Comprehensive Evaluation of Hydrogen Production from Coal Base on AHP & GRA-TOPSIS

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Research

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Abstract Coal is the cornerstone of China's energy. However, with the proposed goal of carbon peak and carbon neutral in China, coal enterprises are in urgent need of exploring the path of transformation and development. Coal to hydrogen is an important way to achieve sustainable development of the coal industry. In this paper, four hydrogen production technologies, including coal gasification, coke oven gas, electrolytic water and solar energy, are studied. A comprehensive evaluation model based on GRA-TOPSIS was constructed. Four kinds of hydrogen production technologies are evaluated and analyzed. The research shows that the coke oven gas is the most suitable hydrogen production technology for the transformation and development of coal enterprises. The evaluation model of hydrogen production technology in the transformation and development of coal enterprises constructed in this paper has a certain guiding effect on the technology selection of coal enterprises in the development of hydrogen industry.

Keywords Hydrogen production technology Comprehensive evaluation AHP GRA-TOPSIS
1 Introduction

On March 5 this year, the government work report stated that this year, China will make solid efforts to achieve a carbon peak and carbon neutrality, and formulate an action plan to achieve a carbon peak by 2030. Optimizing industrial structure and energy structure is the main means to promote carbon peak and carbon neutral in the overall realization of carbon neutral goal. In the past decade and for a period of time in the future, China's energy structure is still dominated by coal (Feng et al. 2019). Under the background of China's "carbon peak by 2030" and "carbon neutral by 2060" goals, large state-owned enterprises, especially energy enterprises, are facing the urgent need of low-carbon transformation, and hydrogen energy is one of the important directions of their transformation. It is of great significance to realize the efficient and clean utilization of coal resources, not only for the transformation and development of enterprises, but also for the acceleration of national carbon peak and carbon neutral work.

In 2016, the National Development and Reform Commission and the National Energy Administration issued the Action Plan for Innovation in Energy Technology Revolution (2016-2030), which listed hydrogen energy as one of the 15 key tasks of energy technology revolution, and hydrogen production from renewable energy and hydrogen fuel cell technology innovation as key tasks (National Development and Reform Commission, 2016). With the guidance of China's policies and the implementation of a large number of hydrogen energy projects, the hydrogen energy technology continues to break through, the industrial system is gradually improved, and
the development of the hydrogen energy field in China has accelerated into the
industrialization stage.

Meanwhile, China is rich in coal resources, and hydrogen production from coal is
the main form of hydrogen production in China (Yan, 2019), which can significantly
increase the added value of coal products (Chen et al. 2019).

However, hydrogen production technology is complex, and the transformation and
development of energy enterprises often require comprehensive consideration from
multiple aspects. Therefore, a comprehensive evaluation system model based on energy,
economy, environment, technology and society has been established based on the
comprehensive study of hydrogen technology selection of various hydrogen production
technologies. In view of the mainstream mature hydrogen production technology and
the consideration of renewable energy utilization, four hydrogen production
technologies including coal gasification hydrogen production, coke oven gas hydrogen
production, water electrolysis hydrogen production and solar energy hydrogen
production were selected for comprehensive evaluation, in order to obtain the optimal
hydrogen production technology through hydrogen energy transformation and
upgrading of energy enterprises. It is of great significance to the transformation and
upgrading of coal industry and coal chemical industry which take hydrogen as the
breakthrough point.

2 Literature review

Technical economy is the internal driving force in the development of coal
industry transformation, there are many influence factors in technology economy, the
need for multiple factors and changes impact on the economy analysis (Zhang et al. 2017), to build the corresponding technical and economic evaluation model, for many factors, at the same time try to realize the evaluation process of standardization and automation. In order to facilitate the comparative analysis between evaluation results and between evaluation results and samples (Hu et al. 2017)

Deciding how to assess hydrogen production technology scientifically is a problem that needs to be handled. In general, there are two types of methods to solve this problem: 1) synthetical assessment approaches, e.g., weighted sum, analytical hierarchy process (AHP) (Saaty, T. L., 2001), technique for order performance by similarity to ideal solution (TOPSIS) (Chen, 2000), AHP and evidential reasoning, AHP and TOPSIS, and fuzzy synthetic evaluation and 2) the approaches based on theory of life cycle assessment (Prince-Richard, S. et al., 2005; Konstantopoulou, P. et al., 2005).

Li Yiyang (Li, 2010) established a model applicable to the evaluation system of hydrogen production technology by using the life cycle evaluation theory, which included the evaluation of material consumption, energy consumption, environment and economy. The research results showed that the comprehensive benefit of hydrogen production from biomass supercritical water gasification was the highest. Luo Bing (Luo et al., 2019) introduced the two main methods of hydrogen production from biomass, namely thermalization method and microbial conversion method, from the aspects of hydrogen production mechanism, technological process, existing problems and development prospects. After comparing and understanding several hydrogen
production methods, it is found that the hydrogen production technology from biomass is the most efficient and environmental protection technology, which can not only optimize the fuel structure and improve the air pollution status in China, but also reduce the secondary pollution caused by the unreasonable utilization mode at present. Xie Xinshuo (Xie et al., 2018) uses traditional hydrogen production technologies (gasification hydrogen production, natural gas hydrogen production, etc.) and new hydrogen production technologies (thermochemical hydrogen production, renewable energy power generation hydrogen production, biomass gasification hydrogen production, etc.) as the object, the research on its life cycle assessment shows that wind power hydrogen production technology has the best environmental protection, and nuclear thermochemical hydrogen production has the potential for large-scale application in the future. Niu Jiao (Niu, 2007) established an evaluation model based on an improved fuzzy evaluation method. The hydrogen production technology with the highest comprehensive benefit is natural gas steam reforming hydrogen production technology, and the hydrogen production technology with the lowest comprehensive benefit is hydrogen production by electrolysis of water.

