Comprehensive Performance Evaluation of Forestry Carbon Sequestration Projects --Taking Two CDM Forestry Carbon Sequestration Projects of Sichuan Province as Examples

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Abstract: Using the theory of ecological theory and systems engineering economy, this article builds forestry carbon sequestration project implementation performance evaluation index system framework. Based on the collected data, this paper implements district 10 counties measuring two representative CDM forestry carbon comprehensive performance level sinks project in Sichuan Province in principal component analysis method. Studies have shown that: 2 CDM forestry carbon sequestration projects 10 comprehensive high performance level to implement the county, ecological, economic and social benefits accounted for significant differences, social> ecological> economic efficiency, and the same between the same project between different implementations of years due to the implementation of the project area, the implementation of regional cultural characteristics, there are differences in the magnitude of farmer household characteristics and project organization mode differences and other factors. Should broaden the participation channels, and optimize the carbon sink forest tenure defined adapt regional cultural characteristics and family characteristics of the management model, so as to stimulate the ongoing participation of farmers and increase the participation of enthusiasm, comprehensive performance optimization structure, enhance forest carbon sinks project comprehensive performance levels.

1. Introduction
As means of monitoring and evaluating the realization of project anticipated targets, the implementation performance evaluation of forestry carbon sequestration projects is of important guiding and reference significance for project investors and managers. As forestry carbon sequestration projects have been carried out in countries around the world, studies on project performance have also gradually attracted the attention and concerns of scholars from different fields. However, its practice is still in the primary stage of development and forestry carbon sequestration trading products are different from the traditional forms of trading products. It requires professional and sophisticated technical operation for the quantity determination and pricing. Therefore, the current domestic studies related to forestry carbon sequestration evaluation focus mainly on perfecting the forestry carbon sequestration trade index system and its pricing problem. By contrast, the evaluation of implementation performance about forestry carbon sequestration is relatively limited. Occasionally, there are some scholars who evaluate the project implementation performance only from the single
dimension, such as emphasis on cost \cite{1}, environmental protection \cite{2-3}, market transaction \cite{4-5}, economic benefits \cite{6-7}, ecological benefits \cite{8-9}. There is little evaluation of comprehensive performance for the ecological, economic and social benefits produced by triple functions of forestry carbon sequestration \cite{10}. Although some scholars started from the ecological, economic and social benefits and constructed the project implementation performance evaluation’s concept index system, they relatively ignored that index data acquisition led to weakened operability. There are still rare practical cases in which empirical verification and detection are conducted on the scientificity of the index system.

In view of this, in order to expand the theoretical research of forestry carbon sequestration projects’ implementation performance evaluation, and promote forestry carbon sequestration projects’ implementation, management, detection and evaluation levels, and provide beneficial reference and enlightenment, this paper plans to apply the ecological economy theory and the theory of system engineering, starts from ecological, social and economic dimensions to construct the implementation performance evaluation system framework of forestry carbon sequestration project, and conduct the empirical evaluation of the comprehensive performance of the implementation of two representative CDM forestry carbon sequestration projects in Sichuan province.

2. Construction of Evaluation Index System

2.1 Evaluation Dimensions

The ecological value theory holds that forestry’s ecological benefit is the lagging economic benefit. The steady growth of forestry economic benefit is on the premise of the play of ecological benefit and also promotes the realization of forestry social benefit. Traditional forestry places undue emphasis on high economic benefit, which leads to the forest resources depletion, ecological environment deterioration and will eventually damage long-term economic and social benefits. Monetary compensation of ecological forestry construction can stimulate the forestry main body, strengthen the forestry ecological benefit and enhance the positive externalities of forestry so as to promote the implementation of the long-term economic and social benefits. The forestry carbon sequestration project has multiple functions to tackle climate changes and promote poverty alleviation. It not only provides a new investment and financing channel for the development of modern forestry, opens up a new way for market-oriented compensation of forest ecological benefit value, but also creates an effective road to “green” increment for forest farmers in poverty-stricken areas. How to accelerate the development of China’s forestry carbon sequestration, realize the forestry carbon sequestration project’s coordinated development of ecological, economic and social benefits has become an important content of China’s forestry ecology construction in the new period. Therefore, the performance evaluation of forestry carbon sequestration project must also be conducted from dimensions: ecological, economic and social benefits.

