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Application of the analytic hierarchy process to a sustainability assessment of coastal beach exploitation: A case study of the wind power projects on the coastal beaches of Yancheng, China

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ABSTRACT

Sustainability assessments of coastal beach exploitation are difficult because the identification of appropriate monitoring methodologies and evaluation procedures is still ongoing. In particular, the most suitable procedure for the application of sustainability assessment to coastal beaches remains uncertain. This paper presents a complete sustainability assessment process for coastal beach exploitation based on the analytic hierarchy process (AHP). We developed an assessment framework consisting of 14 indicators derived from the three dimensions of suitability, economic and social value, and ecosystem. We chose a wind power project on a coastal beach of Yancheng as a case study. The results indicated that the wind power farms on the coastal beach were not completely in keeping with sustainable development theory. The construction of the wind power farms had some negative impacts. Therefore, in the design stage, wind turbines should be designed and planned carefully to minimize these negative impacts. In addition, the case study demonstrated that the AHP was capable of addressing the complexities associated with the sustainability of coastal beaches.

1. Introduction

According to the definition of sustainable development, sustainable development of the coastal zone would not only meet increasing demands but also protect the environment without prejudice toward the access to adequate food security of future generations (Yu et al., 2010). However, this definition of sustainable development is intrinsically vague and nonoperational, and considerable effort has been made to understand the precise meaning of the concept (Sun et al., 2010). A suitable quantification in socio-economic, cultural and scientific terms is required (Marques et al., 2009). From an economic standpoint, the sustainable development of coastal beaches refers to the high-efficiency use of the coastal zone. Therefore, the sustainable development of coastal beaches must recognize not only the quantity and speed of development but also quality and sustainability. However, measures of sustainability have generally been found to be ill defined and applied with incomplete, incorrect or unavailable information and data. The rapid pace of development and lack of relevant data make the management of exploitation and the decision-making process uncertain, making it virtually impossible for any one group of experts or stakeholders to effectively exploit coastal beach resources.

Multi-criteria decision analysis (MCDA) is an effective method of handling complex decision-making by clarifying the advantages and disadvantages of the available options under conditions of uncertainty (Saaty, 1990). Current MCDA methods include utilitarian methods such as MAUT/VT (*Multi-Attribute Utility/Value Theory*), SMART (*Simple Multi-Attribute Rating technique*) and TOPSIS (*Technique for Order Preference by Similarity to an Ideal Solution*); hierarchical methods such as the AHP (*Analytical Hierarchy Process*) and its generalization, the ANP(*Analytic Network Process*); outranking methods such as ELECTRE (*Elimination and Choice Expressing Reality*) and PROMETHEE (*Preference Ranking Organisation Method for Enrichment Evaluations*) and statistical/probabilistic methods such as Bayesian Belief Networks (BBNs). These methods have been utilized extensively in the broad areas of environmental science management and stakeholder involvement (Bello-Dambatta et al., 2009; Edgar et al., 1997; Robert et al., 2002; Simon et al., 2004; Yedla et al., 2003; Li et al., 2006).

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However, fewer methods have been applied to the assessment of coastal beach exploitation. In particular, it is difficult to assess whether an individual project meets the criteria for sustainable development. Innovative approaches and new methodologies may be required to improve the evaluation of sustainable coastal beach exploitation.

In comparison with other methods, AHP has many obvious advantages. It helps to simplify complex decision-making problems by decomposing them into hierarchies and is simple enough to be understood by lay people. Therefore, in this paper, we discuss the validity of AHP for evaluating the sustainability of coastal beach exploitation projects.

2. Methodology

2.1. Structuring a hierarchical model and identifying sustainable indicators

The first step for the application of AHP to evaluate the sustainability of coastal beach exploitation projects was to structure a hierarchical model and identify indicators. The hierarchical model for evaluating the sustainability of coastal beach exploitation projects included four layers.