The above research results are a single or multi-dimensional systematic evaluation of various hydrogen-making technologies by experts and scholars, but the actual application of hydrogen-making technology in a certain field has not been fully considered. Under the current background of "carbon peak and carbon neutrality" and restricted by foreign technology, the traditional 3E evaluation model (Energy, Economic, Environment) (Deng et al., 2006) cannot better reflect the influence of
technical factors and social factors. Therefore, coal enterprises urgently need a set of scientific, comprehensive and targeted evaluation indicators and evaluation methods. Therefore, this article adds two dimensions of technology and society to the analysis of the 3E model, that is, comprehensive analysis of each hydrogen production technology from the five dimensions of energy, economy, environment, technology and society. And combined with a specific mining group for practical applications.

3 Impact analysis and Model Construction

3.1 Impact analysis

Considering the complexity of hydrogen production technology, in this section, we provide theoretical support for the model establishment in Chapter 3.2 by analyzing the influencing factors at five different levels of hydrogen production technology.

3.1.1 Energy influence factors of hydrogen technology

The influence factor of energy dimension is the first consideration in the evaluation of hydrogen technology, whether it is coal hydrogen, solar hydrogen, electrolyte hydrocarbon, coke oven gas hydrogen can not be separated from energy. The influence of hydrogen technology in the energy dimension is mainly reflected in the influence of resource suitability, hydrogen efficiency and the proportion of end-energy consumption change and the proportion of clean energy consumption increase. Therefore, the applicability of resources, hydrogen efficiency and the proportion of changes in end-use energy consumption are introduced as indicators in energy.

(1) Resource applicability. Refers to the application of hydrogen technology,
whether the use of raw materials have special requirements, such as electrolytic water hydrogen needs to contain electrolyte water, or coal hydrogenation furnace on the coal moisture content, sulfur content, ash content and other requirements. The applicability of various hydrogen production technology resources is divided into 5 grades according to the most applicable, more applicable, less applicable, not applicable, as shown in Table 1. The greater the resource suitability value, the better.

Table 1

3.1.2 Economic influence factors of hydrogen production technology

Compared with other energy sources, the cost gap between various types of hydrogen technology is large. At the same time, in order to simplify the calculation, the investment cost of hydrogen plant construction is used as a separate index. (1) The cost per unit of hydrogen production. Refers to the capital investment required to produce hydrogen per unit after the application of the technology. (2) Investment costs. Refers to the investment cost of hydrogen plant construction, including equipment purchase, site purchase and site construction input. (3) Gross enterprise product. Refers to the annual gross domestic product of a hydrogen plant.

3.1.3 Environmental influence factors of hydrogen production technology

In the environmental impact of the main performance in the "three waste", that is, "emissions, waste residue, waste water." The most significant environmental impact is the emission of exhaust gases, so in the subsysysss system of environmental impact factors, and continue to study its CO₂, NOₓ emissions, so as to better reflect
environmental impact factors. (1) Wastewater emissions. Refers to the discharge of wastewater from hydrogen prepared in the application of hydrogen technology. (2) Slag emissions. Refers to the solid waste emissions from the preparation of hydrogen in the application of the hydrogen technology. (3) CO$_2$ emissions. The collection of CO$_2$ and NO$_X$ emissions is focused on emissions from emissions.

3.1.4 Technology influence factors of hydrogen production

The main connotation of hydrogen production technology is the advanced degree of technology, the hydrogen purity index reflects the advanced degree of technology, and the proportion of scientific researchers indirectly reflects the development level of high and new technology. Secondly, external dependence and technology maturity of technology are the important basis for the long-term development of China's coal enterprises (Feng, 2003). In addition, technology maturity is the prerequisite for the long-term development of technology.

(1) Technical reliability. The reliability of technology means that the longer and more complex the process of a technology during the production preparation phase, the less reliable the technology will be. Therefore, the applicability of the four hydrogen production technology resources is divided into 5 grades according to very reliable, more reliable, more reliable, less reliable and unreliable. By qualitative analysis of the length and complexity of the four hydrogen-making technology processes to determine the reliability of each hydrogen-making technology, and give the corresponding value. The greater the value of resource suitability, the better. As shown in Table 1.

(2) Purity of hydrogen production. The percentage by volume of hydrogen
produced by the four hydrogen production techniques prior to PSA. It reflects the adaptability of hydrogen production technology to hydrogen energy terminal use.

(3) Proportion of scientific researchers. Refers to the proportion of researchers in the hydrogen production technology system, which indirectly reflects the advanced degree of the hydrogen production technology. Hydrogen production technology has the characteristics of high professional requirements, both management and technical work need a group of high-quality professional and technical personnel.

(4) The external dependence of technology. This index reflects the adaptability of hydrogen production technology to production and the degree of dependence of hydrogen production technology on foreign technologies.