2.2 Principles for the Index Selection

With reference to the theoretical foundation of ecological economic theory and the theory of system engineering, the selection of forestry carbon sequestration project’s implementation performance evaluation indexes must combine theory with practice to reflect the basic characteristics of project construction. Based on this, this paper puts forward two principles for the selection of forestry carbon sequestration project’s implementation performance evaluation indexes.

(1) Combination of integrity and hierarchy. The implementation performance of forestry carbon sequestration project is relatively complex, which is embodied in several aspects, such as ecological, economic and social benefits, so the evaluation with a single index tends to be unable to draw a correct conclusion. Therefore we should start from the establishment of stable and efficient system engineering and consider the index system constitution as a whole. In the meantime, the index system as a systematic project is multilayered. Therefore index selection should be layered and have definite corresponding relations according to the needs of measurement purposes and different index functions.
(2) Combination of scientificity and operability. Scientificity refers to the selection of evaluation indexes, determination of index weight coefficients, data selection, calculation and synthesis should be on the basis of recognized economics and ecological theories to ensure the evaluation results believable. Operability refers to the index data of performance evaluation can be obtained through survey, measurement and other means.

2.3 Index Analysis

According to the evaluation dimensions and index selection principles, combined with investigation in forestry carbon sequestration project implementation areas and consulting related forestry experts, this paper constructs build three primary indexes, nine secondary indexes and 14 tertiary for ecological, economic and social benefits.

(1) Ecological benefit index: Forestry carbon sequestration projects are forestry activities with tackling climate change as the core (Li Nuyun, 2006), thus its carbon sequestration emission reduction is the main ecological benefit and also the basic standard to measure forestry carbon sequestration project development. And the growth of carbon reserve is the major expression of the forestry carbon sequestration emission reduction; meanwhile, forestry carbon sequestration projects are mainly implemented in key areas of the biodiversity protection and remote areas where soil erosion and water loss are relatively serious, and its contribution to the biodiversity and the control of soil erosion and water loss is also an important aspect to measure ecological benefits of the forestry carbon sequestration project.

(2) Economic benefit index: The economic benefit of forestry carbon sequestration project involves all participants and economic incomes farmers earn from forestry carbon sequestration projects are presented as direct income growth, including labor incomes, timber incomes and CERs revenues; Government revenues are embodied in direct economic incomes produced by the forestry carbon sequestration project and the opportunity cost of forestation. Enterprise benefit, on the one hand, comes from the benefit from the investment in forestry carbon sequestration projects and on the other hand is the reduced cost of emission reduction due to the participation in the forestry carbon sequestration project.

(3) Social benefits: The social benefits of forestry carbon sequestration project are mainly manifested in promoting the employment of farmers in areas where the project is implemented and improving the local ecological environment. At the same time, in terms of community development, because it has a positive impact on alleviating poverty, developing local areas, supporting the development of ethnic minorities and improving local infrastructure construction.

The implementation performance evaluation system framework of forestry carbon sequestration project and expressions of indexes are shown in Table 1.

