Model of Green Evaluation Index of Petrochemical Enterprises by Consistency AHP

Sun Tao
School of Computer Science, Xi’an Shiyou University, Xi’an 710065 Shaanxi
765536036@qq.com

Abstract: AHP can be easily influenced by human subjective consciousness, which may lead to inconsistencies. So it is necessary to process AHP with mathematics methods to achieve logical compatibility. In this paper, the evaluation index model of petrochemical enterprises is constructed according to the improved consistency AHP method, so as to perform comprehensive evaluation for enterprises and strengthen the environmental pollution control. Based on the specific characteristics of petrochemical enterprises, the relevant green index model is established after the specific theoretical framework of index scoring, hierarchy and synthesis of indexes is perfected, and the indexes of green characteristics are decomposed. In order to realize the scientifi city of index transfer, the power exponent with case analysis is used to calculate the specific values of indexes in this paper, and the scientifically evaluated green index which is easy to be compared is calculated, which provides the basis for policies of environmental protection in petrochemical industry.

1. Introduction
The environmental protection problems of petrochemical enterprises should be studied [1] from management policies in addition to technical responsibilities in consideration of the frequent occurrence of such problems. This depends on the scientific evaluation of the environmental influence of enterprises, which is now significantly important. The relevant research literature includes [2] and [3], etc. Analytic hierarchy process (AHP) is adopted to quantitatively evaluate the environmental pollution index of petrochemical enterprises reasonably with various influence factors comprehensively considered in this paper. Less quantitative information is used to keep the thinking process of decision-making mathematical in this method based on the deep analysis of influence factors and their internal relations. AHP is also introduced to environmental protection, such as [4], [5] and [6]. AHP is applied in environmental problems to evaluate the green index of chemical enterprises and provide references for policy making in this paper.

2. Application of AHP
2.1. Index weight scale
AHP determines the weight of evaluation indexes by hierarchy contrast. The relative scale value $\alpha_{ij}$ is generated through importance contrast of any two sub-factors $i$ and $j$ under the same index, when $i = j$, $\alpha_{ij} = 1$, $\alpha_{ij}$ constitutes the importance fuzzy judgement matrix $H$. $\alpha_{ij} = 1/\alpha_{ji}$, $\alpha_{ij} = \alpha_{ik}/\alpha_{jk}$ and $i, j, k = 1, 2, 3, ..., n$ in $H$. The element $\alpha_{ij}$ refers to the importance degree of factor $i$
to factor $j$. The elements in the fuzzy judgement matrix usually take 1, 3, 5, 7 and their reciprocals, and the specific values are as shown in Table 1.

$$H = \begin{bmatrix}
\alpha_{11} & \alpha_{12} & K & \alpha_{1n} \\
\alpha_{21} & \alpha_{22} & K & \alpha_{2n} \\
M & M & O & M \\
\alpha_{n1} & \alpha_{n2} & K & \alpha_{nn}
\end{bmatrix}$$

Table 1 Scale meaning

| Scale | Meaning | Scale | Meaning |
|-------|---------|-------|---------|
| 1     | Two factors are equally important | 3     | One factor is slightly more important than another |
| 5     | One factor is obviously more important than another | 7     | One factor is absolutely more important than another |
| 9     | One factor is much more important than another | 2 - 8 | Intermediate value among the aforementioned values |