Table 2

(5) Technical maturity. Refers to the current development of hydrogen technology at the current stage, but also an important basis for the selection of hydrogen technology. Generally divided into small test, pilot, industrial demonstration, industrial application and commercialization.

Table 3

3.1.5 Social influence factors of hydrogen production technology

In this paper, the current strength of national policy support to reflect the country's leading situation of hydrogen technology, that is, the applicability of policy. In addition, for such a new energy society to its recognition is also an important indicator to measure its social. However, due to the late start of hydrogen energy in China, hydrogenation station, hydrogen vehicles, hydrogen technology and other nouns, the public contact
relatively little, it is difficult to have a good understanding of it. Therefore, experts in
the field of hydrogen energy are selected as the recognition of hydrogen technology as
its social evaluation index.

(1) The applicability of the policy. By studying China's national policies and
standards related to energy, environment and society, the degree of fit between
hydrogen technology and policy reflects the applicability of the policy. As shown in
Table 1.

(2) Social recognition. Hydrogen energy as a new energy, social recognition of it
is also an important measure of its social. As shown in Table 1.

3.2 Model Construction

As a new energy source, hydrogen production technology has abundant sources of
raw materials and complex hydrogen production processes. There are relatively few
researches on the development of hydrogen energy technology by coal companies. It is
reasonable to plan and deploy various technologies in different time periods and regions
For issues such as the order of development of hydrogen production, it is necessary to
conduct an objective and scientific evaluation of various hydrogen production
technologies. Therefore, the premise of the evaluation is to establish a scientific and
reasonable evaluation index system.

3.2.1 Social influence factors of hydrogen production technology

Based on the analysis of influencing factors in Chapter 3.1, the following
Comprehensive Evaluation Index system is established

Table 4
3.2.2 Standardized processing of indicators

(1) Standardized treatment of indicators. In the comprehensive evaluation, due to the existence of qualitative and quantitative different types of indicators, or the value gap between indicators, different scale and other issues, resulting in the original indicators in the calculation and analysis of the impact of the accuracy of evaluation. The presence of indicators with high numerical values has a greater impact on the whole, and the role of indicators with lower numerical levels is relatively weakened. Therefore, we need to standardize all indicators to improve the accuracy of the results. In this paper, the indicator is standardized by the extreme difference method.

(2) Consistent processing of indicator types. In the comprehensive evaluation of multiple indicators, some are indicators with higher indicator values, called positive indicators, and some are indicators with smaller indicator values that evaluate the better, called reverse indicators. First of all, the indicator must be trended, generally the reverse indicator into a positive indicator, which is the consistent processing of the indicator type.

3.2.3 Comparison based on AHP&GRA-TOPSIS

The article chooses the analytic hierarchy process to determine the weights. There are two advantages to determine the weights through the analytic hierarchy process. First, the data requirements for determining the weights through the analytic hierarchy process are relatively small, and it is relatively simple in actual operation. The indicators are analyzed systematically to improve accuracy. Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method, proposed by American scholar Saaty
in 1970. He can transform complex multi-objective problems into single-objective problems, using quantitative and qualitative analysis methods, so he is suitable for solving multi-objective analysis problems.

In order to overcome the shortcomings of gray correlation and TOPSIS method, this paper combines the characteristics of the two methods and integrates the two methods organically. Considering that the traditional TOPSIS method evaluates the schemes according to the Euclidean distance, sometimes it cannot fully reflect the pros and cons of the schemes, and it cannot reflect the difference between the changing trends of various factors within the sample and the ideal sample. Therefore, this paper constructs the GRA-TOPSIS model, makes full use of the characteristics of the gray correlation degree to reflect the situation change between the plan data curves and the similarity of the curve geometry, combines the Euclidean distance and the gray correlation degree, and constructs one from the two aspects of position and shape. This new relative closeness makes up for the shortcomings of the TOPSIS method. This method has clear thinking, simple calculation and strong practicability. The key calculation steps are as follows:

1. **Dimensionless Procession of indicators:**
   
   The data outline of each indicator is not consistent, in order to eliminate the impact of the data outline and the convenience of research to standardize the data, in which the positive indicator refers to the evaluation results play a positive role in promoting the indicators, such indicators belong to the larger the better indicators. Conversely, negative indicators refer to indicators that play a negative role in promoting evaluation
results, and are among the smaller and better indicators.

Positive indicator:

\[ x_{ij}^* = \frac{x_{ij} - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} \]  

(1)

Negative indicator:

\[ x_{ij}^* = -\frac{x_{\text{max}} - x_{ij}}{x_{\text{max}} - x_{\text{min}}} \]  

(2)

(2) Build a decision matrix:

M evaluation objects and N evaluation indexes are set, and the original decision matrix is 

\[ X = \begin{pmatrix} x_{ij} \end{pmatrix}_{m \times n} \]

(3) Weighted normalized matrix of evaluation indicators:

\[ Z = \begin{pmatrix} \omega_j y_{ij} \end{pmatrix}_{m \times n} = \begin{bmatrix} \omega_1 y_{11} & \omega_2 y_{12} & \cdots & \omega_n y_{1n} \\ \omega_1 y_{21} & \omega_2 y_{22} & \cdots & \omega_n y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_1 y_{m1} & \omega_2 y_{m2} & \cdots & \omega_n y_{mn} \end{bmatrix} \]  

