solve the water problem, both water quality and water quantity need to be addressed.
- **Biodiversity:** The theme biodiversity includes two subthemes: ecosystem and species. The unique wetland ecosystem was the precondition for the survival and robustness of bird species in the Reserve. Because the ecosystem and target species were interdependent, they were treated as one evaluation subcriteria under biodiversity.
- **Economic performance:** The Reserve was not created from a pristine state, but restored from a well-developed, populous area with some unsustainable development patterns. Both environmental conservation and social development projects required



financial investments, which were dependent on the overall economic performance of the region and the revenue of the government. Therefore, ranking or selection of projects had to consider their contributions to the local economy. Five subthemes from the CSD theme economic development were chosen and revised as evaluation subcriteria, including the contribution of the evaluated projects to gross domestic product (GDP), contribution to employment, improvement of information and communication technology, research and development, and tourism. Furthermore, the subtheme tourism was revised to green industries to make it more inclusive for other more environmentally friendly industries such as reed weaving, organic farming, and plant nurseries.

- Consumption and production patterns: The CSD theme consumption and production patterns includes four subthemes: material consumption, energy use, waste generation and management, and transportation. The material consumption and energy use were combined into one evaluation subcriterion: reduction of the use of nonrenewable materials and energy. The solid domestic and industrial wastes were not collected and centrally processed, which was harmful to health and environment. In addition, the transportation system needed to be improved to facilitate the tourism industry.

In summary, 11 CSD themes were chosen as the general sustainability criteria for the Reserve. Based on the CSD subthemes, 27 detailed evaluation subcriteria were selected as the regional SD indicators. However, as previously discussed, these subcriteria were not equally important in the specific context of the Reserve. Before these subcriteria were used to evaluate the proposed list of projects (measures), a reasonable and defensible process had to be followed to determine the relative importance of these subcriteria.

### Prioritization of Sustainability Criteria for the Reserve based on the Analytic Network Process

Ranking projects based on prioritized principles is a typical multicriteria decision-making (MCDM) problem, which involves choosing the best one or ones from a set of discrete alternatives. There are many MCDM methods available today, discussed in thousands of articles and dozens of books (Figueira et al. 2005). The AHP and its generalized form, the ANP, are two popular MCDM models developed by Saaty (2005). The ANP is different from AHP in that it permits interdependency among the criteria of the same and different levels, among alternatives, and among alternatives and criteria. Although the AHP method is employed in several planning studies [e.g., Kim (2009) and Delavari-Edalat and Abdi (2010)], there is little research using the ANP method. However, ANP is more advantageous than AHP in this application because the sustainability criteria interact with each other and such interactions may affect their relative importance at the regional level. In this study, the ANP technique was used to derive the weights of the sustainability evaluation criteria and subcriteria and the “absolute measurement” (Saaty 2005) method was used to calculate the project scores: a higher score implies that a project has a higher value in sustainability. The structure of the ANP network and its relationship with alternatives are shown in Fig. 3.

In Fig. 3, the top level is the overall goal of sustainability, which is divided into 11 CSD themes as the main evaluation criteria, which are further divided into 27 evaluation subcriteria. The relationship between the main evaluation criteria and the subcriteria is hierarchical. Among the subcriteria, interdependency of the elements is allowed, which makes the model different than the AHP model. The interdependency of the elements is a more realistic representation of the complex interactions among the subcriteria:

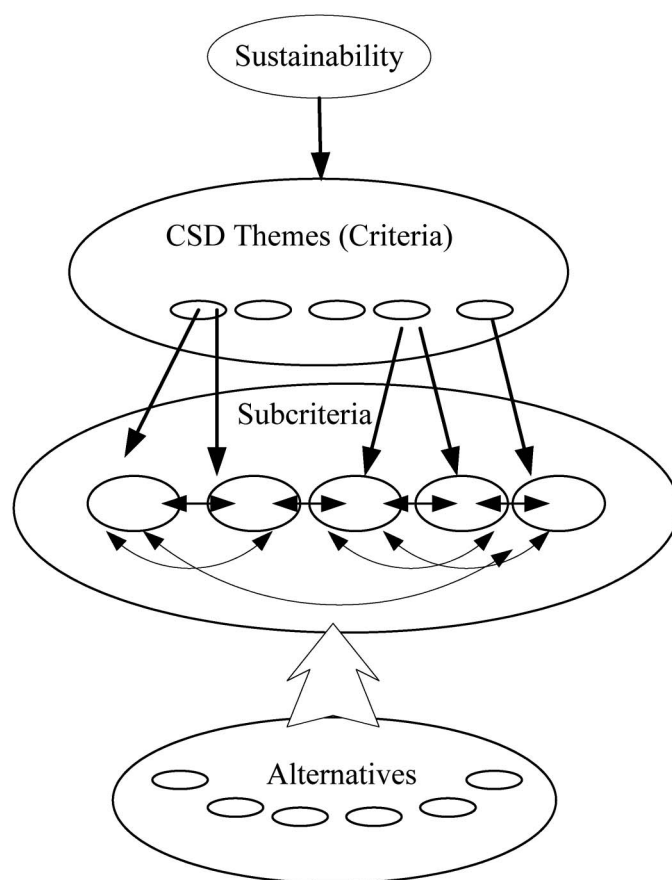


Fig. 3. Framework of the ANP in this study

for example, biodiversity is influenced by water quality, and crop-land protection is influenced by green industries. The lower part of Fig. 3 represents various projects and programs (measures) initially recommended in SD planning. Typically, the ANP network consists of both evaluation criteria and alternatives (Saaty 2005). However, it was impossible for this study to include the large number of the alternatives. Therefore, the ANP model was only used to evaluate the relative importance of the evaluation criteria and subcriteria, and the alternatives were ranked individually based on the weighted subcriteria.

The steps of prioritizing sustainability criteria based on ANP in this study involve (1) performing pairwise comparisons of the main sustainability criteria and checking for consistency of the comparisons, (2) performing pairwise comparisons of subcriteria with respect to each main criterion and checking for consistency, (3) performing pairwise comparisons of relevant subcriteria with respect to a subcriterion of the same level and checking for consistency, (4) deriving weight vectors for comparison matrices, (5) entering the weight factors into a supermatrix as specified by Saaty (2005), and (6) raising the supermatrix to a large power until it converges to a limit supermatrix (Saaty 2005), which provides the weight factors of the subcriteria after considering all the hierarchical relationships and the interactions.

### Pairwise Comparisons and Development of Weight Factors

The pairwise comparisons were based on the previous study that developed the SD plan for the region (Deng et al. 2011). The planning team was composed of two urban planners who are also

**Table 2.** Relative Importance of Sustainability Themes with Respect to the Overall Sustainability Goal

Sustain	Poverty	Governance	Health	Education	Atmosphere	Agriculture	Freshwater	Biodiversity	Economic development	Consumption and production patterns	Natural hazards
Poverty	1	3	1/3	1/3	1	1/3	1/5	1/5	1/3	1/3	1
Governance	1/3	1	1/7	1/7	1/3	1/8	1/9	1/9	1/8	1/7	1/3
Health	3	7	1	1	3	1	1/3	1/3	1	1	3
Education	3	7	1	1	3	1	1/3	1/3	1	1	3
Atmosphere	1	3	1/3	1/3	1	1/3	1/5	1/5	1/3	1/3	1
Agriculture	3	8	1	1	3	1	1/2	1/2	1	1	3
Freshwater	5	9	3	3	5	2	1	1	3	3	6
Biodiversity	5	9	3	3	5	2	1	1	3	3	6
Economic development	3	8	1	1	3	1	1/3	1/3	1	3	5
Consumption and production patterns	3	7	1	1	3	1	1/3	3	1/3	1	3
Natural hazards	1	3	1/3	1/3	1	1/3	1/6	1/6	1/5	1/3	1

architects, one geographic expert, three economists, two project management professionals, and six environmental scientists specialized in SD studies, ecology, water resource, water pollution, and wetland. Because not all the team members were familiar with the ANP approach, the core team members first followed the ANP methodology and determined the comparison scores of the evaluation criteria and subcriteria on a consensus basis and then the other members were consulted for revision and adjustment of the evaluation scores. The evaluation results were also discussed among the planning team members for validation of the reasonability.

