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A Performance Extension Measurement Analysis Model of Enterprise Green Technology Innovation based on Extension Theory

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Abstract

Green technology innovation is the critical path for enterprises to achieve sustainable development. However, corporate green technology innovation in most cases is affected and constrained by multiple factors. It is featured by multi-factor, multi-target, multi-layer and fuzzy uncertainty, etc. Thus it is of great importance to measure and analyze the performance of corporate green technology innovation. To this end, this paper aims to study the performance measurement of corporate green technology innovation and proposes a performance analysis model based on extension theories for corporate green technology innovation. First, the model analyzed relevant factors that influence performance measurement analysis of corporate green technology innovation. Then, based on the analysis, it established the performance measurement analysis index system of corporate green technology innovation. Meanwhile, the model tried to normalize the different types of measurement analysis indexes after which corresponding classical fields and controlled fields were obtained. It then calculated the extension distances and the extension dependencies between different measurement analysis indexes as well as the classical fields and the controlled fields. The size of the extension dependency revealed the ability levels of corporate green technology innovation. Lastly, the model was tested by specific cases.

Keywords: *green technology innovation, performance analysis, extension theory, index system, measure model*

1. Introduction

Along with the rapid development of science and technology, energy scarcity and environmental degradation are getting severer. When pursuing economic profits, corporates should consider more about the coordinative development of economy, society and environment. Therefore, green technology innovation, as a critical path for companies to achieve sustainable development, is attracting more and more attention and has been widely studied [1-3]. The purpose of green technology innovation is to help corporates maximize economic profits and social benefits and keep favorable sustainable development capacity under the following conditions: 1) save as much energy as possible; 2) save as much raw materials as possible; and 3) reduce environmental pollution. The essence of performance measurement analysis of corporate green technology innovation is to help science and technology enterprises maintain a favorable and healthy development [4-5]. The analysis of corporate green technology innovation capacity mainly evaluates their economic information, environmental benefit and social benefit, etc. So far, some scholars have conducted researches about the performance measurement analysis of green technology innovation and acquired some valuable insights [6-9]. Nevertheless, the existing methodologies often ignore the fuzzy uncertain measure

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information obtained during the performance measurement analysis process of green technology innovation. Although some methodologies adopt fuzzy analytical method to analyze the performance measurement of green technology innovation, they choose to generate accurate magnitudes of specific measure indexes before the measurement analysis. Strictly speaking, this is not genuinely fuzzy measurement analysis and cannot reflect the relationship between fuzzy indexes effectively. As a result, these methodologies have certain limitations. On the basis of existing research results, this thesis proposes an improved performance extension measurement analysis model of corporate green technology innovation from the perspective of extension theory.

2. The Performance Measurement Analysis Index System of Corporate Green Technology Innovation

The performance of corporate green technology innovation is influenced by various factors. It has features of multi-factor, multi-target, multi-layer, fuzzy uncertainty and dynamic, *etc*. Currently there is still no unified design philosophy of selecting measurement analysis indexes in the research field of performance measurement analysis index system design of corporate green technology innovation. Different scholars have different understandings about it. The author of this thesis thinks that the selection of indexes should ensure objectivity, accuracy and effectiveness of performance analysis results and it should also be able to conduct comprehensive performance measurement analysis from multiple perspectives and dimensions. This thesis presents a brand new performance measurement analysis index system of corporate green technology innovation as is demonstrated in Table 1. It is expected that this system can evaluate performance of corporate green technology innovation effectively, objectively, comprehensively and scientifically.

Table 1. Performance Measurement Analysis Index System of Corporate Green Technology Innovation

System layer	Criterion layer	index layer
Performance measurement analysis index system of corporate green technology innovation A	green innovation research and development capacity A_1	number of patents owned a_{11}
		innovation development cycle a_{12}
		Independent research and development rate a_{13}
		Training and learning ability a_{14}
	green innovation implementation capacity A_2	level of green equipment a_{21}
		level of green technology a_{22}
		proportion of professional green technology personnel a_{23}
	green innovation management capacity A_3	Entrepreneur's green innovation consciousness a_{31}
		Rationality of innovation mechanism a_{32}
		Rationality of innovation mechanism a_{33}
		Rationality of organizational structure a_{34}

	green innovation marketing capacity A_4	market share a_{41}
		capacity of maintaining market share a_{42}
		Return on marketing a_{43}
	green innovation input capacity A_5	input-output ratio a_{51}
		Conversion rate of scientific and technical achivements a_{52}
		invested cost a_{53}
	green innovation development potential A_6	Intensity of green innovation input a_{61}
		High-tech projects of green cooperation a_{62}
		Conversion cycle of green technology a_{63}

