Environmental impact assessment of green buildings based on gray relative analysis

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Abstract
Employ the gray relative analysis method to build a pattern for the environmental impact assessment of green buildings, providing approaches for the systematic and quantitative assessment of engineering project environmental impact conditions. This article explores major evaluation factors of the environmental impact of green buildings, based on which, the comprehensive assessment indicator system for the environmental impact of green buildings is built. In the instance analysis, the evaluation factors for the environmental impact of engineering projects are determined as the five parts: resource depletion, energy depletion, land ecological alteration, human health damage and ecological quality destruction, with the gray relative analysis method, the article further analyzes the relevancy of the environmental impacts of various enterprise projects to obtain the evaluation value of each project and even the whole enterprise. The research result can provide visual criteria for the environmental impact assessment of green building project development and risk assessment.
Key words: GRAY RELATIVE ANALYSIS METHOD, ENVIRONMENTAL IMPACT, GREEN BUILDINGS, EVALUATION FACTORS

Introduction

The construction industry exerts a prominent influence on the ecological environment: its main pollutant emission accounts for one third, its energy and resource consumptions account for half on the whole globally and it contributes to half of the greenhouse effect in the world. Facing the pressure the construction industry gives to the social and economic sustainable development, the concept of "green building" was born at the right time [1]. Green buildings are built with the most original design philosophy, most advanced energy and water conservation technology, latest construction technique and most environmentally friendly building materials. Under the current international circumstances, nations from all over the world see the development of green buildings as the inevitable course of sustainable development of construction. At present, the construction industry is at its full speed and under the new situation of building a harmonious and conservation-minded society, green buildings will have a far-reaching influence on people's life idea transformation, industrial development and management and technological updates. To develop green buildings is the future direction of the construction industry.

The development of green buildings is still in its early stage. Currently, in the engineering project field, there is still not an evaluation pattern for the environmental impact of green buildings that conforms to the ISO method frame. Most studies are just limited to local application or in their exploratory stage. The relevant environmental data collection and organization work is just started, which cannot provide infrastructural support for the evaluation pattern, so it is necessary to use for reference and assimilate the elements like green building, green construction and green materials currently existent in the project field and then formulate the evaluation pattern for the environmental impact of green buildings that conforms to the international standard and apply it to the engineering practice as soon as possible[1].

The grey system theory is a multi-objective decision analysis method that combines qualitative analysis and quantitative analysis. Its object of study is the grey system between the black system（information unknown）and the white system（information completely identified） i.e. the “poor information” undetermined system with “some information known and some unknown”. The gray relative analysis method is applied the most extensively of the grey theory.

In recent years, the gray relative analysis method has been used extensively in all sorts of evaluations patterns: Based on the gray relative analysis method, Changfu Dong et al.[2] implemented the risk assessment and analysis of the water resources carrying capacity in Erdos City, providing scientific and sound evidence for the administrative decision of the underground water development project in Erdos City；Jingle Liu etc.[3] utilized the gray relative fault tree to implement the risk assessment of green building design, Yandong Yun, et al.[4] used the gray relative analysis method to evaluate the classification factors of the farmland in Latezhongqi, Inner Mongolia；on the basis of the financial evaluation of the investment project and the gray relative analysis method, Bing Chen, etc.[5] proposed the construction of the gray relative evaluation pattern of the financial evaluation of the investment project and proved the feasibility of this method after its application to actual examples. This article will, based on the gray relative analysis pattern, construct an evaluation pattern for the environmental impact of green buildings suitable for the concrete national conditions, providing approaches for the qualitative and quantitative evaluation of the environmental impact of the engineering project.