The comparisons of the criteria with regard to the overall SD goals of the Reserve are shown in the matrix in Table 2, which indicates the relative importance of the row element comparing to the column element. The explanation for the scale of these numbers can be found from references on AHP or ANP [e.g., Saaty (2005)]. When making multicriteria comparisons, evaluators may make inconsistent judgments that may impair the validity of the comparison matrix. Therefore, the consistency of the matrix needs to be checked by examination of the consistency ratio defined by the following equation (Saaty and Vargas 2006):

$$CR = \frac{\mu}{RI} \quad (1)$$

where RI = random index of different orders of the matrix (Saaty and Vargas 2006); and  $\mu$  is calculated from the following equation:

$$\mu = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

where  $\lambda_{\max}$  = principal eigenvalue of the evaluation matrix; and  $n$  = order of the matrix. The typical allowable consistency ratio should be no more than approximately 0.10 (Saaty and Vargas 2006). For example, the matrix in Table 2 has an acceptable consistency ratio of 0.058.

Table 2 shows the relative importance of the sustainability themes (evaluation criteria) with respect to the overall sustainability goal. Each theme consists of several evaluation subcriteria, which also need to be compared pairwise. Table 3 shows an example of the pairwise comparison of the evaluation subcriteria with respect to the theme poverty. The matrix in Table 3 has a consistency ratio of 0.01. There were a total of 11 matrices for the 11 evaluation criteria.

Next, a total of 27 comparison matrices were constructed to capture the interactions of the subcriteria belonging to different themes. Fig. 4 shows an example of how the subcriteria drinking water is influenced by the other subcriteria. First, it is affected by housing under the same theme poverty because improvement of housing conditions, especially relocating some residents to apartment buildings, would enable them to use clean city water. Second, the improvement of education facilities would allow children access to safe drinking water. Third, reduction in the use of

**Table 3.** Relative Importance of Subcriteria with Respect to Poverty

Poverty	Income poverty	Income inequality	Sanitation	Drinking water	Living conditions
Income poverty	1	1/3	1/3	1/5	1
Income inequality	3	1	1	1/3	2
Sanitation	3	1	1	1/3	3
Drinking water	5	3	3	1	7
Living conditions	1	1/2	1/3	1/7	1