The topmost layer of the hierarchy was the goal of the assessment of the sustainable exploitation of the coastal beaches. The second layer corresponded to criteria. According to sustainable development theory and China's Agenda 21 – A White Paper on China's Population, Environment, and Development in the 21st Century, a sustainable indicators system consists of seven impacts. These impacts are society, the economy, resources, the environment, population, popular science and policy. In the initial stages, local decision-makers, stakeholders, experts and government representatives of the region were consulted about what they felt were the critical factors in the seven impacts that would affect the sustainability of coastal beach exploitation. As a result of this survey, the criteria were suitability, value and the environment. 1) Suitability. The suitability of the exploitation projects on the coastal beaches can be seen as a means of achieving harmony between the reasonable use of resources and the effective protection of the environment. Whether a project is appropriate is directly related to the economic and social benefits it yields and the sustainability of beach development. 2) Value. The exploitation of coastal beaches is bound to involve costs, but it also brings economic and social benefits to local governments. Large development projects on coastal beaches involve higher construction and maintenance costs. However, a greater amount of beach development, whether it involves agriculture, the wind power industry or animal husbandry, will produce more economic benefits. Therefore, the value indicator is crucial to stakeholders. 3) Ecosystem. The development of coastal beaches will have impacts on the local ecosystem. For example, the expropriation of lands will result in the emigration of living organisms and the reduction of plant cover. Therefore, to achieve sustainable development, the utilization and exploitation of coastal beaches must remain within the limits that the ecosystem can afford to support and within the carrying capacity of the environment. The third layer was sub-criteria, which explained the concrete meaning of upper-level criteria. According to previous research on exploitation projects, terrain and geological conditions required for projects site selection and the evaluation methods for resources, the suitability analysis included resources and environmental suitability. The value analysis included both economic value and social value. The construction and operation of projects will destroy vegetation and disturb existing ecosystems. Taking into account the impacts of projects on the environment, the ecosystem indicators used in the analysis included the stability of the ecosystem and the magnitude of environmental pollution. The lowest layer was some assessment indicator from influence factors analysis of the concrete projects.

2.2. Normalization of assessment indicators

Data on the indicators in the fourth layer were collected from some statistical studies, environmental yearbooks and the existing literature. To avoid the problem of indicators that could not be compared because of differences in the magnitudes of the raw indicators, min-max normalization was used to transform each raw indicator to a common scale (Salvati and Zitti, 2009), $r_{ij} \in [0,1]$ as follows:

$$r_{ij} = \begin{cases} x_{ij}/x_{ij}^* & \left(x_{ij} \le x_{ij}^*\right) \\ x_{ij}^*/x_{ij} & \left(x_{ij}^* \le x_{ij}\right) \end{cases} \quad (i = 1,2\ldots n;\ j = 1,2\ldots m) \tag{1}$$

$$x_{ij}^* = \begin{cases} \max\{x_{ij}\} \\ \min\{x_{ij}\} \end{cases} \tag{2}$$

where r_{ij} represented the transformed value of x_{ij} and x_{ij} and x_{ij}^* represented the observed and ideal values, respectively. If ideal values were not available for the assessment indicators, Eq. (2) could be used to calculate the ideal values.

2.3. Weights of sustainable assessment indicators

The AHP was used to create weights to measure the impacts on the community of the various proposed elements. The priorities of indicators were determined according to the data or opinions from 50 experts consisting of managers, professors, workers, farmers, tourists, government representatives and others. These experts were segmented into five groups, and every group marked the scores according to 9-point scales respectively. Finally, arithmetic mean method was used to aggregate them suitably. The elements of a particular layer were compared pairwise with respect to a specific element in the layer immediately above. A judgmental matrix was formed and used for calculating the priorities of the corresponding elements. The judgmental matrix was denoted as A. Each entry a_{ij} of the judgmental matrix was formed by comparing the row element A_i with the column element A_j:

$$A = (a_{ij})\ (i = 1,2\ldots,\text{the number of layers};\ j = 1,2\ldots,\ \text{the number of elements})$$