(3)

(4) Determines the positive-ideal solution and negative-ideal solutions of the weighted normalization matrix:

\[ Z^+ = (Z_1^+, Z_2^+, \ldots, Z_n^+) = \omega \]  

(4)

\[ Z^- = (Z_1^-, Z_2^-, \ldots, Z_n^-) = 0 \]

In this Formula:

\[ Z_j^+ = \max Z_{ij} = \omega_j, \quad Z_j^- = \min Z_{ij} = 0, \quad j \in N \]

(5) Calculate the Euclid distance between the schemes and the positive-ideal solution and negative-ideal solutions:

\[ d_i^+ = \sqrt{\sum_{j=1}^{n} (Z_{ij} - Z_j^+)^2}; \]  

(5)

\[ d_i^- = \sqrt{\sum_{j=1}^{n} (Z_{ij} - Z_j^-)^2}; \]

(6) Calculate the gray correlation coefficient matrix between each scheme and the
positive ideal solution and the negative ideal solution $R^+$ and $R^-$. 

$$R^+ = (r_{ij}^+)^n_{i=1}$$, $R^- = (r_{ij}^-)^n_{i=1}$  

$$r_{ij}^+ = \frac{\min_j \min_i |z_i^j - z_o| + \varepsilon \max_j \max_i |z_i^j - z_o|}{|z_i^j - z_o| + \varepsilon \max_j \max_i |z_i^j - z_o|}$$ (6)  

$$r_{ij}^- = \frac{\min_j \min_i |z_i^j - z_o| + \varepsilon \max_j \max_i |z_i^j - z_o|}{|z_i^j - z_o| + \varepsilon \max_j \max_i |z_i^j - z_o|}$$ (7)  

In this Formula: $\varepsilon \in (0,1)$ is the resolution factor, experience is valued 0.5. 

(7) Calculate the gray correlation between each scheme and the positive and negative ideal solutions: 

$$r^+ = \frac{1}{n} \sum_{j=1}^n r_{ij}^+$$, $$r^- = \frac{1}{n} \sum_{j=1}^n r_{ij}^-$$ (9)  

(8) Euclid distance and correlation degree are dimensionless: 

$$D_i^+ = \frac{d_i^-}{\max d_i^-}, D_i^- = \frac{d_i^-}{\max d_i^-}$$  

$$R_i^+ = \frac{r_i^+}{\max r_i^+}, R_i^- = \frac{r_i^-}{\max r_i^-}$$ (10)  

(9) Combine dimensionless distance and correlation degree. The greater the $D_i^+$ and $R_i^+$, the closer the scheme is to the positive ideal solution. The larger the $D_i^-$ and $R_i^-$ is, the farther away the scheme is from the positive ideal solution. Therefore, the combination formula can be determined as follows: 

$$P_i^+ = \alpha D_i^+ + \beta R_i^+, P_i^- = \alpha D_i^- + \beta R_i^-$$ (11)  

In this Formula: $\alpha = \beta = \frac{1}{2}$. 

(10) Relative closeness of the construction scheme: 

$$Q_i^- = \frac{P_i^-}{P_i^++P_i^-}$$ (12)  

(11) The relative closeness degree $Q_i^-$ of each scheme was calculated and ranked.
The greater the relative closeness degree was, the closer it was to 1, indicating the higher the evaluation of the scheme was; On the contrary, the lower the relative closeness, the worse the scheme.

In order to explain the model more intuitively, the model frame diagram is shown as follows:

Fig. 1

4 Application

In this section, the use of AHP&Gray Correlation Ideal Solution is illustrated by evaluating the hydrogen production technologies in a certain mining group.

4.1 Overview of a mining group

A mining group is a modern enterprise group that spans regions and industries. Its Jindong coal base is a production base that guarantees the supply of high-quality anthracite coal in my country. The coals are mainly anthracite, lean coal and lean coal. Its resource reserves are rich, the coal quality is good, the coal seam storage conditions and mining technology conditions are relatively superior, and the production capacity. The utilization rate and coal recovery rate are generally high. At present, we are committed to the development of the hydrogen energy industry and judge the value, influence or the degree of realization of the expected goals of various hydrogen production technologies. And through evaluation and analysis of various hydrogen production technologies suitable for the development of enterprises, the development direction of hydrogen production technology and the feasibility of emerging hydrogen
production technologies are predicted, and the basis for the deployment of related
technologies for enterprises is provided.

4.2 Comparative analysis

There are currently four types of hydrogen production technologies to be selected.

Through data collection, AHP and GRA-TOPSIS have comprehensively evaluated
hydrogen production technologies suitable for the transformation and development of
coal enterprises.

4.2.1 Data Collection

The data and related information come from enterprises such as experts, scholars
and university experts with professional knowledge and management experience.

Through the questionnaires collected in this study, 11 experts were consulted, and the
comparison matrix for each standard was matched and used to evaluate the decision
matrix hydrogen production technology. The four alternatives can make the evaluation
results more in line with the development of the mining group.