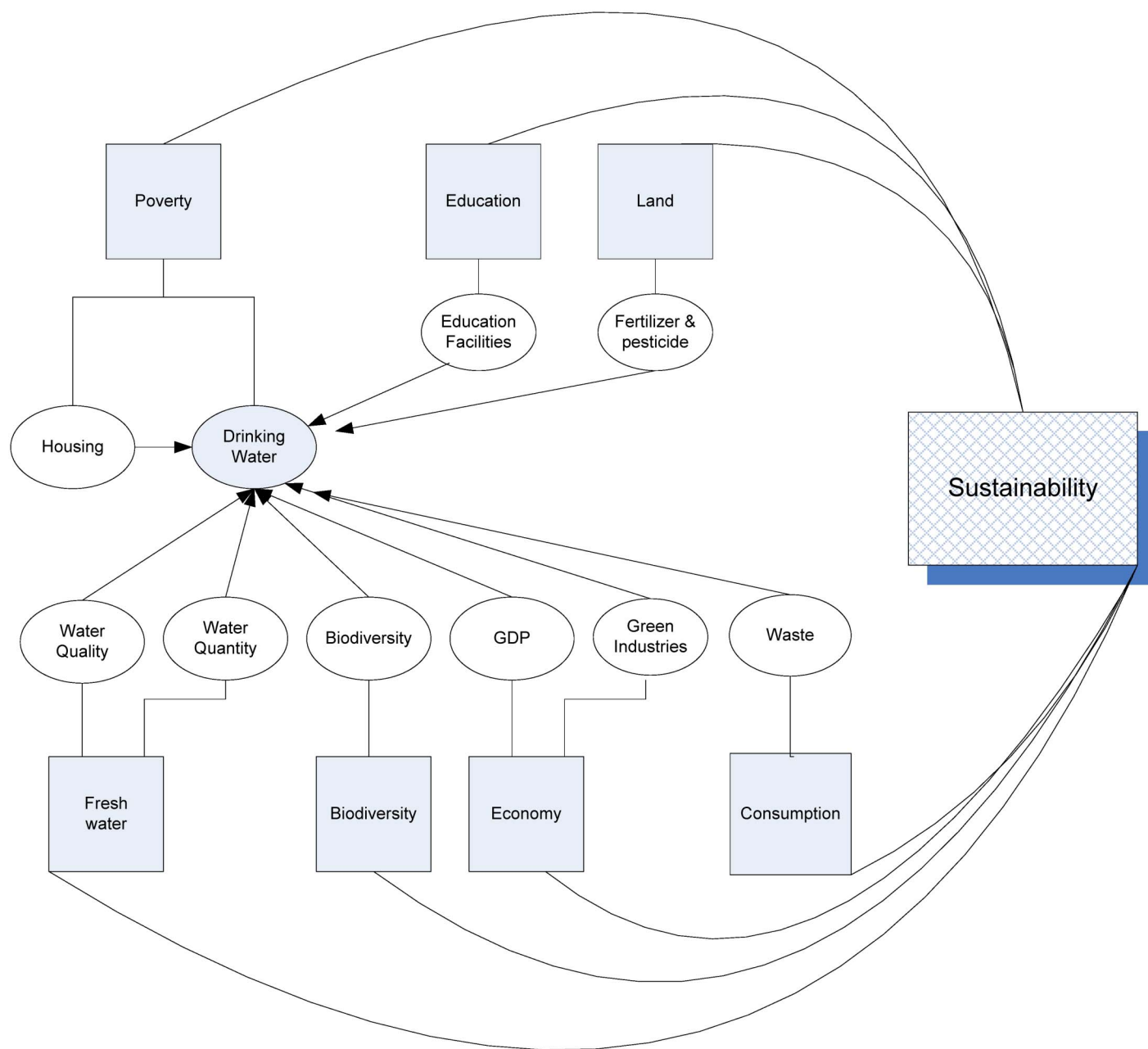


Fig. 4. Dependence of drinking water on the other subcriteria

agricultural fertilizer and pesticide would make surface water less polluted and consequently improve water quality in the lake. It is also obvious that quality and quantity of water source affects drinking water. A healthy wetland may slow the drainage flow from the developed lands and filter out some pollutants before water reaches the streams and the lake; therefore, biodiversity also contributes to drinking water quality. The water diversion efforts and environmental treatment projects need capital investment, which depends on the overall economic performance. Therefore, the drinking water is also related to GDP under the theme economy. The promotion of green industries will possibly lure people and businesses away from some heavily polluted small factories, thus reducing point-source pollution. Finally, better waste management practices can prevent waste from being washed to the lake. In summary, all of these factors affect drinking water to some extent. Table 4 shows the matrix of pairwise comparisons for the factors affecting drinking water. The consistency ratio of the table is 0.05.

Saaty and Vargas recommend that the number of elements to be compared in a comparison matrix should be no more than approximately seven elements, although nine may be acceptable (Saaty and Vargas 2006). The main argument is that if inconsistency occurs in a matrix with more than seven elements, it is difficult to determine which judgment should be modified to improve the inconsistent matrix (Saaty and Vargas 2006). There were two matrices out of the 38 that had an order higher than nine (e.g., 11 elements in Table 2). However, because the consistency ratios of the two matrices were well below the 10% limit at the first time, the orders of these two matrices were allowed to be more than seven.

The relative weights of the elements in a comparison matrix were calculated by the normalized principal eigenvector of the comparison matrix. All the normalized principal eigenvectors were then entered into a supermatrix containing the overall goal, the evaluation criteria, and the subcriteria. To capture the transmission



**Table 4.** Relative Importance of Chosen Subcriteria with Respect to Drinking Water (Note: San=sanitation; E.F.=education facilities; Agr.=agriculture; W.Qn.=water quantity; W.Qu=water quality; Bio=biodiversity; G.I.=green industries)