The entries a_{ij} were governed by the following rules:

$$a_{ij} > 0,\ a_{ij} = 1/a_{ij}\ i \ne j;\ a_{ij} = 1,\ i = j$$

The values of a_{ij} were represented using a 9-point scale suggested by Saaty (2000). The weights of the indicators were calculated using the importance scales in the second and third layers and the values of the indicators in the lowest layer. For this process, the square-root method followed by Eq. (3) was used.

$$\begin{aligned} M_i &= \prod_{j=1}^{m} a_{ij} \\ \overline{w}_i &= \sqrt[n]{M_i} \\ w_i &= \overline{w}_i / \sum_{j=1}^{m} \overline{w}_j (i = 1,2\ldots,n) \end{aligned} \tag{3}$$

Table 1
The values of the random index (RI).

Size	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

2.4. Consistency of the judgmental matrix

The consistency ratio (CR) is used to determine the judgmental matrix's consistency, defined as:

$$CR = CI/RI \tag{4}$$

CI, the consistency index, is used to determine whether and to what extent decisions violate the transitivity rule. The CI values can be calculated using Eq. (5). RI is called the random index. Its values for matrices of different sizes (Saaty, 2000) were shown in Table 1.

$$CI = (\lambda_{max} - n)/(n-1) \tag{5}$$

where n is the order of matrix A; $\lambda_{max,}$ the largest eigen value of matrix A, is defined as:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(Aw)_i}{nw_i} \tag{6}$$

If the CR of the matrix is high, it means that the judgments are not consistent and must be readjusted. A threshold value of 0.10 or less is considered acceptable.

Once the local consistency indexes of the elements from the different layers are available, they are aggregated to obtain the final consistency, a ratio used to represent the ratings of the indicators for achieving the goal. The final consistency can be obtained from Eq. (7):

$$CR_{final} = \frac{\sum_{j=1}^{m} a_j CI_j}{\sum_{j=1}^{m} a_j RI_j} \; (j = 1, 2, \ldots m, \text{the number of elements}) \tag{7}$$

2.5. Structuring the sustainability index assessment model

The assessment values (E_i) of the lowest layer are calculated by multiplying the standard values (A_i) and their weights (w_j). The assessment values of the third layer are equal to the weighted sum of every indicator value corresponding to the lowest layer. Similarly, the assessment values of the second layer are obtained by multiplying the standard values (A_i) in this layer by their weights (w_j).

$$E_i = \sum_{j=1}^{m} A_i w_j \;\; (i = 1, 2 \ldots, n) \tag{8}$$

The sustainability index for the assessment of the sustainability of the exploitation of coastal beaches (E) is calculated from E_i as follows:

$$E = \sum_{i=1}^{n} E_i w_i \tag{9}$$

2.6. Suitability classification for the sustainable exploitation of coastal beaches

The values of the sustainability index ranges between 0 and 1. If the index approaches 0, then the gap between the system and the ideal state is larger. If the index approaches 1, then the gap is smaller. According to the analysis of sustainable development theory and the suggestions of experts from this research field the state of the study area and the general classification criteria applied in the assessment process are considered to define the correspondence between the sustainability indicators and the suitability shown in Table 2.

3. Case study:wind power projects on the coastal beaches of Yancheng, China

3.1. Description of the site and case study problem

The city of Yancheng lies in the east of Jiangsu Province, China. The city has 582 km of coastline (Zou et al., 2004). The total area of coastal beaches, including sand ridges, is 4,530,000 hm^2. The beaches belong to Xiangshui, Binhai, Sheyang, Dafeng and Dongtai counties (Fig. 1). Yancheng is rich in wind power resources. The City Administration reports that the average wind power density in Yancheng's coastal beaches is approximately 100 W/m^2, with 1,000,000 kW of exploitable wind resources (measured at the relatively low height of 10 m above ground). Yancheng has not only unique climatic conditions and geographical advantages but also substantial financial support from Jiangsu Province. However, the coastal beaches of Yancheng include two large biosphere reserves, for the protection of the red-crowned crane (*Grus japonensis*) and the Father David's deer (*Elaphurus davidianus*) (Lu et al., 2007). The area also includes migratory routes used by birds.