3. Performance Extension Measurement Analysis Model of Corporate Green Technology Innovation

3.1. Classical Field Matter Elements of Measurement Analysis Indexes

Performance of corporate green technology innovation needs to be analyzed based on practical situation of corporate development. Hypothetically, there are m measurement analysis indexes that are obtained based on relevant research analysis and expert opinions in this field. And every index has n performance measurement analysis scales of corporate green technology innovation. Then the j th scale classical field matter element model of measurement analysis index is $\boldsymbol{R}_j$:

$$\boldsymbol{R}_j = \begin{bmatrix} O_j & C_{1j} & V_{1j} \\ & \vdots & \vdots \\ & C_{ij} & V_{ij} \\ & \vdots & \vdots \\ & C_{mj} & V_{mj} \end{bmatrix} = \begin{bmatrix} O_{ij} & C_{1j} & \left[\left\langle v_{1j}^a, v_{1j}^b \right\rangle, w_{1j}\right] \\ & \vdots & \vdots \\ & C_{ij} & \left[\left\langle v_{ij}^a, v_{ij}^b \right\rangle, w_{ij}\right] \\ & \vdots & \vdots \\ & C_{nj} & \left[\left\langle v_{mj}^a, v_{mj}^b \right\rangle, w_{mj}\right] \end{bmatrix} \tag{1}$$

In the formula above, $V_{ij} = \left[\left\langle v_{ij}^a, v_{ij}^b \right\rangle, w_{ij}\right]$ refers to the characteristic value interval of the jth measurement analysis scale regarding to the ith measurement analysis index, which is the performance measurement analysis scale classical field of corporate green technology innovation of this index. And it satisfies $v_{ij}^a \le v_{ij}^b$, $1 \le i \le m$, $1 \le j \le n$.

3.2 Controlled Field Matter Elements of Measurement Analysis Indexes

On the basis of constructing classical field matter elements of different measurement analysis indexes, controlled field matter elements of different measurement analysis indexes can also be constructed.

If there is:

$$V_{oj} = \left[\left\langle v_{oj}^{a}, v_{oj}^{b} \right\rangle, w_{oj} \right] = \left[\left\langle \min_{1\le j\le n}\left(v_{ij}^{a}\right), \max_{1\le j\le n}\left(v_{ij}^{b}\right) \right\rangle, w_{ij} \right] \tag{2}$$

Then controlled field matter element model of measurement analysis index $\boldsymbol{R}_{oi}$ is:

$$\boldsymbol{R}_{oj} = \begin{bmatrix} O_{oj} & C_{1o} & V_{1o} \\ & \vdots & \vdots \\ & C_{io} & V_{io} \\ & \vdots & \vdots \\ & C_{mo} & V_{mo} \end{bmatrix} = \begin{bmatrix} O_{oj} & C_{1o} & \left[\left\langle \min_{1\le j\le n}\left(v_{1j}^{a}\right), \max_{1\le j\le n}\left(v_{1j}^{b}\right) \right\rangle, w_{1j} \right] \\ & \vdots & \vdots \\ & C_{io} & \left[\left\langle \min_{1\le j\le n}\left(v_{ij}^{a}\right), \max_{1\le j\le n}\left(v_{ij}^{b}\right) \right\rangle, w_{ij} \right] \\ & \vdots & \vdots \\ & C_{mo} & \left[\left\langle \min_{1\le j\le n}\left(v_{mj}^{a}\right), \max_{1\le j\le n}\left(v_{mj}^{b}\right) \right\rangle, w_{mj} \right] \end{bmatrix} \tag{3}$$

3.3. Processing Performance Measurement Analysis Indexes of Green Technology Innovation

It can be seen from the performance measurement analysis index system of corporate green technology innovation that among the indexes, some are quantitative which can be described precisely and some are qualitative which contain fuzzy information. The latter ones cannot be described by exact numbers and have fuzzy uncertainties. Their values can only be described by means of fuzzy memberships or fuzzy intervals. Meanwhile, some indexes are of benefit type and some are of cost type. In order to unify all the indexes, it is necessary to standardize them. To get a generalized description of the indexes, the paper assumes that all the indexes are fuzzy interval magnitudes while exact point values are exceptions of fuzzy interval magnitudes.