| Primary Indexes | Secondary Indexes | Tertiary Indexes | Notes for Tertiary Index |
|----------------|------------------|------------------|-------------------------|
| Performance Evaluation Index System of Forestry Carbon Sequestration Project | Ecological Benefit Index | Carbon sequestration and emission reduction | Growth rate of carbon reserve \( (X_1) \) | Calculate by using growth curve and biomass conversion factor method, see Gong Rongfa (2015) “Northwestern Sichuan CDM Carbon Sequestration Value Potential Estimation” |
| | | Biodiversity | Change rate of biodiversity \( (X_2) \) | Year-on-year change rates of biodiversity’s direct value and indirect value |
| | | Water loss and soil erosion | Improvement of water loss and soil erosion \( (X_3) \) | Subjective assessment of farmers in the areas where the project is implemented on the improvement of water loss and soil erosion |
| | Economic Benefit Index | Incomes of Farmers | Proportion of labor income \( (X_4) \) | Proportion of farmers’ labor incomes from the participation in carbon sequestration project construction and management in total family annual incomes |
| Social Benefit Index | Enterprise Benefits | Governmental Income | Employment improvement | Environmental improvement | Community Development | Improvement of infrastructure |
|----------------------|---------------------|---------------------|------------------------|--------------------------|----------------------|-----------------------------|
|                      | Proportion of forestry income ($X_1$) | Proportion of timber incomes (converted annually) formed from the implementation of carbon sequestration project in total family annual incomes | Proportion of CERs sales incomes (converted annually) achieved from the trade of carbon sequestration in total family annual incomes | Rate of employment growth ($X_9$) | Rate of employment growth ($X_9$) | Proportion of jobs provided by the forestry carbon sequestration project |
|                      | Proportion of CERs income ($X_6$) | Proportion of CERs sales incomes (converted annually) achieved from the trade of carbon sequestration in total family annual incomes | Proportion of forestry cost expenses due to participation in the forestry carbon sequestration project in the average annual gross incomes | Degree of environmental improvement ($X_{10}$) | Degree of environmental improvement ($X_{10}$) | Proportion of jobs provided by the forestry carbon sequestration project |
|                      | Business investment rate of return ($X_7$) | Enterprise’s benefits for the investment in forestry carbon sequestration project (converted annually) | Year-on-year growth rate of incomes achieved in the areas where the project is implemented | Proportion of jobs provided by the forestry carbon sequestration project | Proportion of jobs provided by the forestry carbon sequestration project | Proportion of jobs provided by the forestry carbon sequestration project |
|                      | Income increase rate ($X_8$) | Year-on-year growth rate of incomes achieved in the areas where the project is implemented | Proportion of forestation cost expenses due to participation in the forestry carbon sequestration project in the average annual gross incomes | Subjective assessment of farmers in the areas where the project is implemented on the environmental improvement | Subjective assessment of farmers in the areas where the project is implemented on the environmental improvement | Subjective assessment of farmers in the areas where the project is implemented on the environmental improvement |
|                      | Forestation cost reduction ($X_5$) | Proportion of forestation cost expenses due to participation in the forestry carbon sequestration project in the average annual gross incomes | Proportion of jobs provided by the forestry carbon sequestration project | Proportion of poor households’ incomes ($X_{12}$) | Proportion of poor households in farmers who benefit from the project | Proportion of poor households in farmers who benefit from the project |
|                      |                              | Proportion of jobs provided by the forestry carbon sequestration project | Proportion of jobs provided by the forestry carbon sequestration project | Proportion of poor households’ incomes ($X_{12}$) | Proportion of poor households in farmers who benefit from the project | Proportion of poor households in farmers who benefit from the project |
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3. **Empirical Evaluation**

3.1 **Data Sources**
In this paper, data are from field survey data obtained in degraded land forestation reforestation project in Northwestern Sichuan (hereinafter referred to as Northwestern Sichuan Project) and Nuohua Southwestern Sichuan’s forestry carbon sequestration, community and biodiversity project (hereinafter referred to as the Southwestern Sichuan Project) conducted by the research group from October to December of 2014 and measured data provided by the local government and forestation entities (enterprises).

Northwestern Sichuan Project is the world’s first clean development mechanism forestation and reforestation (CDM-A/R) project developed and registered successfully based on the climate, community and biodiversity (CCB) standards. It covers five counties, namely Li County Mao County, Beichuan, Qingchun and Pingwu. In 2007, 2251.8 hectares had been afforested in the early stage. In 2013, the first US 250,000 dollars of trade was realized. Southwestern Sichuan cooperation of domestic enterprises and foreign enterprises and also China’s first registered CDM forestation project prepaying the future carbon sequestration funds for forestation. It covers five counties, namely, Zhaojue, Yuexi, Meigu, Leibo and Ganluo. From 2010 to the end of 2014, 4200 hectares had been afforested.