4.2.2 Hierachical structure of hydrogen production technologies Evaluation

Based on the related literature and expert interview, five kinds of dimensions and
their parameters have been given. We establish a hierachical structure for their
comprehensive evaluation, which is shown in Table 7 and includes three levels, goal,
criterion, and factor. Goal level (G) is Comprehensive evaluation (G1); criterion level (A)
is Energy (A1), Economy (A2), Environment (A3), Technology (A4), and Social
(A5) properties. Energy property includes four factors, Resource suitability
(b11), Hydrogen production efficiency (b12), The proportion of end-user energy
consumption changes (b13), increased share of clean energy consumption (b14).

Economy property includes three factors, The cost per unit of hydrogen production (b21), Investment costs (b22), Gross domestic product (b23). Environmental property includes four factors, Slag emissions (b32), CO2 emissions (b33), NOX emissions (b34), Technical reliability (b41), Hydrogen purity (b42). Technology property includes five factors, Technical reliability (b41), Hydrogen purity (b42), The proportion of researchers (b43), External dependence of technology (b44), Technical maturity (b45). Social property includes two factors, Policy applicability (b51) and Social recognition (b52).

4.2.3 Hierarchy Factors of hydrogen production technologies Evaluation

(1) When calculating the weight of the first layer, they are scored by an expert jury, starting from the five levels of energy, economy, environment, technology, and society, and comparing their impact on the hydrogen production technology plan two by one, so as to determine the weight of the indicator. The result of the judgment matrix of the first layer is shown in Table 5.

Table 5

According to the calculation results, energy and environment are the first two factors to be considered in the selection of hydrogen production technology scheme, and their weights are 0.37 and 0.28 respectively. The second is economy and technology, with weights of 0.17 and 0.11. Finally, social, with a ratio of 0.07. The index weight vector of the first layer is $W_1 = [0.37, 0.17, 0.28, 0.11, 0.07]$.

By the same method, the weight of the second layer $W_2$ is calculated through the
judgment matrix and the comprehensive weight of each index is obtained, as shown in Table 6.

### Table 6

#### 4.2.4 Comprehensive evaluation based on gray correlation-TOPSIS method

1. **Build a weighted normalization matrix**

   Using the weights of each index calculated by the hierarchical analysis method, the weighted normalization matrix is constructed with the index data after the non-scale outline.

2. **Determine the positive ideal solution** $Z^+$ and negative ideal solutions $Z^-:

   According to the formula (4), the positive and ideal solution of each indicator is determined to be the weight of the indicator, and the negative ideal solution is 0.

   $Z^+ = (0.1644 \ 0.1278 \ 0.0370 \ 0.0428 \ 0.1156 \ 0.0368 \ 0.0127 \ 0.0575 \ 0.0445$

   $0.1009 \ 0.0825 \ 0.0302 \ 0.0304 \ 0.0074 \ 0.0097 \ 0.0297 \ 0.0461 \ 0.0242)$

   $Z^- = (0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0)$

3. **Calculate the Euclid distance between the schemes and the positive and negative ideal solutions** $d^+$ and $d^-:

   According to the positive and negative ideal solutions and weighted normalization data, the euclid distance between the schemes and the positive and negative ideal
solutions is calculated by using the formula (5).

\[ d_i^+ = (0.1867 \ 0.1022 \ 0.2020 \ 0.1773) \]

\[ d_i^- = (0.1878 \ 0.2262 \ 0.2169 \ 0.1848) \]

(4) Calculate the gray correlation coefficient between each scheme and the positive ideal solution and the negative ideal solution \( r_{ij}^+ \) and \( r_{ij}^- \).

The gray correlation between the scheme and the positive and negative ideal solutions is calculated according to the formulas of the gray association-TOPSIS model (6), (7), and (8). Among them, for the resolution coefficient, the empirical value is 0.5.

**Table 12**

According to the formula (9), the gray association between each scheme and the positive and negative ideal solution is calculated:

\[ r^+ = [0.8436 \ 0.8458 \ 0.7828 \ 0.8132] \]

\[ r^- = [0.7555 \ 0.7459 \ 0.8578 \ 0.7917] \]

(5) Euclid distance and grey relational degree were dimensionless, and were obtained \( D_i^+, D_i^- \) and \( R_i^+, R_i^- \).

**Table 13**

(6) Relative proximity of the construction scheme:

According to the formula (11) will be no scale distance and correlation degree combined. Finally, according to the formula (12) to construct the relative proximity of the hydrogen scheme samples, and according to the size of the relative schedule to sort the samples, the closer the proximity 1, the better the scheme;

**4.3 Results and Analysis**
In this paper, AHP-TOPSIS method and AHP-GC method are used to compare the results of the proposed methods. The weight of each influencing factor adopted by the three methods is the same. The closeness index results of the three methods are shown in Table 14.

**Table 14**

It can be seen from Table 14 that the results of the three methods are basically consistent and close, which shows that the proposed AGT is reasonable and feasible to evaluate the performance of the design scheme. Because the gray closeness index of Option 1 and Option 2 is similar, AHP-GC cannot determine the best solution between Option 1 and Option 3, and AGT can do this. In other words, the result of AGT is a comprehensive evaluation value of AHP-TOPSIS and AHP-GC. When evaluating the performance of the design plan, a mixed feature involving positional relationship and situation changes between data sequences is used. Therefore, the AGT method overcomes the one-sidedness of the AHP-TOPSIS and AHP-GC methods, and makes the evaluation results more objective and true.