If the performance measurement analysis index i is a reverse index, and its corresponding magnitude is $V_{ij} = \left\langle v_{ij}^{a}, v_{ij}^{b} \right\rangle$, then the corresponding magnitude of the transformed positive index of i is U_{ij}:

$$U_{ij} = \left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle = \left\langle \min_{1\le j\le n}\left(v_{ij}^{a}\right) / v_{ij}^{a}, \min_{1\le j\le n}\left(v_{ij}^{a}\right) / v_{ij}^{b} \right\rangle \tag{4}$$

And if i is positive index, and its corresponding magnitude is $V_{ij} = \left\langle v_{ij}^{a}, v_{ij}^{b} \right\rangle$, then its corresponding magnitude of the transformed reverse index is U_{ij}:

$$U_{ij} = \left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle = \left\langle v_{ij}^{a} / \max_{1\le j\le n}\left(v_{ij}^{b}\right), v_{ij}^{b} / \max_{1\le j\le n}\left(v_{ij}^{b}\right) \right\rangle \tag{5}$$

If i is, and its corresponding magnitude is $V_{ij} = \left\langle v_{ij}^{a}, v_{ij}^{b} \right\rangle$, then its corresponding magnitude of the transformed positive index is U_{ij}:

$$U_{ij} = \left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle = \left\langle \min_{1\le j\le n}\left(v_{ij}^{a}, v_{ij}^{o}\right) / \max_{1\le j\le n}\left(v_{ij}^{b}, v_{ij}^{o}\right), \min_{1\le j\le n}\left(v_{ij}^{b}, v_{ij}^{o}\right) / \max_{1\le j\le n}\left(v_{ij}^{b}, v_{ij}^{o}\right) \right\rangle \tag{6}$$

3.4. Extension Dependency of Performance Measurement Analysis of Green Technology Innovation

If the current magnitude of corporate green technology innovation regarding to the measurement analysis index i is the point value V_{ip}, then the extension distance between the magnitude and the jth measurement analysis scale is ρ_{ij}^{p}:

$$\rho_{ij}^{p} = \left| V_{ip} - \frac{u_{ij}^{a} + u_{ij}^{b}}{2} \right| - \frac{u_{ij}^{b} - u_{ij}^{a}}{2} \qquad (7)$$

If V_{ip} is the middle point of the interval $\left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle$, then V_{ip} is the closest from the jth measurement analysis scale, which means that ρ_{ij}^{p} is the smallest.

If the current magnitude of corporate green technology innovation regarding to the measurement analysis index i is the interval magnitude $V_{ip} = \left\langle v_{ip}^{a}, v_{ip}^{b} \right\rangle$, then the extension distance between the interval magnitude and the jth measurement analysis scale is ρ_{ij}^{p} as:

$$\rho_{ij}^{p} = \frac{1}{2}\left(\left| v_{ip}^{a} - \frac{u_{ij}^{a} + u_{ij}^{b}}{2} \right| + \left| v_{ip}^{b} - \frac{u_{ij}^{a} + u_{ij}^{b}}{2} \right| \right) - u_{ij}^{b} + u_{ij}^{a} \qquad (8)$$