2.2. Consistency adjustment

Table 2 Average Random Consistency Pointers of Matrices of 1 - 9 Order

| Order | 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|

The logic of importance must be: if $A$ is more important than $B$, and $B$ is more important than $C$, then $C$ is more important than $B$. The consistency check of judgement matrix $H$ is required in order to verify the rationality of the logic. Let $Hw = \lambda_{max}w$, where $\lambda_{max}$ is the maximum characteristic root of $H$, and $w$ is the maximal convector. The consistency index $CI = \frac{\lambda_{max} - n}{n - 1}$ shall meet certain requirements; otherwise the judgement matrix shall be adjusted. $CI = 0$ when the judgement matrix is completely consistent. The larger $\lambda_{max}$, the larger $CI$, and the poorer consistency of the matrix. $CI$ is compared with the average random consistency pointer $RI$, so as to verify that whether the consistency of the judgement matrix is satisfactory. The value of $RI$ for matrix of order 1-8 is as shown in Table 2. The consistency less than $RI$ is deemed to meet the requirements, and then the eigenvector $w$ is normalized to generate each factor weight. The logic error $A > B > C > A$ may occur due to subjective judgement error, and such non-consistency judgement matrix may be tolerated. It is natural that the individual logic paradox in multi-factor comparison may easily occur because of human limitations, while such paradox shall be adjusted properly. A method with no human intervention is proposed in this paper.

$h_{ij} = 1/h_{ji}$ and $h_{ij} = h_{jk} / h_{ik}$ when $H$ is absolutely consistent. The following concepts are introduced in order to realize the consistency of the matrix. 1. Let $H = [h_{ij}] \in R^{n \times n}$, then $H$ is a reciprocal matrix if $h_{ij} = 1/h_{ji}$. 2. Let $H$ be a reciprocal matrix, then $H$ is a reciprocal matrix if $h_{ij} = h_{jk} / h_{ik}$. 3. Let $K = [k_{ij}] \in R^{n \times n}$, then $K$ is an antisymmetric matrix if $K_{ij} = -K_{ji}$. 4. Let $K$ be an antisymmetric matrix, then $K$ is a transfer matrix if $K_{ij} = K_{ik} + K_{ij}$, and $K = \log H (k_{ij} = \log h_{ij}, \forall ij)$ if $H$ is a consistent matrix, then it is not difficult to find that $K$ is a transfer matrix according to the above concepts. When constructing the judgement matrix $H$, the value is usually obtained from pairwise comparison of factors $i, j$ at the same hierarchy, $h_{ij}$ is directly
valued as $h_i = 1/h_y$, and $H$ is a reciprocal matrix. While its consistency cannot be guaranteed, and $K = \log H$ is only an antisymmetric matrix rather than a transfer matrix.

By constructing $K^* = K$, and $H^*$ is obtained to replace $H$ through inverse transformation $H^* = 10^K$. $K^*$ is called the optimal transfer matrix, which shall meet: $S^*_k = \min \left( \sum_{i=1}^{n} \sum_{j=1}^{n} (k^*-k) \right)$, then $K^*$ shall be $k^*_{ij} = \frac{1}{n} \sum_{m=1}^{n} (k_{im} - k_{jm}), \forall i, j$ by solving this equation. $H^*$ is called the proposed optimal consistent matrix, the weight of this hierarchy, namely $w_i$, is obtained by normalizing the eigenvector of the maximum characteristic root of the matrix.

2.3. Transfer of weight hierarchy power exponent

When calculating the index weight $w_i$ of each hierarchy, the traditional method is to simply score each underlying factor then multiplied by the weight $w_i$, and transfer it to the upper hierarchy. This paper believes that the power exponent should be combined as described below. Vector $X = (x_1, x_2, ..., x_k)$ indicates k performance pointer of petrochemical enterprise environment, $Q$ indicates the index, and let $Q = F(X)$, the function $F(X)$ shall meet the following requirements:

1. $F(X)$ shall be a continuous function, and the correlation index changes continuously with the change of pointer performance. The smaller change of the parameter, the smaller change of the index value, i.e. $F(X) \rightarrow 0$ when $\Delta X \rightarrow 0$.

2. $F(X)$ shall meet the requirements of diminishing marginal utility. With continuous increase of the index value, the increment of the index is less and less under the same increment $\Delta X$. Namely $F(X) - F(X^*) \leq dF(X)(X - X^*)$, and the function is a concave function.