Through the previous evaluation and research on various hydrogen production technologies, the ranking of the comprehensive evaluation of various hydrogen production technologies has been obtained. Now the research results are further analyzed, and the ranking is as follows:

**Table 15**

![Fig. 2](image-url)

It can be seen from Fig. 2 that coke oven gas hydrogen production is the most...
closely related hydrogen production technology, with a closeness of 0.5925, indicating that coke oven gas hydrogen production is the preferred hydrogen production technology for a mining group's transformation and development of hydrogen energy. On the one hand, because coke oven gas is compared with the traditional hydrogen production method, hydrogen extraction is not only a more environmentally friendly comprehensive utilization of resources, but also has very considerable economic benefits; on the other hand, in the example, coal enterprises are the mainstay, and the output of coke oven gas is abundant. Through reasonable purification technology, hydrogen energy can be produced on a large scale, compared with electrolysis of water to produce hydrogen, and the cost is low. The second in the ranking of relative closeness is the traditional coal gasification hydrogen production, which has already been produced on a large scale in my country, with relatively mature technology and low cost, but there are also problems such as high carbon emissions and many gas impurities. The hydrogen production technology ranked last is hydrogen production by electrolysis of water, with a relative closeness of 0.4851. Although its raw material is non-polluting water, it consumes a lot of electric energy in its preparation, so it has relatively low scores in economic and environmental dimensions.

5 Conclusions

This paper takes coal gasification hydrogen production, coke oven gas hydrogen production, electrolysis water hydrogen production and solar hydrogen production as the research objects, and conducts a multi-dimensional comprehensive evaluation by constructing a multi-level comprehensive evaluation index system. At the same time,
the model was verified based on the actual situation of a certain mining group, and the
following conclusions were drawn:

The GRA-TOPSIS method is used to construct a comprehensive evaluation model
of hydrogen production technology. By combining Euclidean distance and gray
correlation, a new relative closeness is constructed from two aspects of position and
shape, which can make up for the respective defects of GRA and TOPSIS; through
calculations According to the comprehensive closeness of various hydrogen production
technologies, the comprehensive closeness of coke oven gas hydrogen production
technology is the highest, which is the most suitable hydrogen production technology
choice for a certain mining group's hydrogen energy development, followed by coal
gasification hydrogen production technology; this model can Provide a certain
theoretical basis for coal enterprises to select hydrogen production technology as a
breakthrough point for transformation;

There are still some shortcomings in the research of this paper, and future research
can be further deepened and broadened: In this research, the qualitative indicators are
quantified by the expert scoring method and the range method. However, with the
improvement of national policies and the development of hydrogen production
technology , Related cognition and data will also change. A more scientific and
comprehensive evaluation model is still needed to adapt to future development; as
currently emerging hydrogen production technologies such as biomass hydrogen
production have certain difficulties in data collection, with the deepening of relevant
research, a more comprehensive approach can be considered. Other emerging hydrogen
production technologies could be included in the research object.

Acknowledgments

3
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## Table and Figure Caption

### Table Captions

1. **Table 1** Applicability, Reliability and Recognition
2. **Table 2** External dependence of Technology
3. **Table 3** Technology maturity
4. **Table 4** Comprehensive evaluation index system of hydrogen production technology
5. **Table 5** Criterion layer judgment matrix
6. **Table 6** Weight value of comprehensive evaluation index of hydrogen production technology
7. **Table 7** Energy dimension weighted normalization matrix
8. **Table 8** Economic dimension weighted normalization matrix
9. **Table 9** Environment dimension weighted normalization matrix
10. **Table 10** Technical dimension weighted normalization matrix
11. **Table 11** Social dimension weighted normalization matrix
12. **Table 12** Sequence of difference between weighted normalized matrix and positive ideal solution
13. **Table 13** Dimensionless processing results
14. **Table 14** Comprehensive evaluation and ranking table of hydrogen production technical scheme
### Table 1

| Level          | Very high | High | Moderate | Low | Minor |
|----------------|-----------|------|----------|-----|-------|
| Resource applicability | 5         | 4    | 3        | 2   | 1     |
| Technical reliability |           |      |          |     |       |
| Policy applicability  |           |      |          |     |       |
| Social recognition  |           |      |          |     |       |

### Table 2

| External dependence | Very low | Low | Moderate | High | Very high |
|---------------------|----------|-----|----------|------|-----------|
| Level               | 5        | 4   | 3        | 2    | 1         |

### Table 3

| Technology maturity | Commercialization | Industrial application | Industrial demonstration | Pilot | Small test |
|---------------------|-------------------|-------------------------|--------------------------|-------|------------|
| Level               | 5                 | 4                       | 3                        | 2     | 1          |
Table 4

| Goal level (G) | Criterion level (A) | Factor level (B) |
|----------------|---------------------|------------------|
| Comprehensive evaluation index system of hydrogen production technology (I) | Energy (A₁) | Resource suitability (b₁₁) |
| | | Hydrogen production efficiency (b₁₂) |
| | | The proportion of end-user energy consumption changes (b₁₃) |
| | | Increased share of clean energy consumption (b₁₄) |
| | Economic (A₂) | The cost per unit of hydrogen production (b₂₁) |
| | | Investment costs (b₂₂) |
| | | Gross domestic product (b₂₃) |
| | Environment (A₃) | Wastewater emissions (b₃₁) |
| | | Slag emissions (b₃₂) |
| | | CO₂ emissions (b₃₃) |
| | | NOx emissions (b₃₄) |
| | | Technical reliability (b₃₅) |
| | | Hydrogen purity (b₃₆) |
| | Technology (A₄) | The proportion of researchers (b₄₁) |
| | | External dependence of technology (b₄₄) |
| | | Technical maturity (b₄₅) |
| | Social (A₅) | Policy applicability (b₅₁) |
| | | Social recognition (b₅₂) |
1 **Table 5**