Particularly, when the optimal point of V_{ip} is not at the middle point of the interval $\left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle$, if it satisfies $v_{ij}^{o} \in \left\langle u_{ij}^{a}, \frac{u_{ij}^{a} + u_{ij}^{b}}{2} \right\rangle$, then the current extension distance between the measurement analysis index i of corporate green technology innovation and the jth measurement analysis scale ρ_{ij}^{p} is:

$$\rho_{ij}^{p} = \begin{cases} u_{ij}^{a} - v_{ip}^{a} & \frac{v_{ip}^{a} + v_{ip}^{b}}{2} \le u_{ij}^{a} \\ \frac{\left(u_{ij}^{b} - v_{ij}^{o}\right) * \left(v_{ip}^{a} - u_{ij}^{a}\right)}{u_{ij}^{a} - v_{ij}^{o}} & \frac{v_{ip}^{a} + v_{ip}^{b}}{2} \in \left\langle u_{ij}^{a}, v_{ij}^{o} \right\rangle \\ v_{ip}^{b} - u_{ij}^{b} & \frac{v_{ip}^{a} + v_{ip}^{b}}{2} \ge v_{ij}^{o} \end{cases} \qquad (9)$$

If the condition of $v_{ij}^{o} \in \left\langle \frac{u_{ij}^{a} + u_{ij}^{b}}{2}, u_{ij}^{b} \right\rangle$ is satisfied, then current extension distance between the measurement analysis index i of corporate green technology innovation and the jth measurement analysis scale ρ_{ij}^{p} is:

$$\rho_{ij}^{p} = \begin{cases} u_{ij}^{a} - v_{ip}^{a} & \frac{v_{ip}^{a} + v_{ip}^{b}}{2} \le v_{ij}^{o} \\ \frac{\left(u_{ij}^{a} - v_{ij}^{o}\right) * \left(u_{ij}^{b} - v_{ip}^{b}\right)}{u_{ij}^{b} - v_{ij}^{o}} & \frac{v_{ip}^{a} + v_{ip}^{b}}{2} \in \left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle \\ v_{ip}^{b} - u_{ij}^{b} & \frac{v_{ip}^{a} + v_{ip}^{b}}{2} \ge u_{ij}^{b} \end{cases} \qquad (10)$$

Thus, the current extension dependency function K_{ij} of the measurement analysis index i of corporate green technology innovation capacity and the jth measurement analysis scale is:

$$K_{ij} = \begin{cases} -\rho_{ij}^{p} / \left| u_{ij}^{a} - u_{ij}^{b} \right| & \left\langle v_{ip}^{a}, v_{ip}^{b} \right\rangle \in \left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle \\ 0 & \rho_{ij}^{o} - \rho_{ij}^{p} = 0 \\ \rho_{ij}^{p} / \left(\rho_{ij}^{o} - \rho_{ij}^{p} \right) & \left\langle v_{ip}^{a}, v_{ip}^{b} \right\rangle \notin \left\langle u_{ij}^{a}, u_{ij}^{b} \right\rangle \end{cases} \tag{11}$$

In the function above, ρ_{ij}^{o} represents the current extension distance between the measurement analysis index i and its corresponding controlled field matter element.

Taking into account that different measurement analysis index might have different weight w_i, the weighting extension dependency Ψ_j between the measurement analysis indexes of corporate technology innovation and the jth measurement analysis scale is:

$$\Psi_j = \sum_{i=1}^{m} \left(w_i * K_{ij} \right) \tag{12}$$

Then according to the size of weighting extension dependency Ψ_j, the current performance level of corporate green technology innovation can be obtained. The rule of optimal selection is as follows:

$$\Psi_o = max\left(\Psi_1, \Psi_2, \cdots, \Psi_n \right) = \Psi_k \tag{13}$$

The performance measurement analysis level of corporate green technology innovation k which corresponds to Ψ_k is the current performance level of corporate green technology innovation. By doing so, a precise quantitative description of the current performance level of corporate green technology innovation is realized. The results can offer support and guidance to the following corporate green sustainable development.

3.5. Model and Algorithm Implementation

Taken all information mentioned above into account, there are seven specific steps to implement the performance extension measurement analysis model of corporate green technology innovation and they are as follow:

Step 1: On the basis of the implementing of corporate green technology, establish the performance measurement analysis index system of corporate green technology innovation;

Step 2: With the guidance of the index system above, construct classical field matter elements and controlled field matter elements of different types of measurement analysis indexes;

Step 3: Standardize different types of measurement analysis indexes to generate unified indexes;

Step 4: Collect performance measurement analysis index data of current corporate green technology innovation through research and analysis and then standardize all of them;

Step 5: Calculate the extension distance between the measurement analysis index data of current corporate green technology innovation and the corresponding classical field matter elements and controlled field matter elements;