The problem for this paper is to determine whether wind power development on these coastal beaches is sustainable according to sustainable development theory.

3.2. Identification of sustainable indicators

3.2.1. Suitability

According to previous research on the wind energy, resources consisted of wind energy, land availability and power grid capacity (Gu, 2006; Gu and Zhao, 2008; Zhang et al., 1997). Taking into account both construction and the impacts of the operation of the wind power project on the air, water and noise environment, the indicators of environmental suitability included air, water and sound environment qualities.

3.2.1.1. Wind energy capacity. One of the basic conditions for building wind farms is the availability of strong and stable wind from a constant direction. Meteorologists believe that when the wind speed varies within the range of 3.0–20.0 m/s, its energy can be utilized with current technology in China (Zhang et al., 1997), and thus the wind energy within this speed range is called effective wind energy. The coastal beaches of Yancheng are relatively rich in wind energy. The density of effective wind energy is 100 W/m^2

Table 2
Suitability of coastal beaches sustainable exploitation.

Suitability	Very unsuitable	Unsuitable	Weakly unsuitable	Weakly suitable	Suitable	Very suitable
Sustainability index	0.00–0.15	0.16–0.30	0.31–0.50	0.51–0.70	0.71–0.85	0.86–1.00

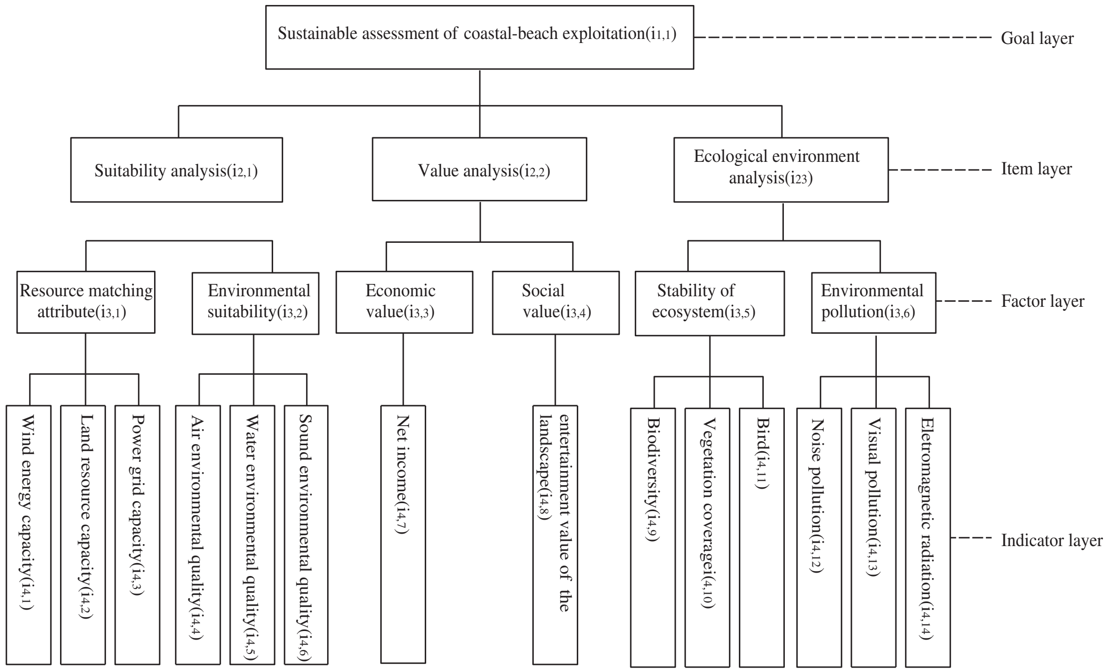

Fig. 1. Sustainability indicator system for the exploitation of coastal beaches.

with 1,000,000 kW of exploitable wind resources. Thus, the wind energy resource in Yancheng is usable for wind power generation.

3.2.1.2. Land resource capacity. The construction and operation of wind farms involve certain requirements for terrain, geological conditions and land area. Yancheng has 582 km of coastline, and the total area of coastal beaches, including sand ridges, is 4,530,000 hm^2. However, due to the presence of the elk nature reserve and the red-crowned crane nature reserve, the area of usable land is correspondingly lower.

