An Evaluation Model for Sustainable Development of China’s Textile Industry: An Empirical Study

Hong ZHAO¹, Xiaodong LU², Ting YU³ and Yanbin YIN⁴

¹ Professor, School of Economics of Tianjin Polytechnic University, Tianjin, China
² Lector, School of Textiles of Tianjin Polytechnic University, Tianjin, China
³ Student, School of Economics of Tianjin Polytechnic University, Tianjin, China
⁴ Professor, School of Economics of Tianjin Polytechnic University, Tianjin, China
E-mail: zhaohong300160@126.com

Abstract. With economy’s continuous rapid growth, textile industry is required to search for new rules and adjust strategies in order to optimize industrial structure and rationalize social spending. The sustainable development of China’s textile industry is a comprehensive research subject. This study analyzed the status of China’s textile industry and constructed the evaluation model based on the economical, ecologic, and social benefits. Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) were used for an empirical study of textile industry. The result of evaluation model suggested that the status of the textile industry has become the major problems in the sustainable development of China’s textile industry. It’s nearly impossible to integrate into the global economy if no measures are taken. The enterprises concerned with the textile industry status should be reformed in terms of product design, raw material selection, technological reform, technological progress, and management, in accordance with the ideas and requirements of sustainable development. The results of this study are benefit for 1) discover the main elements restricting the industry’s sustainable development; 2) seek for corresponding solutions for policy formulation and implementation of textile industry; 3) provide references for enterprises’ development transformation in strategic deployment, fund allocation, and personnel assignment.

1. Introduction

With a continuously rapid growth in China’s economy, it is required to search for new rules, summarize experiences, and adjust strategies for the textile industry. Sustainable development of the textile industry is a comprehensive research subject, as it is related to dynamic balances and common coordination among different aspects of the textile industry, in terms of the economy, resources, the environment, and ecology. In this paper, the Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) approaches were used for an empirical study of China’s textile industry. The economic condition, social environment, natural ecology, and scientific technology as related to sustainable development were taken into consideration [1]. The natural ecology, providing raw materials for the sustainable development of the textile industry, forms the material basis as well as the fundamental factor. Economic condition is the vigor of the industry’s development. A proper social environment facilitates the supply of human resources and creates industrial demands. Scientific technology allows for innovation that drives a sustainable development. These four closely coordinated factors stimulate the textile industry’s development by influencing each other.
2. Evaluation model

Analytic Hierarchy Process (AHP), based on a multi-objective structure, was used to calculate and evaluate the importance of several alternatives depending on subjective judgment. Evaluation targets included target hierarchy, criterion hierarchy and project hierarchy, in which evaluating variables were compared in a judgment matrix and a numerical matrix. As a common method in empirical analysis, AHP allows for processing and qualitative sorting of quantitative data, and the calculation of the evaluation index weight and standardized weight of the evaluated variables.

Data Envelopment Analysis (DEA), an evaluation method based on the concept of “evaluating the relative efficiency” by A. Charnes and W.W.Cooper (the \( \mathcal{C}^2\mathcal{R} \) Model), first appeared in 1978 and gradually evolved into a common analysis method in management science and system engineering. DEA can measure the relative efficiency of decision making units (DMUs) of the same type. The “projection principle” can do further analysis on non-DEA effective causes of DMUs to provide references for decision makers. DEA was implemented as follows: picking up a series of input and output indexes as DMUs, analyzing effective factors by the Duality Theory, and evaluating the relevant indexes. The weight was calculated out of realistic data during this process, allowing for an objective analysis.