Step 6: Calculate the extension dependency function and weighting extension dependency between the measurement analysis index data of current corporate green technology innovation and the corresponding classical field matter elements;

Step 7: Based on the size of the weighting extension dependency, find out the level of current corporate green technology innovation and offer support and guidance to the following corporate green sustainable development

4. Case Analysis and Testing

In the following chapter, the performance measurement analysis of a specific company's green technology innovation will be studied to further explain and analyze the model and algorithm introduced in this thesis. By soliciting expert opinions and corporate researches, classical fields in the performance measurement analysis index system of corporate green technology innovation are obtained and relevant indexes are collected. Specific results are demonstrated in Table 2.

Table 2. Performance Measurement Analysis Indexes of Corporate Green Technology Innovation

Criterion layer	weight	index layer	weight	Measurement level			Measured value
				I LEVEL	II LEVEL	III LEVEL	
green innovation research and development capacity A_1	0.20	number of patents owned a_{11}	0.15	0-10	10-20	20-40	16
		innovation development cycle a_{12}	0.30	1.0-2.0	0.5-1.0	0-0.5	0.4-0.6
		Independent research and development rate a_{13}	0.30	0-0.2	0.2-0.5	0.5-1.0	0.6
		Training and learning ability a_{14}	0.25	0-0.4	0.4-0.7	0.7-1.0	0.8
green innovation implementation capacity A_2	0.20	level of green equipment a_{21}	0.35	0-0.4	0.4-0.7	0.7-1.0	0.6
		level of green technology a_{22}	0.35	0-0.4	0.4-0.7	0.7-1.0	0.65-0.75
		proportion of professional green technology personnel a_{23}	0.30	0-0.2	0.2-0.4	0.4-1.0	0.3
green innovation management capacity A_3	0.12	Entrepreneur's green innovation consciousness a_{31}	0.20	0-0.4	0.4-0.7	0.7-1.0	0.8
		Rationality of innovation mechanism a_{32}	0.30	0-0.4	0.4-0.7	0.7-1.0	0.7-0.8
		Rationality of innovation mechanism a_{33}	0.20	0-0.5	0.5-0.8	0.8-1.0	0.8-0.9

		Rationality of organizational structure a_{34}	0.30	0-0.5	0.5-0.8	0.8-1.0	0.75-0.85
green innovation marketing capacity A_4	0.15	market share a_{41}	0.40	0-0.2	0.2-0.4	0.4-1.0	0.15
		capacity of maintaining market share a_{42}	0.30	0-0.5	0.5-0.8	0.8-1.0	0.4
		Return on marketing a_{43}	0.30	0-0.2	0.2-0.4	0.4-1.0	0.3
green innovation input capacity A_5	0.18	input-output ratio a_{51}	0.30	0-0.2	0.2-0.5	0.5-1.0	0.4
		Conversion rate of scientific and technical achievements a_{52}	0.40	0-0.2	0.2-0.5	0.5-1.0	0.6
		invested cost a_{53}	0.30	0-100	100-300	300-500	400
green innovation development potential A_6	0.15	Intensity of green innovation input a_{61}	0.30	0-0.5	0.5-0.8	0.8-1.0	0.95
		High-tech projects of green cooperation a_{62}	0.30	0-2	2-5	5-10	4
		Conversion cycle of green technology a_{63}	0.40	2-4	1-2	0-1	0.8

Based on the extension distance calculation model introduced in the thesis, the extension distances between the performance measurement analysis indexes of the current corporate green technology innovation and related classical fields and controlled fields are obtained. The specific results are shown in Table 3.