3.2 **Forestry Carbon Sequestration Project Implementation Performance Evaluation based on Principal Component Analysis**

3.2.1 Feasibility Test

(1) KMO and Bartlett Test of Sphericity. In order to ensure the stability and accuracy of model analysis and reduce the impact on the research conclusion due to data dimension difference, efficiency coefficient method and standardized treatment are adopted on the standardized treatment of original data. SPSS19.0 is used to conduct KMO and Bartlett Test of Sphericity on the data. The KMO value is 0.527 and the Bartlett Test of Sphericity is significant (P<0.001), showing the independence between all variable data complies with the premise of component analysis.

(2) Communality Test. The variables’ standard deviations fluctuate in a narrow range, indicating that the communality of variables is relatively high and it is feasible to extract the common components.

Table 2 Results of Communality Test

| Index | Variable | Initial Value | Extraction Value | SD       |
|-------|----------|---------------|------------------|----------|
| X₁    | 1.000    | 0.843         | 0.071472093      |
| X₂    | 1.000    | 0.920         | 0.032903873      |
| X₃    | 1.000    | 0.886         | 0.041163630      |
| X₄    | 1.000    | 0.740         | 0.001405784      |
| X₅    | 1.000    | 0.778         | 0.103734768      |
| X₆    | 1.000    | 0.972         | 0.207226332      |
| X₇    | 1.000    | 0.839         | 0.067887787      |
| X₈    | 1.000    | 0.826         | 0.165434282      |
| X₉    | 1.000    | 0.850         | 0.002968256      |
| X₁₀   | 1.000    | 0.844         | 0.001597898      |
| X₁₁   | 1.000    | 0.709         | 0.054988486      |
| X₁₂   | 1.000    | 0.918         | 0.064791215      |
| X₁₃   | 1.000    | 0.964         | 0.350978244      |
| X₁₄   | 1.000    | 0.886         | 0.041163630      |

3.2.2 Assessment Process

(1) Extraction of Common Components. As shown in Scree Plot of contribution rate corresponding to the eigenvalue, the variation degree of eigenvalue lowers significantly from the component number greater than 4, showing that extracted four common components are significant for the information description of the original variables. By calculating the eigenvalue, variance explanation rate and cumulative variance explanation rate and based on the principle that eigenvalue is greater than 1, four main components are extracted (Table 3).

Table 3 Total Variance Explained

| Component | Initiative Eigenvalue | Extraction Sums of Squared Loadings |
|-----------|-----------------------|------------------------------------|
|           | Variance ( % )        | Cumulative ( % )                   |
| 1         | 5.375                 | 38.393                             |
| 2         | 3.291                 | 23.505                             |
| 3         | 2.076                 | 14.829                             |
| 4         | 1.232                 | 8.803                              |
| …         | …                     | …                                  |
| 14        | -3.135E-16            | -2.239E-15                         |

(2) Principal Component Extraction. Orthogonal rotation with Kaiser Normalization is adopted to extract the principal components. According to the rotated principal component loading matrix, four principal components are determined (Table 4).
Table 4 Results of Extraction of Principal Components

| Variable | Component 1 | Component 2 | Component 3 | Component 4 |
|----------|-------------|-------------|-------------|-------------|
| X₁       | 0.105       | 0.858       | 0.199       | 0.237       |
| X₂       | 0.183       | 0.480       | 0.190       | 0.788       |
| X₃       | 0.926       | 0.101       | 0.129       | 0.023       |
| X₄       | 0.633       | 0.269       | 0.074       | 0.512       |
| X₅       | 0.045       | 0.094       | 0.875       | 0.037       |
| X₆       | 0.861       | 0.107       | 0.468       | 0.027       |
| X₇       | 0.855       | 0.268       | 0.146       | 0.119       |
| X₈       | 0.294       | 0.113       | 0.841       | 0.138       |
| X₉       | 0.287       | 0.280       | 0.618       | 0.555       |
| X₁₀      | 0.665       | 0.087       | 0.166       | 0.605       |
| X₁₁      | 0.530       | 0.629       | 0.132       | 0.121       |
| X₁₂      | 0.047       | 0.944       | 0.062       | 0.146       |
| X₁₃      | 0.017       | 0.890       | 0.040       | 0.411       |
| X₁₄      | 0.926       | 0.101       | 0.129       | 0.023       |

(3) Determination of Principal Component Weight. Variance contribution ratio (Table 3) is used to calculate the weight of each principal component (the weight of a principal component = the principal component’s variance contribution ratio ÷ the sum of four principal components’ contribution ratios, Table 5).