This paper employed the DEA/AHP approaches according to characteristics of the textile industry. Evaluation models of DEA/AHP were divided into two phases: first, picking up two DMUs in one team and calculating its efficiency value by DEA; second, building an AHP matrix by ranking all the DMUs by the single hierarchy analysis method based on the efficiency value in the first phase, and in the end transforming all the AHP ranking values into DEA/AHP efficiency values. This model emphasized the objective changes of the index weight to avoid any subjective judgment. In this model, DEA was used to improve the calculation efficiency of AHP by putting every efficiency value as decision-making threshold value, and the single hierarchy analysis method in total ranking of the AHP judgment matrix contained several multiple-level hierarchical judgment and decision making efficiency values, in order to guarantee an objective reference value. The model was built with MATLAB, as follows:

2.1 Building judgment matrix

[2] Given: there are \( n \) DMUs and \( m \) input indexes (negative indexes) in each DMU, and \( s \) output indexes (positive indexes). Given: \( X_{ij} \) is the \( j \)th input index of the \( i \)th DMU. Pick up two DMUs A and B and confirm the DMU relative efficiency through cross-efficiency evaluation. \( E_{AB} \) is the objective function’s optimal solution of \( LP_1 \) and \( E_{BA} \) is of \( LP_2 \). The model can be described by these equations:

\[
LP_2, \text{ st } \begin{cases} 
\sum_{i=1}^{m} v_i x_{iB} = 1 \\
\sum_{r=1}^{s} u_r y_{rB} \leq 1 \\
\sum_{r=1}^{s} u_r y_{rA} - E_{AA} \sum_{i=1}^{m} v_i x_{iA} \leq 0 \\
u_r \geq 0, r = 1, 2, \ldots, s \\
v_i \geq 0, i = 1, 2, \ldots, m
\end{cases}
\]

\[
LP_1, \text{ st } \begin{cases} 
\sum_{i=1}^{m} v_i x_{iA} = 1 \\
\sum_{r=1}^{s} u_r y_{rA} \leq 1 \\
\sum_{r=1}^{s} u_r y_{rB} - \sum_{i=1}^{m} v_i x_{iB} \leq 0 \\
u_r \geq 0, r = 1, 2, \ldots, s \\
v_i \geq 0, i = 1, 2, \ldots, m
\end{cases}
\]
\[ E_{AA} = \max \sum_{r} u_{r} v_{r} \tag{3} \]
\[ E_{BB} = \max \sum_{r} u_{r} v_{r} \tag{4} \]

where \( u_{r} \) is input index weight and \( v_{r} \) is output index weight; \( E_{AA} \) is efficiency value of A and \( E_{BB} \) is cross-efficiency value of B. According to the DEA/AHP model, \( E_{AA} = E_{AB} \cdot E_{BA} = E_{BB} \).

The AHP judgment matrix was built based on the model. \( a^{jk} \) is the AHP judgment matrix and \( C=[a^{jk}]_{n \times n} \) is the element in Line I and Row K.

\[ a^{jk} = \frac{E_{jj} + E_{jk}}{E_{kk} + E_{kj}} \tag{5} \]

\( A=[a^{jk}]_{n \times n} \) is the result of effective analysis of every DMU in the DEA model.

### 2.2 Total ranking in the AHP model

Total ranking of DUMs through a single hierarchy process in the AHP judgment matrix was performed. As for \( A_{n \times n}=[a^{jk}]_{n \times n} \), \( \lambda_{\text{max}} \) and \( w:w=(w_{1}, w_{2}, ..., w_{n})^{T} \), they were calculated by the root method, referring to the relevant importance of the jth DMU. The \( m \)th component \( w_{m} \) of the eigenvector \( w \) reflects the relevant importance of the \( m \)th DMU, which is the total ranking value in the AHP model. The total ranking value in AHP was turned into a DEA/AHP efficiency value. That is, the biggest component of the eigenvector \( w \) was chosen and given an efficiency value of 1, and the corresponding efficiency values, dividing 1 by other components, were obtained. The details are shown in equation (6):

\[ a^{jk} = a_{kk} = 1, a_{kj} = \frac{1}{a^{jk}} \tag{6} \]

For AHP, first, some values were set:
The weight factor of \( n \) factors was \( W \):

\[ W^{T} = [w_{1}, w_{2}, ..., w_{n}] \tag{7} \]

The relevant importance matrix \( A \) was obtained out of comparing every two factors of \( n \): \( A=(a_{ij}) \)

Among: \( a_{ij}=w_{i}/w_{j} \quad a_{ij}=1/a_{ij} \)

Then: If \( A \) is a consistency matrix, \( n \) is its eigenvalue and \( W \) is its eigenvector. Hence, \( AW=\lambda W \quad \lambda_{\text{max}} \geq n \)