3. Metric consistency. The same index has different value under different sub-index dimensions. Therefore, the metric consistency is necessary to ensure the consistency of green indexes. Let the green index $\Omega$ be a K-dimensional linear metric space of the performance index, $\Omega_k$ is another K-dimensional linear metric space of the performance index, and $E = (e_1, e_2, ..., e_k)$, $\Omega_k = E \Omega_k$. $x = (x_1, x_2, ..., x_k)$ and $x' = (x_1', x_2', ..., x_k')$ are the two different indexes in $\Omega_k$, then the indexes in $\Omega_k$ are $Y = (y_1, y_2, ..., y_k) = (e_1 x_1, e_2 x_2, ..., e_k x_k)$ and $Y' = (y_1', y_2', ..., y_k') = (e_1 x_1', e_2 x_2', ..., e_k x_k')$. The function $F(x)$ could meet $F(X)/F(X^*) = F(Y)/F(Y^*)$ for any $E = (e_1, e_2, ..., e_k) \in K^*$, and then the pointer function meets the requirements of metric consistency. Metric consistency assures the consistency of index calculated under different dimensions, i.e. the index increases by 10% under a certain dimension, then the calculated index under the other dimensions will increase by 10%.

The power function just meets the above requirements: $F(X) = \mu g x_1^{n_1} x_2^{n_2} \cdots x_k^{n_k} \sum w_i = 1$, $i = 1, 2, 3, ..., k$ and $x_1, x_2, ..., x_k$ can be directly substituted into various parameters. $\mu$ is the adjustment factor to solve different index comparison, and its value is 1 in case of the comparison of same index.

3. Index system construction

The indexes selected must reflect the core factors of the enterprise’s green index, and feature small correlation with quantified calculations and decomposition into multi-hierarchy preferred. A complete green index evaluation system of petrochemical enterprises is constructed according to the characteristics of petroleum enterprises and reference literature [7], which includes five aspects, namely resource consumption, pollutant emission, resource reclamation, comprehensive compliance rate and technological management. The details are as shown in Table 3: (1) Resource consumption. Resource consumption refers to the quantity of energy, materials, water and others consumed by unit output value of the enterprise during the whole process of production. (2) Recycling of resources.
Recycling of resources refers to the recovery and utilization of waste gas, waste water, waste heat or renewable resources produced during the production. (3) Pollutants emission. A large amount of waste gas, waste residues and waste water are discharged during mining and refining, which should be strictly monitored. (4) Technology management. Technology management supporting performance is indicated by two indexes: research and development ability on new technologies for energy-saving and emission reduction and management system measures. (5) Harmless treatment. The harmlessness is reflected by pollutant emission compliance rate and the use of green resources.

The possibility of index value in each hierarchy is set in [0, 1], and the qualitative and quantitative indexes are processed respectively. (1) Qualitative indexes evaluation. A five-level evaluation set \( R = \{ r_1, r_2, r_3, r_4, r_5 \} \) scored by experts is established. \( r_1 = 0.2 \), namely “poor”; \( r_2 = 0.4 \), namely “relatively poor”; \( r_3 = 0.6 \), namely “fair”; \( r_4 = 0.8 \), namely “relatively good; \( r_5 = 1 \), namely “good”. (2) Quantitative indexes evaluation. The degree of completion \( F \) is introduced. The upper limit \( f^+ \) and lower limit \( f^- \) of each index is determined. The target value of positive index is the upper limit \( f^+ \) and the lower limit \( f^- \) if for that of negative index. The completion degree of positive and negative indexes is \( F \), and the calculation results are as shown in Table 4.