Table 5 Weights of Principal Components

| Eigenvalue | Weight |
|------------|--------|
| Component 1 | 5.375 | 0.449 |
| Component 2 | 3.291 | 0.275 |
| Component 3 | 2.076 | 0.173 |
| Component 4 | 1.232 | 0.103 |

(4) Construction of Total Score Calculation Formula. In accordance with the principal components obtained in Table 4, the calculation formulas of principal components are written as follows:

\[ F_1 = 0.926 \times X_3 + 0.633 \times X_4 + 0.861 \times X_6 + 0.855 \times X_7 + 0.665 \times X_{10} + 0.926 \times X_{14} \]  
(1)

\[ F_2 = 0.858 \times X_1 + 0.629 \times X_{11} + 0.944 \times X_{12} + 0.890 \times X_{13} \]  
(2)

\[ F_3 = 0.875 \times X_5 + 0.841 \times X_8 + 0.618 \times X_9 \]  
(3)

\[ F_4 = 0.788 \times X_2 \]  
(4)

\[ F = 0.449 \times F_1 + 0.275 \times F_2 + 0.173 \times F_3 + 0.103 \times F_4 \]  
(5)

3.2.3 Evaluation Results and Analysis

In accordance with the calculation formula of the total score \( F \), the author acquires the scores of the implementation performance of the forestry carbon sequestration projects of 10 counties (districts) in Northwestern Sichuan and Southwestern Sichuan project areas and respective scores of economic benefit, ecological benefit and social benefit.
Table 6 Scores of the Implementation Performance

| County    | F         | Ecological Benefit | Social Benefit | Economic Benefit |
|-----------|-----------|--------------------|----------------|------------------|
| Beichuan  | 1.27688588| 0.361580118        | 0.69589964     | 0.219406128      |
| Qingchuan | 1.08069914| 0.388322322        | 0.53224662     | 0.160130200      |
| Li County | 1.48746682| 0.399096932        | 0.74358468     | 0.344785206      |
| Pingwu    | 1.16996250| 0.406243886        | 0.58164138     | 0.182077236      |
| Mao County| 1.46353200| 0.396096932        | 0.75489534     | 0.31255443       |
| Zhaojue   | 1.15277419| 0.340547802        | 0.69206269     | 0.120163689      |
| Yuexi     | 1.16460666| 0.355704302        | 0.70443743     | 0.104464933      |
| Meigu     | 1.15326296| 0.356341294        | 0.70058402     | 0.09633765       |
| Leibo     | 1.28078957| 0.403861673        | 0.74223045     | 0.134697452      |
| Ganluo    | 1.27286058| 0.36476746         | 0.70993383     | 0.198159286      |

(1) Overall Analysis

The comprehensive performance in the 10 counties where two CDM forestry carbon sequestration projects were implemented is relatively high. In recent years, many kinds of natural disasters because of environmental degradation have enhanced farmers’ awareness of strengthening ecological environment protection and construction. Farmers have been increasingly more willing to participate in ecological projects, such as forestry carbon sequestration. Excessive outflow of rural labor force and the participating means of becoming a shareholder with forest ownership have increased the participation of households short of manpower. Government’s strict restrictions on carbon emission and the domestically increased emission reduction obligation have prompted enterprises to strengthen investment in forestry carbon sequestration projects. In addition, the governmental policies on forestry carbon sequestration projects have made development conditions of forestry carbon sequestration greatly improved.