### 2.3 Model application

The model can be applied by comparing some evaluation indexes affecting textile industry, such as total industrial discharges, waste water facilities and industrial waste gas emission. The comparison can be done as follows:

\[ A = \begin{bmatrix} 1 & 5 & 3 \\ 1/5 & 1 & 1/3 \\ 1/3 & 3 & 1 \end{bmatrix} \]

\[ A = \begin{bmatrix} 1 & 5 & 3 \\ 1/5 & 1 & 1/3 \\ 1/3 & 3 & 1 \end{bmatrix} \]
Summation
1) Keep the total of every row 1.
\[ b_i = \frac{a_i}{\sum_{j=1}^{m} a_j} \]
\[ R = \begin{bmatrix} 0.652 & 0.556 & 0.692 \\ 0.130 & 0.111 & 0.077 \\ 0.218 & 0.333 & 0.231 \end{bmatrix} \]
\[ v_j = \sum_{i=1}^{n} b_i \]
\[ V = \begin{bmatrix} 1.900 \\ 0.318 \\ 0.782 \end{bmatrix} \]

3) Normalization method.
\[ w_i = \frac{v_i}{\sum_{i=1}^{n} v_i} \]
\[ W = \begin{bmatrix} 0.633 \\ 0.106 \\ 0.261 \end{bmatrix} \]
\[ AW = \begin{bmatrix} 1 & 5 & 3 & 0.633 \\ 1/5 & 1/3 & 0.106 & 0.319 \\ 1/3 & 3 & 1 & 0.261 \end{bmatrix} \]
\[ \lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} (AW)_{ij} \]
\[ C.I. = \frac{\lambda_{\text{max}} - n}{n-1} \]

4) Consistency examination.
\[ \lambda_{\text{max}} = \frac{1}{3} \begin{bmatrix} 1.946 & 0.319 & 0.787 \end{bmatrix} \]
\[ C.R. = \frac{C.I.}{R.I.} \]

R. 1. is average random consistency index, C*R < 0.1 means the acceptance of the consistency of the judgment matrix.

5) Synthetical importance: turn the relevant weight into evaluating point by normalization method.
\[ S_{ij}^k = \frac{W_{ij}^k}{\max W_{ij}} \beta \]
where \( S_{ij}^k \) is the evaluating point value of the cross point of Line I and Row J in Hierarchy K, and \( \beta \) is the largest evaluating point value.

Note that in the above, \( S*10=[10 \quad 1.67 \quad 4.12] \)

2.4 Model analysis
DMU is the manufacturing process in which a set number of productive factors are input to produce the largest quantity of products (the ith DMU is usually remarked as DUMi). Hence DMU refers to a process turning input into output.

With the C^2R Model in DEA, one can first do an analysis on the input and output indexes of the chosen DMUs. A DMU takes in many inputs and outputs. In table 1, there are n DMUs of the same type and every DMU has m kinds of input factors and s kinds of output factors. The input and output vectors of DMU are shown in table 1.

**Table 1.** Table of input and output vectors of DMU

| No. | Weight | 1 | 2 | ... | j | ... | DMU | 1 | 2 | ... | j | ... | n |
|-----|--------|---|---|-----|----|-----|-----|---|---|-----|----|-----|---|
| Input data | 1 | v_1 | x_11 | x_12 | ... | x_ij | ... | x_in |
|          | 2 | v_2 | x_21 | x_22 | ... | x_2j | ... | x_2n |
|          | ... | ... | ... | ... | ... | ... | ... | ... |
|          | m | v_m | x_m1 | x_m2 | ... | x_mj | ... | x_mn |
|          | 1 | u_1 | y_11 | y_12 | ... | y_1j | ... | y_1n |
| Output data | 2 | u_2 | y_21 | y_22 | ... | y_2j | ... | y_2n |
|          | ... | ... | ... | ... | ... | ... | ... | ... |
|          | s | u_s | y_s1 | y_s2 | ... | y_sj | ... | y_sn |

x_ij is the data of the ith input in the jth DMU,
y_ij is the data of the ith output in the jth DMU, \( v_i \) is the weight of the ith input,
u_i is the weight of the ith output, \( i=1,2,...,m \) \( r=1,2,...,s \) \( j=1,2,...,n \)