Steps for the evaluation of the grey correlation analysis pattern

(1) Determine reference data series and compared data series. Apply the gray correlation analysis to evaluate them, but above all the reference data series and compared data series have to be determined. The reference data series is written as and the compared data series is written as, which are generally expressed as:

$$x_0 = \{x_0(1), x_0(2), x_0(3), ...x_0(n)\};$$
$$x_i = \{x_i(1), x_i(2), x_i(3), ...x_i(n)\}; i = 1,2,3......, m.$$
(1)

(2) Calculate the correlation coefficient. After the reference data series and compared data series have been determined, compare the reference data series and the compared data series and calculate the differences of all the points. Its computational formula is:

$$\Delta_i(k) = |x_0(k) - x_i(k)| \quad (2)$$

In the formula, indicates the absolute difference of and at Index.

The computational formula of a correlation coefficient is:

$$\xi_i(k) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \zeta \min_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \zeta \max_i \max_k |x_0(k) - x_i(k)|}$$
(3)

The above equation can also be expressed as:

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_i(k) + \zeta\Delta_{\max}} \quad (4)$$

In the equation, $\xi_i(k)$ is the relative difference of x_0 and x_i at Point k. This form of relative difference is called the correlation coefficient of x_0 and x_i at Point k. ζ is the resolution system, whose values lie in the section of [0,1] and the introduction of which is to reduce the effect of the extreme value on calculation. In the practical application, the resolution system should be chosen according to the correlation degree between sequences and generally it is the most proper to define ζ as 0.5.

(3) Calculate absolute correlation degree. The correlation coefficient only expresses the correlation degree between different time-points. As there are a lot of correlation coefficient data, the information is disperse and not easy to be compared. To make the information concentrate, the average value of the correlation coefficients can be calculated, i.e.:

$$r_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \quad (5)$$

In the equation, when r_i lies in the section of (0,1), it means no factor of the system is strictly irrelevant. The larger r_i is, the closer Evaluation Object i is to the ideal object.

The application of the gray relative analysis method in the evaluation of the environmental impact of buildings

The evaluation of the environmental impact of buildings is one subsystem of the building risk assessment. Due to the complicacy of the natural environment, the impact factors of this subsystem are also intricate and some factors are usually undetermined, so the information that evaluation system of the environmental impact of buildings relies on is “partially complete” [6]. Actually, when an enterprise is implementing the evaluation of the environmental impact of buildings, it is impossible to exhaust all known or unknown influencing factors. In most cases, some important indicators are chosen for evaluation based on a certain standard, so the utilized environmental information in the evaluation of the building environmental impact is unlikely to be complete, which shows that the evaluation system of the building environmental impact is typically grey and conforms to the application condition of the gray relative analysis method [7].

Suppose the building environmental impact is to be implemented on M projects in one enterprise. Its specific application is as follows.

(1) Build an indicator evaluation system on the basis of the comprehensive analysis of the relevant factors affecting the superiority of the plan. When selecting indicators, the principles that ought to be complied with are: Scientificity, systematicness, measurability, comparability, and possible mutual independence.

(2) Determine the reference data series and compared data series. First, choose N major indicators in the numerous indicators, then choose satisfactory indicator values as the reference data series, and express them with the vector quantity $x_0 = \{x_0(1), x_0(2), x_0(3), ...x_0(n)\}$. the N environmental impact indicator sequences and the reference sequence for the M projects in the enterprise, altogether n+1 vector quantities make up the sample space of the gray financial evaluation Ω , i.e.:

$$\begin{bmatrix} x_0(1) & x_0(2) & ... & x_0(N) \\ x_1(1) & x_1(2) & ... & x_1(N) \\ x_2(1) & x_2(2) & ... & x_2(N) \\ ... & ... & ... & ... \\ x_M(1) & x_M(2) & ... & x_M(N) \end{bmatrix} \quad (6)$$

(3) Preprocess the original data of indicators. The preprocessing involves the unification of the indicator types and nondimensionalization of indicators.