3.2.1.3. Power grid capacity. The city of Yancheng lies in Jiangsu Province. Jiangsu power grid is one of the largest provincial grids in China. Currently, the total power load of Jiangsu Province adds up to 56,000 MW, far less than the potential wind power contained in the wind energy resources of Jiangsu Province.

3.2.1.4. Air quality. Machinery and transport vehicles will generate dust that will impact local air quality during the construction of the wind farms. Therefore, the wind power development projects must meet the local environmental requirements for air quality. According to the air quality standard implemented in Yancheng, the achievement ratio of the local air quality standard is 90%.

3.2.1.5. Water environmental quality. Human activities will generate wastewater and impact the local water resources during the construction and operation of wind farms. Wind power projects must therefore meet the local environmental requirements for water quality. According to the water quality standard implemented in Yancheng, the achievement ratio of the local water quality standard is 98%.

3.2.1.6. Sound environmental quality. Previous data have shown that wind power development could cause noise pollution. Therefore, wind power projects must meet the local environmental requirements for noise pollution. According to the environmental quality standard for noise implemented in Yancheng, the achievement ratio for the local environmental quality standard for noise pollution is 60%.

3.2.2. Value

The value analysis included both economic value and social value. The indicator used to assess economic value was net income, which was used to assess social value was the entertainment value of the landscape.

3.2.2.1. Net income. The value of wind power has traditionally been assessed based on net income. Net income includes costs and gross income. Average costs for wind electricity generation in Jiansu province range between 0.45 and 0.60 yuan/kWh. The income from a wind power project is created by selling electricity to the power grids. In 2009, the average price of wind-based electricity in Jiangsu province was only 0.61 yuan/kWh. Thus, the net income of a wind power project is very limited. However, wind power projects could drive local economic development and yield social benefits. According to a valuation model proposed by Kennedy (Kennedy, 2005), the social benefit of wind power in Yancheng was moderate.

3.2.2.2. The entertainment value of the landscape. Considering that the operation of wind farms would add landscape features to the coastal beach, the entertainment value of the landscape would still be relatively high.

3.2.3. Ecosystem

The construction and operation of wind power projects will destroy vegetation and disturb existing ecosystems. Wind turbines and electromagnetic radiation will negatively impact bird migrations. And taking into account the impacts of turbines on the visual and noise environment, the ecosystem indicators used in the analysis included the stability of the ecosystem and the magnitude of environmental pollution. The stability of the ecosystem consisted of indicators of biodiversity, vegetation cover and birds. The indicator of environmental pollution included measures of noise, visual pollution and electromagnetic radiation.

3.2.3.1. Biodiversity. Yancheng's coastal beach, where there are two of the largest biosphere reserves in the world (the red-crowned crane (*G. japonensis*) and the Father David's deer (*E. davidianus*)),

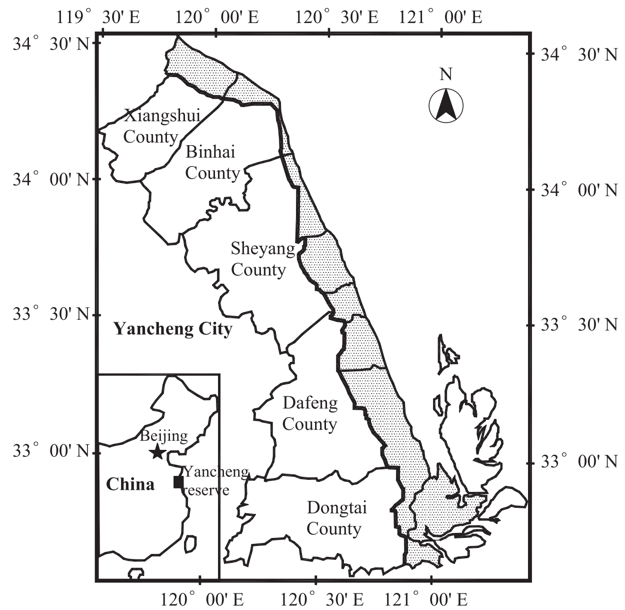

Fig. 2. Map of Yancheng coastal beaches.

is high in biodiversity. It is also a stopover site for over 300 species of migratory birds (Zhu et al., 2004). Additionally, a total of 500 plant species belonging to 400 genera and 100 families are found in Yancheng's coastal beaches, most of which are herbaceous plants with a few woody plants and shrubs.