There are obvious differences for the proportions of ecological, economic and social benefits: social benefit > ecological benefit > economic benefit. The two CDM forestry carbon sequestration projects are concentrated in remote and poor ethnic minority areas. The implementation of the projects has increased their social benefits by attracting foreign investment, creating jobs, increasing channels for income growth and improving the infrastructure construction. With the development of carbon sequestration forest, the annual growth rate of carbon reserves gradually decreases due to the increase of carbon reserve base and the ecological benefit accounts for a dropping proportion of the comprehensive benefits. Farmers participate in the forestry carbon sequestration in the main mode of labor input and forest ownership occupies relatively low ratio. They obtain relatively fewer carbon sequestration benefits and timber benefits, so the economic benefit accounts for the lowest proportion.

(2) Contrastive Analysis between Projects

As for Northwestern Sichuan and Southwestern Sichuan projects, the former project was implemented earlier. Its comprehensive performance and ecological benefit are slightly higher that those of Southwestern Sichuan project, but they do not differ greatly. The social benefit of Southwestern Sichuan project is significantly higher than that of Northwestern Sichuan for the possible reason that farmers who participated in the Southwestern Sichuan project are ethnic minorities. Therefore, the carbon sequestration project’s contribution to the social stability is higher than that of Northwestern Sichuan project in which part of ethnic minorities participated. In addition, the regions where Southwestern Sichuan project was implemented were poorer than those where Northwestern Sichuan project was implemented, so poor farmers benefited more from the society. For the economic benefit, the Southwestern Sichuan project achieved lower economic benefit than the Northwestern Sichuan project, which is possibly because of the difference between the property ownership for the two projects. In the Southwestern Sichuan project, farmers had weaker rights to benefits of CERs and timber and the Southwestern Sichuan project was implemented later than the
Northwestern Sichuan project, so the carbon sequestration benefit was relatively lower. On the other hand, the Southwestern Sichuan project was a bilateral project invested directly by enterprises and professional foresting organizations were hired for both carbon sequestration forestation and management, which reduced the revenues which farmers could earn by participating in the forestry carbon sequestration project with labor force.

(3) Contrastive Analysis of the Same Project in Different Implementation Areas

For different implementation areas of the same project, ecological benefits have slight differences due to such natural factors as rainfall, soil characteristics and climate and social factors like ecological awareness. Farmers in earthquake stricken areas have stronger awareness of ecological protection, which can promote farmers to enhance the protection of carbon sequestration forest. Economic benefits differ in different implementation areas due to differences of CERs and timber yield ownerships caused by the project’s organizational mode. For the social benefit, there are obvious discrepancies in different implementation areas because of cultural conventions, poverty, transport facilities and other factors. On the whole, the comprehensive benefit does not differ significantly as a result of the interactions of differences among ecological, social and economic benefits.

4. Conclusion and Inspiration

Generally speaking, the comprehensive performances of two CDM forestry carbon sequestration projects are relatively high. Because of the income and employment improvements for poor farmers and ethnic minorities, the projects’ social benefits account for the highest proportion. Ecological benefit occupies a gradually falling proportion with the slow growth rate of the carbon reserves. Economic benefit holds a relatively small ratio due to the profit ownership allocation. There are some differences at various degrees between different projects and the same project’s different implementation areas due to factors like years of implementation, cultural characteristics and farmers’ family features in the implementation areas and the project’s organizational modes.

On the basis of strengthening forestry carbon sequestration project’s comprehensive performance, enhancing the proportion of economic benefit in comprehensive performance is beneficial to stimulating the enthusiasm of farmers to continue to participate in forestry carbon sequestration projects and increase the forest land and labor inputs into the forestry carbon sequestration and then improve the project’s social and ecological benefits. In the process of projects being implemented, the relevant personnel should make reasonable planning and utilization of local cultural customs and family characteristics, avoid cultural restrictions on the forestry carbon sequestration project development, improve the conditions of forestry carbon sequestration project development; further broaden channels for farmers to participate in, optimize forestry carbon sequestration delimitation of property rights and division of the revenue ownership and improve farmers’ earnings in the construction and development of forestry carbon sequestration projects so as to enhance the comprehensive performance of the forestry carbon sequestration project.

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