Given \( X_j = (x_{j1}, x_{j2}, ..., x_{jn})^T \), \( Y_i = (y_{i1}, y_{i2}, ..., y_{in})^T \), \( v = (v_1, v_2, ..., v_m)^T \), \( U = (u_1, u_2, ..., u_s)^T \)

The efficiency evaluation index equation of the Jth DMU is:

\[ U_j = \alpha X_j + \gamma Y_i \]

\[ x_{ij} = \frac{v(x_{ij} - \gamma y_{ij})}{\alpha x_{ij}} + \gamma y_{ij} \]

\[ y_{ij} = \frac{\gamma y_{ij}}{\alpha x_{ij}} + \frac{v(x_{ij} - \gamma y_{ij})}{\alpha x_{ij}} \]

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\[ x_{ij} = \frac{v(x_{ij} - \gamma y_{ij})}{\alpha x_{ij}} + \gamma y_{ij} \]

\[ y_{ij} = \frac{\gamma y_{ij}}{\alpha x_{ij}} + \frac{v(x_{ij} - \gamma y_{ij})}{\alpha x_{ij}} \]
$$E_j = \frac{U^TY_j}{V^TX_j}$$

By performing efficiency evaluation of the j DMU, the C^R model is:

$$\begin{align*}
\max & \quad \frac{U^TY_0}{V^TX_0} \\
\text{s.t.} & \quad \frac{U^TY_j}{V^TX_j} \leq 1 \\
& \quad u \geq 0 \\
& \quad v \geq 0
\end{align*}$$

In order to judge the validity of DMU, dual problem of linear programming can be used, and the dual model of C^R model becomes:

$$\begin{align*}
\min \theta = \theta^* \\
\text{s.t.} & \quad \sum_{j=1}^{n} \lambda_j x_j + s = \theta x_0 \\
& \quad \sum_{j=1}^{n} \lambda_j y_j - s = y_0 \\
& \quad s^- \geq 0, s^+ \geq 0
\end{align*}$$

The basic variables of C^R model are listed as follows:

- $\theta^*$ is efficiency value of DMU, $X_j$: a set of input factors of ; and $X_j = (x_{j1}, x_{j2}, \ldots, x_{jm})$; $Y_j$: a set of output factors of DMU, and $Y_j = (y_{j1}, y_{j2}, \ldots, y_{jn})$; $\lambda_j$ is the portfolio ratio of the j DMU in the rebuilt DMU combination DMU_0; S and $S^*$ are slack variables.

The optimal solutions of the dual program include $\lambda^*, \theta^*, S^*$ and $S'^*$, in which $\theta^*$ is the relevant efficiency value of DMU. The economic implications of the C^R model refer to the following:

- if the evaluated DMU is relevantly efficient, only when $\theta^*=1$ and all the optimal slack variables $S^*-S'^*=0$, the output $Y_0$ of the economic system constituted by n DMUs based on the initial input $X_0$ can get to the optimal value.
- if $\theta^*=1$ and $\theta^* \neq 0$ or $S'^* \neq 0$, DMU is weakly efficient in DEA. In the economic system constituted by n DMUs, the initial output $Y_0$ can be kept invariant when the input $X_0$ decreases $S'$; the output can increase $S^*$ when the input $X_0$ remains invariant.
- if $\theta^*<1$, DMU is inefficient in DEA: In the economic system constituted by n DMUs, the initial output can be kept invariant with the input reduced to the $\theta^*\%$ of the initial input.

3. Construction of the evaluation index system

This empirical study focused on how the source input of environmental protection in the textile industry (in this paper we primarily referred to the clean energy production) could affect wastewater reduction and the reduction’s influence on the industry’s international competitiveness. The representative indexes were analyzed, which reflected implementation of clean energy production investment, source treat capabilities and China’s textile industry’s international competitiveness at this stage [3].