3.2.3.2. Vegetation. Vegetation coverage on the coastal beaches of Yancheng was very high in the past. Since 1981, the coastal beach area has been exploited intensely by local people for economic purposes. At present, the vegetation coverage in the area is only 50%.

3.2.3.3. Birds. It is established that birds are one of the largest victim groups in fatal collisions with wind turbines around the world. In Yancheng's coastal beaches, there are 300 species of migratory birds. The construction of wind farms will impact bird migration.

3.2.3.4. Noise pollution. Previous investigations have shown that developing wind power could cause noise pollution (Julian et al., 2007). The noise levels of wind turbines in operation are approximately 102 dB (A). However, the average noise level is only 31 dB (A) at a distance of 1000 m from the wind turbines, equal to the noise level of a bedroom at night (Han et al., 2009). On coastal beaches, there is little human activity. Thus, noise pollution would not strongly impact humans. However, it will certainly impact the animals living on the coastal beaches.

3.2.3.5. Visual pollution. Visual pollution is produced by wind farms in two ways: the shadow flicker caused by the moving blades and minor reflections caused by the reflection of sun rays off of the wind turbine's body (Saidur et al., 2011). Wind turbines in Yancheng are constructed on coastal beaches with few residential communities, so visual pollution would not have an impact on humans. However, it would certainly impact the animals living on coastal beaches.

3.2.3.6. Electromagnetic radiation. All electrical equipment can generate electromagnetic radiation when running. For wind power projects, the radiation comes from the generators, substations and transmission lines. During the construction of wind farms, anti-magnetic, anti-radiation etc. measures would be considered. In this way, radiation should be reduced to a minimum and not impact humans or animals.

The complete indicator system framework was shown in Fig. 2. As Fig. 2 illustrates, an arbitrary indicator was denoted by $i_{m,n}$, where m was the layer number and n was the number assigned to a particular indicator in the m-th layer. The topmost layer of the hierarchy was the goal of the assessment of the sustainable exploitation of coastal beaches, ($i_{1,1}$). The second layer contained the suitability analysis ($i_{2,1}$), the value analysis ($i_{2,2}$), and the ecosystem analysis ($i_{2,3}$). The third layer was the resource availability ($i_{3,1}$), the environmental suitability ($i_{3,2}$), the economic value ($i_{3,3}$), the social value ($i_{3,4}$), the stability of the ecological system ($i_{3,5}$), and environmental pollution ($i_{3,6}$). The lowest layer comprised 14 variable assessment indicators.

Values of the indicators in the fourth layer came from data collected from statistical studies, environmental yearbooks, the natural biosphere reserves in Yancheng and the existing literature and then were normalized with the max-min method. The values of the 14 indicators were shown in Table 3.

The weights of indicators or factors from analysis of data and opinion of experts were shown in Table 3. Pairwise comparisons of wind energy capacity, land resource capacity and power grid capacity with respect to resource matching, their weights and CR were shown in Table 4. E_i and E were calculated by Eq. (7) and Eq. (8), the assessment results were shown in Table 3.

Table 3
Suitability assessment of wind power project on Yancheng coastal beaches.