Drinking water	Sanitation	Education facilities	Housing	Agriculture	Water quantity	Water quality	Biodiversity	GDP	Green industries	Waste
Sanitation	1	5	3	3	1/4	1/6	4	3	2	1/2
Education facilities	1/5	1	1/2	1/4	1/7	1/8	1/3	1/3	1/4	1/4
Housing	1/3	2	1	1/2	1/6	1/7	1/4	1/2	1/2	1/4
Agriculture	1/3	4	2	1	1/4	1/5	1	2	1	1/2
Water quantity	4	7	6	4	1	1/2	2	4	4	3
Water quality	6	8	7	5	2	1	5	6	5	4
Biodiversity	1/4	3	4	1	1/2	1/5	1	4	1	1/2
GDP	1/3	3	2	1/2	1/4	1/6	1/4	1	1/2	1/3
Green industries	1/2	4	2	1	1/4	1/5	1	2	1	1/2
Waste	2	4	4	2	1/3	1/4	2	3	2	1

of the influences among all the possible paths of the supermatrix, the supermatrix needs to be raised to powers until it converges (Saaty 2005). In the converged matrix, for every element on the left of the supermatrix, it will have the same value across all the columns. This matrix is called the limit supermatrix (Saaty 2005). The number in the limit supermatrix represents an element's relative influence with respect to the overall goal after all the possible interactions among them have been considered. The weights from the limit supermatrix for each evaluation subcriterion are shown in Table 5. To check the sensitivity of the weights against the two evaluation methods, ANP and AHP, the weights derived from AHP are also shown in Table 5. As can be seen, the results are significantly different; it appears that the inclusion of the connections between the assessment elements affects the evaluation decisions.

Table 5 reveals that the top three priorities based on the ANP method are green industries, GDP, and water quality. Biodiversity, which was initially thought by the planners to be the top priority

and has the highest score in AHP, surprisingly ranked fourth. After a further discussion of the findings among the planning team members, the authors believed that the rankings from ANP seemed more reasonable: although the primary goal of the Reserve was to enhance biodiversity, the precondition for reaching this goal was financial support, preferably from the green industries. The ANP technique seems to be a valuable tool for the planners to consider the complex interaction of system components and prioritize the interrelated criteria and subcriteria.

### Constraints and Opportunities

In identifying potential solutions based on the ranked sustainability criteria, the constraints and opportunities of the system also need to be analyzed. Nine categories of major constraints were identified in this study. For example, one of the major constraints was the lack of the self-sustained natural ecosystem, despite the fact that it had maintained biological diversity in recent years and provided habitats for a large number of bird species. The natural river basin had been destroyed by artificial hydraulic facilities, and it would be difficult to restore the upstream rivers because they are administered by governments in other regions. Therefore, emphasis had to be placed on the measures that can be done in the Reserve. Due to the size limit of this paper, not all these constraints are discussed. On the other hand, eight categories of opportunities were identified. For example, one opportunity is that China is currently promoting the New Rural Cooperative Medical Care Program in the rural areas. A rural resident who voluntarily enrolls in this program makes a small contribution and the government contributes the rest. The enrolled person can receive cost deductions on medical expenses. This would help reduce poverty caused by high medical expenses. The understanding of the constraints and opportunities is important for the development and ranking of SD measures in the next step.

### Development and Ranking of Measures

As previously mentioned, the capital and social development projects that would benefit SD were proposed in the first study. The absolute measurement method was used to compute the rating scores for each alternative (project). A numerical scale from 0 to 4 was used to rate each alternative against every evaluation subcriterion. Zero means that the project does not contribute to the particular criterion at all, 1 means that the project "is helpful, but not significant," 2 means that the project is "helpful," 3 means that the project is "very helpful," and 4 means that the project is "extremely helpful." After all the numbers having been assigned, the total score of the project was calculated by the following equation:

**Table 5.** Evaluation Weights Developed from the Limit Supermatrix

Evaluation Subcriteria	Weight from ANP	Weight from AHP
Green industries	0.173	0.044
GDP	0.112	0.028
Water quality	0.108	0.101
Biodiversity	0.083	0.202
Water quantity	0.076	0.101
Living conditions	0.074	0.002
Waste generation	0.055	0.078
Sanitation	0.043	0.006
Transportation	0.035	0.032
Drinking water	0.032	0.015
Research and development	0.030	0.004
Education facilities	0.020	0.021
Vulnerability to natural hazards	0.019	0.022
Chemical fertilizer use and pesticides	0.018	0.050
Information technology	0.018	0.007
Income poverty	0.016	0.002
Health care facilities	0.016	0.014
Employment	0.016	0.028
Air pollution	0.013	0.032
Crime	0.009	0.013
Subsidies to crop loss	0.009	0.019
Disaster preparedness and response	0.007	0.007
Nonrenewable material and energy	0.007	0.013
Health care subsidies	0.004	0.070
Education subsidies	0.004	0.063
Arable and permanent cropland	0.003	0.022
Income inequality	0.000	0.006