(4) Calculate the absolute difference of the reference data series and various compared data series. Convert the gray transformational interval values to the sequence $Y_K = \{Y_K(1), Y_K(2), Y_K(3), ...Y_K(N)\}$ and according to Equation (2) and based on the difference sequence, obtain the biggest difference of the extreme values $\delta_{\max}$ and their smallest difference $\delta_{\min}$.

(5) Calculate the indicator correlation coefficient. The value of the correlation coefficient r_i is the correlation degree between the enterprise environmental impact situation and the reference value. The greater the correlation degree is, the more satisfactory the enterprise project environmental impact situation is and vice versa. Therefore, the gray correlation order arranged according to the extent of the correlation degree is the good and bad sequence of the enterprise projects environmental impact situation.

The application of the gray relative analysis method enables us not only obtain the result of the environmental impact evaluation, but also further analyze the difference degree between the evaluated objects and its reason.

Instance analysis

Identification of the evaluation factors of the project environmental impact

As to the selection of the evaluation factors of the environmental impact, different scholars have different opinions. Some scholars pay more attention to the sustainable development of resource utilization, some emphasize the destruction of the human living environment and others center on the ecological environment change, but most scholars just stress one specific impact and don’t take into consideration the joint impact exerted by several factors. So in the identification of the evaluation factors of the environmental impact, An Guo’s [1] method is used for reference to determine the evaluation factors of the project environmental impact as the five aspects: resource depletion, energy depletion, land ecological alteration, human health damage and ecological quality destruction, which make up the evaluation pattern for the environmental impact of green buildings (Figure 1).

Evaluation of the project environmental impact

Before the comparison, there are the five indicators of resource depletion, energy depletion, land ecological alteration, human health damage and ecological quality destruction after their quantification, and therefore there are the five parameter influence values, but the units and representative meanings of the five values are different. To create comparability between one another, the five parameter influence values are normalized according the normalization method of the ISO standard framework. This article uses the national average level of the respective quantitative index as the standardized reference value for the three impact factors: energy depletion, resource depletion and land ecological alteration ; the standardized reference value for the impact factor-the ecological quality destruction is calculated according to partial statistical data of Wuhan biodiversity ; the disability adjusted life years, which is caused by Shanghai air quality problem and calculated by Yunhui Zhang[8], is used as the standardized reference value for the impact factor-the human health damage. They are as the following 3 detailed aspects:

(1) Per capita holding quantity of coal, iron ore and arable land. According to the statistical data in 2007, the population of China is 1.32129 billion, the basic reserve of coal is 326.126 billion tons, the basic reserve of iron ore is 22.3644 billion tons and the national arable land is 1.82574 billion mu, converted into per capita holding quality of coal 246.82t, per capita holding quality of iron ore 16.93t and per capita holding quality of arable land 1.38 mu.

(2) The potential influence value of the disappearance of per capita species. Here “species disappearance” does not mean “species extinction” at all, but the reduction of the species types in the reference area due to human activities. Abroad, the calculation of this indicator is mainly based on the experimental survey. According to An Guo’s [1] result, the potential influence value of the disappearance of per capita species is 9.63PDF•m2•yr in Wuhan in 50 (calculated according to the design period of general buildings) years.

(3) Per capita disability adjusted life years. Researchers calculated that the population of Shanghai, China was 16 million in 2000, when the total DALY caused by Shanghai air quality problem was about 103,064 years, converted into per capita DALY about 6.44×10-3 year. The object of this investigation was the human health impact of the environmental problem and its result has the reference value for cities similar to Shanghai. Without the support of more data, it can be used as the terminal-type standardized reference value of the engineering project.

Evaluation of the project environmental impact

(1)Basic information. After the experts’ grading, the environmental impact indicator data of the 4 projects in some green building construction company are shown in Table 1 and Figure 1.