|       | energy   | economy | environment | technology | society |
|-------|----------|---------|-------------|------------|---------|
| energy| 1.0000   | 4.2122  | 1.1212      | 2.7576     | 4.8182  |
| economy| 0.2374  | 1.0000  | 1.5000      | 0.9000     | 1.7000  |
| environment| 0.8919 | 0.6667  | 1.0000      | 4.2728     | 5.2000  |
| technology| 0.3626 | 1.1111  | 0.2340      | 1.0000     | 1.3000  |
| society | 0.2075   | 0.5882  | 0.1923      | 0.7692     | 1.0000  |

2

3 **Table 6**

| Goal level | Criterion level(A) | Weight (W_i) | Factor level(B) | Weight (W_a) | Comprehensive weights |
|------------|-------------------|--------------|-----------------|--------------|-----------------------|
| A1         | 0.3719            | b_{11}       | 0.4420          | 0.1644       |
|            |                   | b_{12}       | 0.3436          | 0.1278       |
|            |                   | b_{13}       | 0.0994          | 0.0370       |
|            |                   | b_{14}       | 0.1150          | 0.0428       |
|            |                   | b_{21}       | 0.7003          | 0.1156       |
| A2         | 0.1651            | b_{22}       | 0.2230          | 0.0368       |
|            |                   | b_{23}       | 0.0767          | 0.0127       |
|            |                   | b_{31}       | 0.2014          | 0.0575       |
| A3         | 0.2854            | b_{32}       | 0.1559          | 0.0445       |
|            |                   | b_{33}       | 0.3535          | 0.1009       |
|            |                   | b_{34}       | 0.2892          | 0.0825       |
|            |                   | b_{41}       | 0.2810          | 0.0302       |
|            |                   | b_{42}       | 0.2828          | 0.0304       |
| A4         | 0.1074            | b_{43}       | 0.0693          | 0.0074       |
|            |                   | b_{44}       | 0.0903          | 0.0097       |
|            |                   | b_{45}       | 0.2766          | 0.0297       |
| A5         | 0.0703            | b_{51}       | 0.6562          | 0.0461       |
|            |                   | b_{52}       | 0.3438          | 0.0242       |
### Table 7

| Scheme                  | Resource suitability | Hydrogen production efficiency | The proportion of end-user energy consumption changes | Increased share of clean energy consumption |
|-------------------------|----------------------|--------------------------------|-----------------------------------------------------|--------------------------------------------|
| Coal gasification       | 0.0000               | 0.0709                         | 0.0370                                              | 0.0428                                     |
| Coke oven gas           | 0.1061               | 0.0895                         | 0.0167                                              | 0.0338                                     |
| Electrolytic water      | 0.1644               | 0.1278                         | 0.0009                                              | 0.0068                                     |
| Solar                   | 0.0932               | 0.0000                         | 0.0000                                              | 0.0000                                     |

### Table 8

| Scheme                  | The cost per unit of hydrogen production | Investment costs | Gross domestic product |
|-------------------------|-----------------------------------------|------------------|------------------------|
| Coal gasification       | 0.1156                                  | 0.0094           | 0.0127                 |
| Coke oven gas           | 0.1021                                  | 0.0368           | 0.0087                 |
| Electrolytic water      | 0.0000                                  | 0.0318           | 0.0008                 |
| Solar                   | 0.0522                                  | 0.0000           | 0.0000                 |

### Table 9

| Scheme                  | Wastewater emissions | Slag emissions | CO$_2$ emissions | NO$_X$ emissions |
|-------------------------|----------------------|----------------|------------------|------------------|
| Coal gasification       | 0.0460               | 0.0335         | 0.0668           | 0.0550           |
| Coke oven gas           | 0.0575               | 0.0391         | 0.0864           | 0.0751           |
| Electrolytic water      | 0.0000               | 0.0000         | 0.0000           | 0.0000           |
| Solar                   | 0.0410               | 0.0445         | 0.1009           | 0.0825           |

### Table 10

| Scheme                  | Technical reliability | Hydrogen purity | The proportion of researchers | External dependence of technology | Technical maturity |
|-------------------------|-----------------------|-----------------|-------------------------------|----------------------------------|--------------------|
| Coal gasification       | 0.0279                | 0.0000          | 0.0000                        | 0.0009                           | 0.0297             |
| Coke oven gas           | 0.0000                | 0.0235          | 0.0015                        | 0.0000                           | 0.0000             |
| Electrolytic water      | 0.0302                | 0.0304          | 0.0062                        | 0.0097                           | 0.0266             |
| Solar                   | 0.0092                | 0.0304          | 0.0074                        | 0.0042                           | 0.0094             |
### Table 11

| Scheme                  | Policy applicability | Social recognition |
|-------------------------|----------------------|--------------------|
| Coal gasification       | 0.0219               | 0.0242             |
| Coke oven gas          | 0.0000               | 0.0000             |
| Electrolytic water     | 0.0048               | 0.0000             |
| Solar                  | 0.0461               | 0.0123             |