A common index system can be established in the E-R model, in which frequency statistics, theory analysis and setting indexes developed by consulting experts according to scientific and reasonable principles. In order to show the operability and flexibility of the evaluation index system, regional textile industry’s development needed to be taken into consideration to evaluate the availability and reliability of the indexes under the influence of society, economy and environment. The evaluation system is illustrated in figure 1.
Figure 1. Flow chart of building evaluation index system of the sustainable development of X city’s textile industry.

This index system consisted of 4 hierarchies. Target hierarchy A was the comprehensive index of the sustainable development of X city’s textile industry, which reflected the coordination among the development situation and economy, society, and environment. Criterion hierarchy B included four parts: B_1 (index of the sustainable development of textile industry), B_2 (coordination degree between sustainable development of the textile industry and society), B_3 (coordination degree between sustainable development of the textile industry and economy) and B_4 (coordination degree between sustainable development of the textile industry and environment). Restraint hierarchy C reflected indexes restraining Hierarchy B and it covered three aspects: C_1 (the status quo of the textile industry), C_2 (development degree) and C_3 (development situation). Due to the evaluated region and evaluation focus, the evaluation methods for sustainable development of the textile industry were different in the choice of the index system.

The final, chosen evaluation indexes are shown in table 2.

Table 2. Evaluation index system of textile industry’s sustainable development

| 1st class indexes                        | 2nd class indexes                     | 3rd class indexes                      |
|------------------------------------------|---------------------------------------|----------------------------------------|
| Indexes of textile industry’s sustainable development | Indexes of economic benefits | Indexes of gross scale                  |
|                                         |                                       | Total production value                 |
|                                         |                                       | Used capital value                     |
|                                         |                                       | Ratio of trade value in GDP            |
|                                         |                                       | Construction indexes                  |
|                                         |                                       | Ratio of finished products             |
|                                         |                                       | Ratio of product materials             |
|                                         |                                       | Efficiency indexes                    |
|                                         |                                       | Contribution rate to GDP               |
Pulling degree to FDI increase

| Indexes of social benefits | Employment of textile industry | Average salary of textile industry |
|----------------------------|--------------------------------|-----------------------------------|
| Indexes of ecological benefits | Net emissions of waste water of textile industry | Net emissions of waste gas of textile industry |
|                             | Net discharges of solid wastes of textile industry | Net emissions of energy of textile industry |

### 4. Calculative process of evaluation model

The indexes for sustainable development of the textile industry included a large number of economic benefits indexes, social benefits indexes and ecological benefits indexes. In this study only ecological benefits indexes were being analyzed. [4] To realize the ecological benefits indexes for sustainable development of the textile industry, data needed to be analyzed from different aspects. Given three of the indexes were decisive (C₁, C₂ and C₃), some main influencing factors of textile industry were chosen, such as the total number of enterprises, total discharges of industrial waste water (ten thousand tons), standard discharges of industrial waste water (ten thousand tons), waste water treatment facilities (set), processing power of waste water treatment facilities (ten thousand tons/day), operating expense of the year (ten thousand yuan), emissions of industrial waste gas (million standard cubic meters), fuel burning, production technology, emissions of industrial smoke (ton), emissions of industrial SO₂ (ton), emissions of industrial dust (ton), standard emissions of industrial SO₂ (ton), standard emissions of industrial dust (ton), waste gas treatment facilities (set), desulfurization facilities (set), total of industrial solid wastes (ten thousand ton), discharges of hazardous wastes and industrial solid wastes (ton), comprehensive quantity of industrial solid wastes (ten thousand tons), ratio of hazardous wastes and industrial solid wastes, comprehensive reusing value of wastes (ten thousand yuan), and so on. In AHP, priority ranking of the influencing factors for sustainable development of the textile industry can be performed (the weight and calculation procedures are given) [5].

A, B, and C respectively referred to the three hierarchies of the influencing factors. The paired comparison method was employed in the model to obtain the following judgment matrices as shown in tables 3- tables 5.