\[
F = \frac{f_0 - f^-}{f^+ - f^-} \times 100\% , \quad F = \frac{f_0 - f^+}{f^+ - f^-} \times 100\%
\]

| Objective hierarchy | First-level index I | Second-level index II | Third-level index III | Index type |
|---------------------|---------------------|-----------------------|-----------------------|------------|
| Enterprise’s green index U | Resource consumption U1 | Energy-saving U11 | Energy consumption of unit output value U111 | Quantitative |
| | | | Materials consumption of unit output value U112 | Quantitative |
| | | Water-saving U12 | Water consumption of unit output value U121 | Quantitative |
| Pollutant emission U2 | Waste water U21 | Petroleum emission of unit output value U211 | Quantitative |
| | | COD emission of unit output value U212 | Quantitative |
| | | BOD emission of unit output value U213 | Quantitative |
| | | Sulfide emission of unit output value U214 | Quantitative |
| | | Phenols emission of unit output value U215 | Quantitative |
| | Waste gas U22 | SOx emission of unit output value U221 | Quantitative |
| | | NOx emission of unit output value U222 | Quantitative |
| | | CO emission of unit output value U223 | Quantitative |
| | | CO2 emission of unit output value U224 | Quantitative |
| Resources recovery U3 | Solid pollution U23 | Pollutant emission of unit output value U231 | Quantitative |
|----------------------|---------------------|---------------------------------------------|--------------|
| Waste water U31      | Repeated utilization rate of waste water U311 | Quantitative |
|                      | Repeated utilization rate of waste liquor U312 | Quantitative |
| Waste gas U32        | Cyclic utilization rate of waste heat U321     | Quantitative |
|                      | Cyclic utilization rate of waste gas U322      | Quantitative |
| Solid wastes U33     | Recovery utilization rate of waste materials U331 | Quantitative |
|                      | Recovery utilization rate of garbage U332     | Quantitative |
| Harmlessness U4      | Comprehensive compliance rate U41           | Compliance rate of waste water discharge U411 | Quantitative |
|                      | Compliance rate of waste gas emission U412  | Quantitative |
|                      | Compliance rate of toxic substances emission U413 | Quantitative |
| Green resource U42   | Utilization rate of renewable resources U421 | Quantitative |
|                      | Utilization rate of green materials U422     | Quantitative |
| Technology management U5 | Green technology research U51        | Compliance with policies U511         | Qualitative |
|                      | Green design U512                            | Qualitative |
|                      | Investment ratio U513                        | Qualitative |
| Management measures U52 | Employees’ familiarity with the concept U521 | Qualitative |
|                      | Complete system U522                         | Qualitative |
|                      | Enterprise execution U523                    | Qualitative |

### Table 4 Green Index Score and AHP Importance Setting of a Petrochemical Enterprise

|   | I   | II  | III  |
|---|-----|-----|------|
| U |    | U1  | U11  |
|   |    | (1/3 1) | (1 3) |
| U1 | 1 1 3 5 3 | 1 1 5 7 3 | U11 0.35 tons of coal/ RMB 10,000  
(0.2, 0.50) | (1/5 1) |
|   | 1/3 1/5 1/3 5 | 1/5 1/7 3 1 3 | U111 0.35 tons of coal/ RMB 10,000  
(0.2, 0.50) | (1/5 1) |
| U12 | 17.7 tons / RMB 10,000 (10, 25) |   |   |
| U12 | 17.7 tons / RMB 10,000 (10, 25) |   |   |