Table 3. The Extension Distances of Performance Measurement Analysis of the Current Corporate Green Technology Innovation

index layer	Extension distance		
	I LEVEL	II LEVEL	III LEVEL
number of patents owned a_{11}	0.15	-0.1	0.1
innovation development cycle a_{12}	0	0.25	0.25
Independent research and development rate a_{13}	0.4	0.1	-0.1
Training and learning ability a_{14}	0.4	0.1	-0.1
level of green equipment a_{21}	0.2	-0.1	0.1
level of green technology a_{22}	0.3	0	0
proportion of professional green technology personnel a_{23}	0.1	-0.1	0.1

Entrepreneur's green innovation consciousness a_{31}	0.4	0.1	-0.1
Rationality of innovation mechanism a_{32}	0.35	0.05	-0.05
Rationality of innovation mechanism a_{33}	0.35	0.05	-0.05
Rationality of organizational structure a_{34}	0.30	0	0
market share a_{41}	-0.05	0.05	0.25
capacity of maintaining market share a_{42}	-0.1	0.1	0.4
Return on marketing a_{43}	0.1	-0.1	0.1
input-output ratio a_{51}	0.2	-0.1	0.1
Conversion rate of scientific and technical achivements a_{52}	0.4	0.1	-0.1
invested cost a_{53}	0.6	0.2	-0.2
Intensity of green innovation input a_{61}	0.45	0.15	-0.05
High-tech projects of green cooperation a_{62}	0.2	-0.1	0.1
Conversion cycle of green technology a_{63}	0.3	0.05	-0.05

On the basis of the extension dependency function calculation model introduced in the thesis, the extension dependency functions of the performance measurement analysis indexes of the current corporate green technology innovation and related classical fields are obtained. The specific results are shown in Table 4.

Table 4. The Extension Dependency Functions of the Performance Measurement Analysis Indexes of the Current Corporate Green Technology Innovation

index layer	Extension dependency functions		
	I LEVEL	II LEVEL	III LEVEL
number of patents owned a_{11}	-0.231	0.4	-0.200
innovation development cycle a_{12}	0	-0.333	-0.333
Independent research and development rate a_{13}	-0.500	-0.200	0.200
Training and learning ability a_{14}	-0.667	-0.333	0.333
level of green equipment a_{21}	-0.333	0.333	-0.200

level of green technology a_{22}	-0.500	0	0
proportion of professional green technology personnel a_{23}	-0.250	0.500	-0.250
Entrepreneur's green innovation consciousness a_{31}	-0.667	-0.333	0.333
Rationality of innovation mechanism a_{32}	-0.583	-0.083	0.167
Rationality of innovation mechanism a_{33}	-0.700	-0.100	0.25
Rationality of organizational structure a_{34}	-0.600	0	0
market share a_{41}	0.250	-0.250	-0.625
capacity of maintaining market share a_{42}	0.200	-0.200	-0.500
Return on marketing a_{43}	-0.250	0.250	-0.250
input-output ratio a_{51}	-0.333	0.333	-0.200
Conversion rate of scientific and technical achivements a_{52}	-0.500	-0.200	0.200
invested cost a_{53}	-0.750	-0.500	0.500
Intensity of green innovation input a_{61}	-0.900	-0.750	0.25
High-tech projects of green cooperation a_{62}	-0.333	0.333	-0.250
Conversion cycle of green technology a_{63}	-0.600	-0.200	0.200

Based on the extension dependency calculation model introduced in the thesis, the sequence of the extension dependency of the performance measurement analysis indexes of the current corporate green technology innovation is obtained:

$\Psi_o = (-0.412, -0.067, -0.019)$. From this sequence it can be seen that the current ability level of the corporate green technology innovation is Ψ_{III}, however, the difference between Ψ_{III} and Ψ_{II} is not obvious. Thus, targeted improvements to deal with the weak links are necessary so that the model is able to offer support and guidance for corporate green sustainable development in the future.

5. Conclusions

This paper, to deal with the existing problems of corporate green technology innovation, has proposed a performance extension measurement analysis model of corporate green technology innovation. This model standardizes different types of measurement analysis indexes via the establishment of a performance measurement analysis index system of corporate green technology innovation. Then it constructs corresponding classical field matter elements and the controlled field matter elements of relevant indexes after which the extension distances and extension dependencies of the corporate green technology innovation capacities and the classical field matter elements are calculated by the extension distance and dependency calculation model. The size of the extension dependency shows the capacity level of corporate green technology innovation. The model demonstrates well-defined physical significance and its calculation is simple, accurate and can easily be applied to computers. As a result, it can provide a new way of intelligent implementation for the measurement of corporate green technology innovation. Meanwhile, the testing results of the practical cases have proven that the proposed model and algorithm are effective.

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