### Table 12

| Scheme                  | Resource suitability | Hydrogen production efficiency | Increase share of clean energy consumption | The cost per unit of hydrogen production | Investment costs | Gross domestic product | Wastewater emissions | Slag emissions |
|-------------------------|----------------------|---------------------------------|---------------------------------------------|--------------------------------------|-----------------|------------------------|---------------------|------------------|
| Coal gasification       | 0.1644               | 0.0569                          | 0.0000                                      | 0.0000                               | 0.0274          | 0.0000                 | 0.0115              | 0.0110          |
| Coke oven gas          | 0.0583               | 0.0383                          | 0.0204                                      | 0.0090                               | 0.0135          | 0.0000                 | 0.0040              | 0.0054          |
| Electrolytic water     | 0.0000               | 0.0000                          | 0.0361                                      | 0.0360                               | 0.1156          | 0.0050                 | 0.0119              | 0.0575          |
| Solar                  | 0.0712               | 0.1278                          | 0.0370                                      | 0.0428                               | 0.0634          | 0.0368                 | 0.0127              | 0.0165          |

| Scheme                  | CO₂ emission emissions | NOX emission emissions | Techno Hydrogen purity | Reliability | Policy applicability | Social recognition |
|-------------------------|-------------------------|------------------------|------------------------|-------------|----------------------|---------------------|
| Coal gasification       | 0.0341                  | 0.0275                 | 0.0023                 | 0.0304      | 0.0074               | 0.0088              | 0.0000              | 0.0242          |
| Coke oven gas          | 0.0145                  | 0.0074                 | 0.0302                 | 0.0069      | 0.0059               | 0.0000              | 0.0297              | 0.0461          |
| Electrolytic water     | 0.1009                  | 0.0825                 | 0.0000                 | 0.0000      | 0.0012               | 0.0097              | 0.0031              | 0.0413          |
| Solar                  | 0.0000                  | 0.0000                 | 0.0210                 | 0.0000      | 0.0000               | 0.0055              | 0.0203              | 0.0000          |
### Table 13

| Scheme              | $D_i^+$ | $D_i^-$ | $R_i^+$ | $R_i^-$ |
|---------------------|--------|--------|--------|--------|
| Coal gasification   | 0.9241 | 0.8306 | 0.9975 | 0.8807 |
| Coke oven gas       | 0.5057 | 1.0000 | 1.0000 | 0.8696 |
| Electrolytic water  | 1.0000 | 0.9589 | 0.9255 | 1.0000 |
| Solar               | 0.8778 | 0.8331 | 0.9615 | 0.9229 |

### Table 14

| Scheme              | AHP-TOPSIS | AHP-GC | AHP-GC&TOPSIS |
|---------------------|------------|--------|---------------|
| Coal gasification   | 0.473357269 | 0.4689064 | 0.5032        |
| Coke oven gas       | 0.664142924 | 0.46512623 | 0.5925        |
| Electrolytic water  | 0.489509419 | 0.51934562 | 0.4851        |
| Solar               | 0.4869367   | 0.48975801 | 0.4992        |

### Table 15

| Scheme              | $P_i^+$ | $P_i^-$ | Relative closeness | Rank |
|---------------------|--------|--------|--------------------|------|
| Coal gasification   | 0.9140 | 0.9024 | 0.5032             | 2    |
| Coke oven gas       | 1.0000 | 0.6877 | 0.5925             | 1    |
| Electrolytic water  | 0.9422 | 1.0000 | 0.4851             | 4    |
| Solar               | 0.8973 | 0.9004 | 0.4992             | 3    |
Figure Captions

Fig. 1 Model frame diagram

Fig. 2 Relative closeness of comprehensive evaluation of hydrogen production technology
Impact Analysis for hydrogen production technology

Establish a hierarchy structure of evaluation criteria

Eleven related experts

Formulate a fundamental scale of values

Eleven related experts

Step 1: AHP

Formulate pair-wise comparison matrices

Obtain the weights of each criterion for hydrogen production technology

Calculate the final consistency ratio $C_i$< 0.1

Construct a decision matrix for hydrogen production technology

Step 2: GRA-TOPSIS

Calculate the normalized decision matrix $Y_{ij}$

Calculate the weighted normalized decision matrix $Z_{ij}$

Obtain the positive-ideal and negative-ideal solution

Calculate the gray correlation coefficients to positive-ideal and negative-ideal solutions

Calculate the gray correlation degrees to positive-ideal and negative-ideal solutions

Normalize the gray correlation degrees to obtain the gray correlation closeness index

Obtain the gray correlation closeness index

Calculate the separation measures to positive-ideal and negative-ideal solutions

Normalize the positive-ideal and negative-ideal solutions

Obtain the distance closeness index

Calculate the integrated closeness index via a nonlinear programming model with constraints

Rank the alternatives

Fig. 1
Fig. 2

| Method               | Relative Closeness |
|----------------------|--------------------|
| Coal gasification    | 0.5032             |
| Coke oven gas        | 0.5925             |
| Electrolytic water   | 0.4851             |
| Solar                | 0.4992             |
Figure 1
Model frame diagram
Figure 2

Relative closeness of comprehensive evaluation of hydrogen production technology