Table 1. The environmental impact indicator data of 4 projects in construction companies

Project No.	Resource depletion	Energy depletion	Land ecological alteration	Human heath damage	Ecological quality destruction
1	0.80	1.67	0.80	0.76	0.70
2	0.45	1.25	0.96	0.65	0.52
3	0.50	1.80	1.20	0.50	0.80
4	0.92	2.40	1.45	0.85	0.75

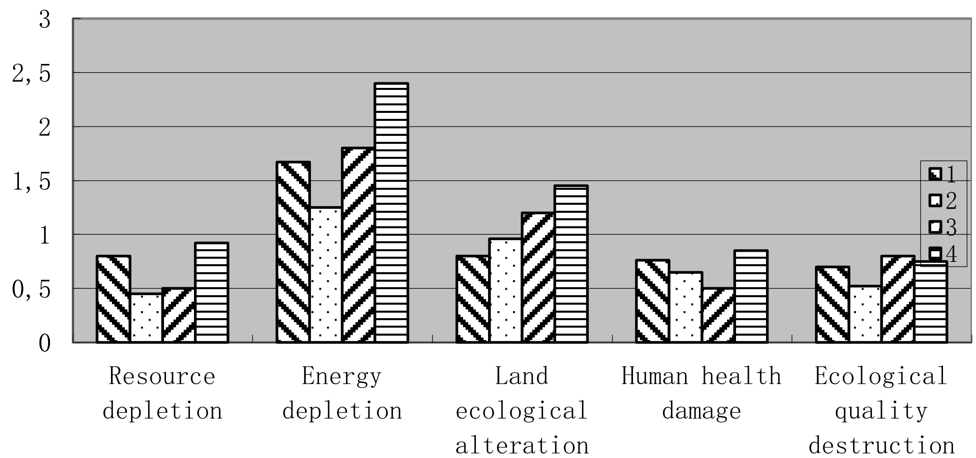

Figure 1. The environmental impact indicator data of 4 projects in construction companies

(2) Employ the gray relative analysis method to implement evaluation of 4 years of financial performance in Enterprise W. The detailed steps are as follows:

1) Construct the reference sequence according to experience：

$$X_0 = \{0.65, 2.00, 1.00, 0.85, 0.80\} \quad (7)$$

The 5 vector quantities, including the 4 indicator sequences for the enterprise project environmental impact and the reference sequence, make up the sample space of the gray relative environmental impact evaluation, shown in Table 2:

Table 2. Sample Space of the Gray Relative Environmental Impact Evaluation

Sample No.	Resource depletion	Energy depletion	Land ecological alteration	Human health damage	Ecological quality destruction
0	0.65	2.00	1.00	0.85	0.80
1	0.80	1.67	0.80	0.76	0.70
2	0.45	1.25	0.96	0.65	0.52
3	0.50	1.80	1.20	0.50	0.80
4	0.92	2.40	1.45	0.85	0.75

2) Nondimensionalize the various project indicators for this enterprise, as Table 3:

Table 3. Result of the Nondimensionalization of Various Project Indicators

Sample No.	Resource depletion	Energy depletion	Land ecological alteration	Human health damage	Ecological quality destruction
0	0.425	0.652	0.308	1.000	1.000
1	0.745	0.365	0.000	0.743	0.643
2	0.000	0.000	0.246	0.429	0.000
3	0.106	0.478	0.615	0.000	1.000
4	1.000	1.000	1.000	1.000	0.821

3)Calculate the absolute difference according to Equation (2) and the result is shown in Table 4.

Table 4. The Computational Result of the Absolute Difference

Sample No.	Resource depletion	Energy depletion	Land ecological alteration	Human health damage	Ecological quality destruction
1	0.320	0.287	0.308	0.257	0.357
2	0.425	0.652	0.062	0.571	1.000
3	0.319	0.174	0.307	1.000	0.000
4	0.575	0.348	0.692	0.000	0.179

Thus, the biggest difference of the extreme values δ max=1.000 and its smallest difference δ min=0.000.

4) Calculate correlation coefficient and the absolute correlation degree and arrange them, as Table 5 and Figure 2.