Indicators layer	Value	Weight	E'_1	Factors layer	Weight	E_1	Item layer	Weight	E
Wind energy capacity ($i_{4,1}$)	0.8	0.500							
Land resource capacity ($i_{4,2}$)	0.6	0.167	0.667	Resource matching ($i_{3,1}$)	0.750				
Power grid capacity ($i_{4,3}$)	0.5	0.333				0.709	Suitability analysis ($i_{2,1}$)	0.333	
Air environment quality ($i_{4,4}$)	0.9	0.333							
Water environment quality ($i_{4,5}$)	1.0	0.333	0.833	Environmental suitability ($i_{3,2}$)	0.250				
Sound environment quality ($i_{4,6}$)	0.6	0.333							
Net income ($i_{4,7}$)	0.6	1.000	0.600	Economic value ($i_{3,3}$)	0.500	0.700	Value analysis ($i_{2,2}$)	0.333	0.600
Recreation value ($i_{4,8}$)	0.8	1.000	0.800	Social value ($i_{3,4}$)	0.500				
Biodiversity ($i_{4,9}$)	0.6	0.111							
Plant coverage ($i_{4,10}$)	0.6	0.111	0.289	Stability of ecological system ($i_{3,5}$)	0.750				
Bird ($i_{4,11}$)	0.2	0.778				0.392	Ecological environment analysis ($i_{2,3}$)	0.333	
Noise pollution ($i_{4,12}$)	0.7	0.333							
Visual pollution ($i_{4,13}$)	0.5	0.333	0.700	Environmental pollution ($i_{3,6}$)	0.250				
Electromagnetic radiation ($i_{4,14}$)	0.9	0.333							

E'_1: Scores in indicator layer. E_1: Scores in factor layer. E: Scores in item layer.

Table 4
Pairwise comparisons of indicators with respect to resource matching and their weights.

Resource availability ($i_{3,1}$)	Wind energy capacity ($i_{4,1}$)	Land resource capacity ($i_{4,2}$)	Power grid capacity ($i_{4,3}$)	*W*
Wind energy capacity ($i_{4,1}$)	1	3	2	0.500
Land resource capacity ($i_{4,2}$)	1/3	1	1/2	0.167
Power grid capacity ($i_{4,3}$)	2/3	2	1	0.333

Consistency:0.01.

4. Conclusion and discussion

The impacts of coastal beach exploitation projects are uncertain due to incomplete or unavailable data. It is therefore difficult for local decision-makers and stakeholders to decide whether an exploitation project is suitable for a coastal beach. In this paper, we presented a complete process using the AHP for the suitability assessment of the sustainable exploitation of coastal beaches based on three dimensions: suitability, economic and social value, and ecosystem. We chose wind power projects on Yancheng's coastal beaches as a case study to show the validity of AHP for evaluating the sustainability of coastal beach exploitation projects. The results shown the final score for the assessment of the sustainability of the wind power exploitation on coastal beaches was 0.6. According to the suitability criteria of the sustainable exploitation of coastal beaches (see Table 2), wind power projects were weakly suitable for the Yancheng coastal beaches. This indicated that the Yancheng coastal beaches offered some favorable conditions for developing wind power. However, the energy produced by wind turbines is not free from negative impacts. It has been observed that wildlife is killed by collisions with wind turbines in many cases. Wind farms also create noise that is annoying in the vicinity of the wind turbine installation. The visual landscape is also impacted by wind turbines. So some protective measures must be taken when designing and building wind farms on these beaches because of the two large natural biosphere reserves in the area. Thus many of these negative impacts can be minimized. For example, at the tower design stage, new turbine models with tubular steel towers having smooth exteriors may be used to prevent birds from nesting there. At the same time, the assessment results were compared to the final exploitation decision that was taken by local decision-makers, stakeholders, and government representatives on the most appropriate remedial technique for this case. The built wind farms have being in operating properly.

And the case study indicated that the AHP was capable of addressing the complexities associated with the sustainability of coastal beaches. It simplified complex decision problem by decomposing impact factors into hierarchies, was simple enough to be understood by local people. In assessment process using AHP some negative impacts could be discovered. It benefited to improve design and building plans. It is hoped that the method presented in this paper will be advantageously employed to analyze the sustainability of coastal beaches in the future.

Although they were highlighted, this paper was not concerned with the philosophical arguments of the need for or use of the techniques reviewed. Furthermore, it did not claim to be conclusive or exhaustive. More research should be conducted in the future.

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