**Table 6.** Examples of the Top- and Bottom-Ranked Projects

Project name	Project description	Cost (10 <sup>6</sup> RMB) <sup>a</sup>	Project score	Rank
Wetland Newtown	A subdivision with apartment buildings that can accommodate 30 to 50 thousand people	1,150	2.90	Top 5
Sewage pipe	Install sewage pipe in the villages and towns	4	2.88	Top 5
Biogas power plant	Supply electricity that meets power demand of a town of 30 to 50 thousand people	5	2.83	Top 5
Village relocation	Relocate 5,271 households	438	2.79	Top 5
Factory relocation	Relocate small factories around the lake area	100	2.79	Top 5
Internet upgrade	Install internet server for the Reserve administration	0.05	0.74	Bottom 3
Wetland nature and humanity museum	A new 2,000 m <sup>2</sup> building with conference rooms	4	0.70	Bottom 3
Culture and history museum	A renovation project of a building currently used for other purposes	1	0.55	Bottom 3

<sup>a</sup>RMB is the of Chinese currency unit. 1 RMB = 0.16 USD, on March 28, 2013.

$$TC_{\text{alternative}} = \sum_{i=1}^{27} S_i \times N_i \quad (3)$$

where  $TC_{\text{alternative}}$  = the total score for the evaluated project;  $S_i$  = assigned scale from 0 to 4 for the evaluation subcriterion  $i$ ; and  $N_i$  = weight for the evaluation subcriterion  $i$  from the limit supermatrix.

The projects were then ranked based on their total scores. Out of the approximately 80 projects, the top five and the bottom three ranked projects are shown in Table 6. The projects in Table 6 are ranked by the scores of sustainability. However, the capacity of the government to carry out such projects depends on the required amount of investment for the projects and the financial resources the government can secure. Of course, some of the projects generate revenues. For example, the Wetland Newtown project develops apartment buildings, some of which can be sold to buyers other than the resettlement families; the biogas power plant can sell electricity to the two nearby cities. The financial viability of the projects may be appraised separately by using financial analysis techniques such as the net present value (NPV) and rate of return. The sustainability scores provide the decision makers supplementary information on the intangible benefits and costs of carrying out these projects.

## Summary and Conclusion

A framework of turning general SD concepts into practical measures at the regional level is proposed in this study. A region is a relatively independent, complex social-ecological system that is believed to be critical to achieve overall SD of the world. Yet every region has its unique characteristics that result in different emphases on SD. The framework consists of the processes of identifying the general sustainability indicators, analyzing the regional social-ecological system, specializing and weighing the regional sustainability criteria, and selecting effective measures based on the weighted criteria and regional constraints and opportunities.

The process is illustrated through a detailed case study of developing SD strategies for a national nature reserve in China, the Hengshui Lake Natural Reserve. It was partially restored from the unsustainable past, but with a fragile ecosystem and multiple stakeholders competing for scarce resources. Eleven sustainability criteria and 27 subcriteria were developed based on the general CSD sustainable development indicators. The relative importance of the criteria and subcriteria was evaluated based on the ANP technique. Candidate measures to promote SD of the region were proposed and ranked based on the weighted criteria and subcriteria and the constraints and opportunities of the region.

The framework is helpful in streamlining the decision making of SD at the regional level. It was found that ANP was a useful

multicriteria decision analysis (MCDA) tool for evaluating a multiple dimension problem such as the one in this study. The strength of ANP lies in it (1) breaking down a complex system into simpler elements, (2) allowing decision makers to compare the relative importance of two elements at a time, and (3) capturing the underlying interactions among those elements. The limit supermatrix of ANP provides some counterintuitive yet valuable results in the case study. Particularly, it was found that the most important sustainability criterion for the Reserve was not the enhancement of biodiversity per se, but the development of green industries followed by GDP and water quality. Based on the total score that each project received, the proposed SD projects were evaluated and ranked based on their sustainability scores. However, a comprehensive evaluation of these projects would also need to consider the financial resources the projects demand and the financial benefits they can provide.

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