#### Table 3. A-B Judgment matrix

|   | A   | B₁  | B₂  | B₃  | B₄  | B₅  | B₆  |
|---|-----|-----|-----|-----|-----|-----|-----|
|   | B₁  | 1   | 1   | 1   | 4   | 1   | 1/2 |
|   | B₂  | 1   | 1   | 2   | 4   | 1   | 1/2 |
|   | B₃  | 1   | 1/2 | 1   | 5   | 3   | 1/2 |
|   | B₄  | 1/4 | 1/4 | 1/5 | 1   | 1/3 | 1/3 |
|   | B₅  | 1   | 1   | 1/3 | 3   | 1   | 1   |
|   | B₆  | 2   | 2   | 2   | 3   | 3   | 1   |

#### Table 4. B₁, B₂, B₃ - C Judgment matrix

| B₁ B₂ B₃ | C₁     | C₂     | C₃     |
|-----------|--------|--------|--------|
| C₁        | 1,1,1  | 1/4,1/4,3 | 1/2,1/5,1/3 |
|    | C_2 | 4,4,1/3 | 1,1,1 | 3,1/2,1/7 |
|----|-----|---------|-------|-----------|
| C_3 | 2,5,3 | 1/3,2,7 | 1,1,1 |

**Table 5.** B_4 B_5 B_6 - C Judgment matrix

| B_4 B_5 B_6 | C_1    | C_2    | C_3    |
|-------------|--------|--------|--------|
| B_1         | 1,1,1  | 1/3,1,7| 5,7,9  |
| B_2         | 3,1,1/7| 1,1,1  | 7,7,1  |
| B_3         | 1/5,1/7,1/9 | 1/7,1/7,1 | 1,1,1 |

In AHP, considering the influencing factors for sustainable development of the local textile industry in China, the first factor was a restricted factor needing key treatment. Hierarchy total ranking was obtained and its result was the weight of the evaluation index system (Table 6). In this table, C_1 refers to the evaluation weight of the status quo of textile industry, C_2: the evaluation weight of developing degree, and C_3: the evaluation weight of developing situation. The total ranking result of B_1 to B_6 indicated the weight of indexes of the industry’s influencing factors.

**Table 6.** Hierarchy total ranking

|    | B_1 | B_2  | B_3  | B_4  | B_5  | B_6  | Hierarchy total ranking |
|----|-----|------|------|------|------|------|-------------------------|
|    | 0.1507 | 0.1792 | 0.1886 | 0.0472 | 0.1464 | 0.2879 |                          |
| C_1 | 0.1365 | 0.0974 | 0.2426 | 0.2790 | 0.4667 | 0.7986 | 0.3952                  |
| C_2 | 0.6250 | 0.3331 | 0.0879 | 0.6491 | 0.4667 | 0.1049 | 0.2996                  |
| C_3 | 0.2385 | 0.5695 | 0.6694 | 0.0719 | 0.0667 | 0.0965 | 0.3052                  |

Table 6 shows that the status quo of textile industry (C_1) is the highest weight in the overall evaluation of the three indicators system, thus becoming the most important problem for China's textile industry to promote the sustainable development of economy.

5. Conclusion

In this paper, AHP and DEA approaches were used for an empirical study of China's textile industry. The economic condition, social environment, natural ecology, and scientific technology were used to establish the models. The AHP model prioritized the factors influencing the sustainable development of the textile industry. The results suggested that the status of the textile industry has become the major problems in the sustainable development of China’s textile industry. The enterprises concerned with the textile industry status should be reformed in terms of product design, raw material selection, technological reform, technological progress, and management, in accordance with the ideas and requirements of sustainable development.

6. References

[1] Ma, Chuandong. Economy of Sustainable Development [M]. Jinan: Shandong People Press. 2011:332-336.
[2] Zhao, Junli. Analysis of China's industrial upgrading based on the adjustment of American textile industry [J]. International Trade.2010:131-136
[3] Zhang, Fengtao. Research on Cluster Competitiveness of China’s Textile Industry [D]. Northeast Normal University. 2012:31-36.
[4] Dong, Wenwen. Export Status of China’s Textile Industry and Measures for Sustainable Development [J]. Foreign Trade. 2013:11-12.

[5] Ding, Jue. Research on Factor Intensity Reversal and China’s Textile Industry’s Upgrading [D]. Zhejiang University. 2010:54-58.