Table 5. Various Project Correlation Coefficients and Absolute Correlation Degree

Sample No.	Resource depletion	Energy depletion	Land ecological alteration	Human health damage	Ecological quality destruction	Absolute correlation degree
1	0.610	0.635	0.619	0.661	0.583	0.622
2	0.541	0.434	0.890	0.467	0.333	0.533

3	0.611	0.742	0.620	0.333	1.000	0.661
4	0.465	0.590	0.419	1.000	0.736	0.642

Infer from the above calculations :r3＞r4 ＞r1＞r2.

From the terminal environmental impact evaluation values obtained with the gray relative analysis method, it can be concluded that: The marshalling sequence(from good to bad)of the comprehensive environmental impact conditions of the four projects in the enterprise is Project 3, Project 4, Project 1 and Project 2, of which, the correlation degree of Project 3 with the reference sequence is the greatest, reaching 0.661, indicating that the environmental impact condition of Project 3 is the best, while Project 2 has the slightest correlation degree with the reference sequence, only 0.533, indicating that the environmental impact condition of Project 2 is the worst.

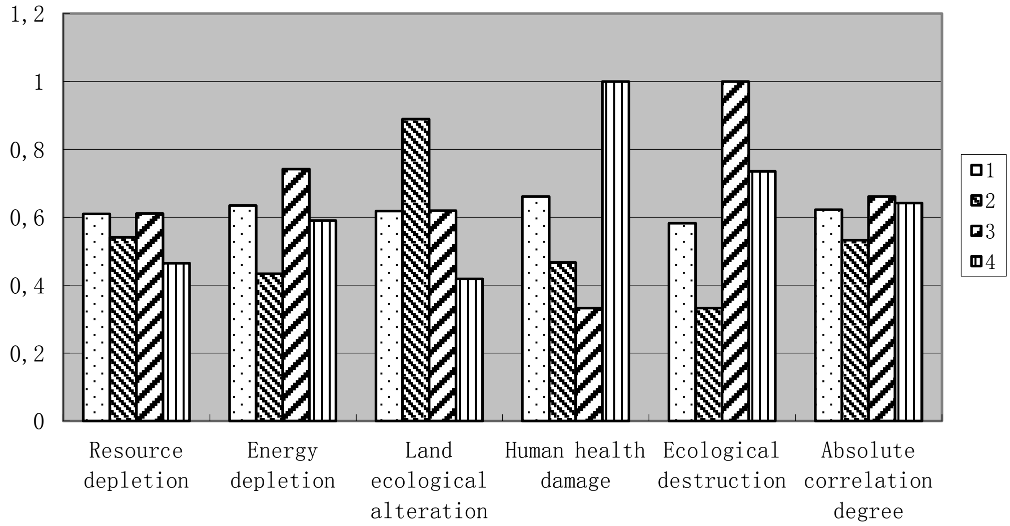

Figure 2. Various Project Correlation Coefficients and Absolute Correlation Degree

Conclusion and Analysis

This article has discussed the main evaluation factors of the environmental impact of green buildings and constructed the evaluation indicator system of the green building project environmental impact. In the instance analysis, the engineering project environmental impact evaluation factors are determined as the five aspects: resource depletion, energy depletion, land ecological alteration, human health damage and ecological quality destruction ; in the evaluation process, the gray relative analysis pattern algorithm was employed to obtain various project comprehensive evaluations and further analyze the enterprise overall evaluation, providing visual criteria for the environmental impact assessment of green building project development and risk assessment.

Green building is a complicated systematic project, so to give play to the green building evaluation system in it, not only do the scientificity and accuracy of the evaluation method have to be ensured to some extent, but also it has to be combined with its authentication and publicity to facilitate the green building to be extensively recognized in the whole society, and with the help of the market, the whole industry to be developed and flourish in the direction of “environmentally friendly and resource saving”.

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