|   | I   | II  | III  |
|---|-----|-----|------|
| U |    | U1  | U11  |
|   |    | (1/3 1) | (1 3) |
| U1 | 1 1 3 5 3 | 1 1 5 7 3 | U11 0.35 tons of coal/ RMB 10,000  
(0.2, 0.50) | (1/5 1) |
|   | 1/3 1/5 1/3 5 | 1/5 1/7 3 1 3 | U111 0.35 tons of coal/ RMB 10,000  
(0.2, 0.50) | (1/5 1) |
| U12 | 17.7 tons / RMB 10,000 (10, 25) |   |   |
| U12 | 17.7 tons / RMB 10,000 (10, 25) |   |   |
|   |   |   |
|---|---|---|
| U2 | U21 | U211 0.03475 kg / RMB 10,000 (0.01, 0.05) |
|   |   | U212 1.39kg / RMB 10,000 (1.0, 2.0) |
|   |   | U213 0.84kg / RMB 10,000 (0.5, 1) |
|   |   | U214 2.1kg / RMB 10,000 (1.5, 2.5) |
|   |   | U215 0.0035kg / RMB 10,000 (0.001, 0.005) |
| U22 | U221 1.042kg / RMB 10,000 (0.8, 1.5) |
|   |   | U222 2.5kg / RMB 10,000 (0.5, 2.6) |
|   |   | U223 10kg / RMB 10,000 (5, 30) |
|   |   | U224 50kg / RMB 10,000 (10, 80) |
| U23 | U231 2.03kg / RMB 10,000 (1.5, 4.0) |
| U3 | U31 | U311 80% (20%, 100%) |
|   |   | U312 45% (20%, 90%) |
| U32 | U321 50% (10%, 80%) |
|   |   | U322 50% (40%, 80%) |
|   | U33 | U323 80% (60%, 98%) |
|   |   | U324 10% (5%, 50%) |
| U4 | U41 | U411 80% (75%, 98%) |
|   |   | U412 92% (90%, 99%) |
|   |   | U413 99% (98%, 100%) |
| U42 | U421 30% (20%, 60%) |
|   |   | U422 95% (80%, 99%) |
| U5 | U51 | U511 r4 |
|   |   | U512 r5 |
|   |   | U513 r6 |
| U52 | U521 r4 |
|   |   | U522 r5 |
|   |   | U523 r6 |

Table 5 Calculation of Bottom Index Values and Index Weights

|   | CI, RI, weight | II | CI, RI, weight | III | CI, RI, weight |
|---|---|---|---|---|---|
|   |   |   |   |   |   |
| U   | U1     | U11  | 0, 0 | 0.7500 | 0.2500 | U111 0.5000 | 0, 0 | 0.8333 | 0.1667 |
|-----|--------|------|------|--------|--------|--------------|------|---------|--------|
|     |        | U12  |      |        |        | U112 0.4316  |      |          |        |
|     |        |      |      |        |        | U121 0.4867  |      |          |        |
| U2  | U21    |      | 0.01 | 0.91   | 0.58   | 0.0            |      |          |        |
|     |        |      |      |        |        | U211 0.3812  |      |          |        |
|     |        |      |      |        |        | U212 0.3000  |      |          |        |
|     |        |      |      |        |        | U213 0.3200  |      |          |        |
|     |        |      |      |        |        | U214 0.4000  |      |          |        |
|     |        |      |      |        |        | U215 0.3750  |      |          |        |
|     |        |      |      |        |        | U221 0.6543  |      |          |        |
|     |        |      |      |        |        | U222 0.0476  |      |          |        |
|     |        |      |      |        |        | U223 0.8000  |      |          |        |
|     |        |      |      |        |        | U224 0.4286  |      |          |        |
|     |        | U23  |      |        |        | U231 0.7880  |      |          |        |
|     | U31    |      | 0.00 | 0.00   | 0.00   | U311 0.7500  |      |          |        |
|     |        |      |      |        |        | U312 0.3571  |      |          |        |
|     | U32    |      | 0.00 | 0.00   | 0.00   | U321 0.5714  |      |          |        |
|     |        |      |      |        |        | U322 0.5000  |      |          |        |
|     |        |      |      |        |        | U323 0.5263  |      |          |        |
|     |        |      |      |        |        | U324 0.1111  |      |          |        |
|     | U33    |      |      |        |        | U311 0.7500  |      |          |        |
|     | U41    |      | 0.00 | 0.00   | 0.00   | U411 0.2174  |      |          |        |
|     |        |      |      |        |        | U412 0.2222  |      |          |        |
|     |        |      |      |        |        | U413 0.5000  |      |          |        |
|     | U42    |      |      |        |        | U421 0.3500  |      |          |        |
|     |        |      |      |        |        | U422 0.7895  |      |          |        |
|     | U51    |      | 0.00 | 0.00   | 0.00   | U511 0.8000  |      |          |        |
|     |        |      |      |        |        | U512 1.0000  |      |          |        |
|     |        |      |      |        |        | U513 0.6000  |      |          |        |
Once the specific value of each sub-index in table 4 is calculated, the completeness is calculated for quantitative values, and the score is given for qualitative values. Meanwhile, all fuzzy judgement matrix with CI is not 0 in table 5 is adjusted in accordance with the algorithm described in Section 2.2. The normalized eigenvector is the eigenvector corresponding to the maximum eigenvalue of the proposed optimal consistent matrix, and the vector is the index weight when the model is 1. All index weights as well as the quantitative score of the most basic index are obtained, and then the green index value of enterprise environment can be calculated. The value of index under each hierarchy is calculated with power function according to the data in table 5, and the green index value of the petrochemical enterprise environment is $U = 0.4693$. It can be seen from the calculation results that the green index is finally quantified as a measurable non-dimensional value, which is conducive to the comparison between horizontal and vertical enterprises. The index value between 0 and 1 can be used to scientifically evaluate the energy-saving and emission reduction and green environmental protection of enterprises and greatly facilitate the launch of decision-making with human interventions eliminated.

4. Conclusion

In this paper, a model is established for evaluation of environmental green indexes of petrochemical enterprises. AHP evaluation is applied, a strategy to solve the consistency is put forward, and the evaluation mathematical model is established in combination with the power exponent method. Also a hierarchical index system is established to integrate uncertainties into quantitative indexes according to the actual conditions, which has brought great convenience. Enterprises should constantly strengthen theoretical and methodological research in this area and properly research green technology and other basic work in order to achieve the overall goals of building a conservation-oriented society.

References

[1] Andrew A. King and Michael J. Lenox. Industry Self-Regulation Without Sanctions: The Chemical Industry's Responsible Care Program.ACAD MANAGE J August 1, 2000 vol. 43 no. 4
[2] Michael N Moore,Michael H Depledy,James W Readman,D.R Paul Leonard. An integrated biomarker-based strategy for ecotoxicological evaluation of risk in environmental management. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis. Volume 552, Issues 1–2, 18 August 2004,Pages: 247-268
[3] A.N. Anozie,A.R. Bakare,J.A. Sonibare,T.O. Oyebisi. Evaluation of cooking energy cost, efficiency, impact on air pollution and policy in Nigeria. Energy. Volume 32, Issue 7, July 2007, Pages: 1283-1290
[4] Riccardo Rossi, Massimiliano Gastaldi, Gregorio Gecchele.Comparison of fuzzy-based and AHP methods in sustainability evaluation: a case of traffic pollution-reducing policies. European Transport Research Review.March 2013, Volume 5, Issue 1, Pages:11-26
[5] Mona Haddad Zouheir Fawaz. Evaluation of microalgal alternative jet fuel using the AHP method with an emphasis on the environmental and economic criteria. Environmental Progress & Sustainable Energy, Volume 32,Issue 3,October 2013 pages:721-733
[6] Rong-Her Chiu, Le-Hui Lin, and Shih-Chan Ting.Evaluation of Green Port Factors and Performance: A Fuzzy AHP Analysis.Mathematical Problems in Engineering,Volume 2014 (2014), Article ID 802976,12 pages
[7] Renxin, Research on Energy-saving and Emission Reduction Behavior of Oil Enterprises Based
on Policy Environment [D]. Master's Thesis of Southwest Petroleum University, June 2012, Pages: 24-35

[8] Ojumu, T. V., Bello, O. O., Sonibare, J. A., Solomon, B. O. Evaluation of microbial systems for bioremediation of petroleum refinery effluents in Nigeria. African Journal of Biotechnology Vol. 4 (1), January 2005. Pages: 31-35

[9] Z. Chen, G.H. Huang, A. Chakma. Integrated environmental risk assessment for petroleum-contaminated sites-A North American case study. Water Science and Technology, Volume 38, Issues 4–5, 1998, Pages: 131-1