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

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Research

Keywords: Hydrogen production technology, Comprehensive evaluation, AHP, GRA-TOPSIS

Posted Date: May 6th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-480265/v1

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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 subsysyss system of environmental impact factors, and continue to study its CO_2, NO_X 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：

$$x'_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

Negative indicator：

$$x'_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \tag{2}$$

(2) Build a decision matrix:

M evaluation objects and N evaluation indexes are set, and the original decision matrix is X= $\left(x_{ij}\right)_{m \times n}$

(3) Weighted normalized matrix of evaluation indicators:

$$Z = \left(\omega_j y_{ij}\right)_{m \times n} = \begin{bmatrix} \omega_1 y_{11} & \omega_2 y_{12} & \cdots & \omega_n y_{1n} \\ \omega_1 y_{21} & \omega_2 y_{22} & \cdots & \omega_n y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_1 y_{m1} & \omega_2 y_{m2} & \cdots & \omega_n y_{mn} \end{bmatrix} \tag{3}$$

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

$$\begin{aligned} Z^{+} &= (Z_1^{+}, Z_2^{+}, \ldots, Z_n^{+}) = \omega \\ Z^{-} &= (Z_1^{-}, Z_2^{-}, \ldots, Z_n^{-}) = 0 \end{aligned} \tag{4}$$

In this Formula：

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

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

$$\begin{aligned} d_i^{+} &= \sqrt{\sum_{j=1}^{n} (Z_{ij} - Z_j^{+})^2}; \\ d_i^{-} &= \sqrt{\sum_{j=1}^{n} (Z_{ij} - Z_j^{-})^2} \end{aligned} \tag{5}$$

(6) Calculate the gray correlation coefficient matrix between each scheme and the

positive ideal solution and the negative ideal solution R^+ and R^- .

$$R^+ = (r_{ij}^{\ +})_{m \times n}, R^- = (r_{ij}^{\ +})_{m \times n} \tag{6}$$

$$r_{ij}^{\ +} = \frac{\min\limits_i \min\limits_j \left| z_j^+ - z_{ij} \right| + \varepsilon \max\limits_i \max\limits_j \left| z_j^+ - z_{ij} \right|}{\left| z_j^+ - z_{ij} \right| + \varepsilon \max\limits_i \max\limits_j \left| z_j^+ - z_{ij} \right|} \tag{7}$$

$$r_{ij}^{\ -} = \frac{\min\limits_i \min\limits_j \left| z_j^- - z_{ij} \right| + \varepsilon \max\limits_i \max\limits_j \left| z_j^- - z_{ij} \right|}{\left| z_j^- - z_{ij} \right| + \varepsilon \max\limits_i \max\limits_j \left| z_j^- - z_{ij} \right|} \tag{8}$$

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：

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

(8) Euclid distance and correlation degree are dimensionless:

$$\begin{gathered} D_i^+ = \frac{d_i^+}{\max d_i^+}, D_i^- = \frac{d_i^-}{\max d_i^-}, \\ R_i^+ = \frac{r_i^+}{\max r_i^+}, R_i^- = \frac{r_i^-}{\max r_i^-} \end{gathered} \tag{10}$$

(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:

$$P_i^+ = \alpha D^- + \beta R^+, P_i^- = \alpha D^+ + \beta R^- \tag{11}$$

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

(10) Relative closeness of the construction scheme:

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

(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）, CO_2 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_i =[0.37，0.17，0.28，0.11，0.07].

By the same method, the weight of the second layer W_{ii} 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.

Table 7

Table 8

Table 9

Table 10

Table 11

(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.

$$Z^{+}=(0.1644\quad 0.1278\quad 0.0370\quad 0.0428\quad 0.1156\quad 0.0368\quad 0.0127\quad 0.0575\quad 0.0445\quad 0.1009\quad 0.0825\quad 0.0302\quad 0.0304\quad 0.0074\quad 0.0097\quad 0.0297\quad 0.0461\quad 0.0242)$$

$$Z^{-}=(0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\ 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0)$$

(3)Calculate the Euclid distance between the schemes and the positive and negative ideal solutions d_i^{+} and d_i^{-}.

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).

$$d_i^+ = (0.1867\ 0.1022\ 0.2020\ 0.1773)$$

$$d_i^- = (0.1878\ 0.2262\ 0.2169\ 0.1884)$$

(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:

Acording 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 amd 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

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

References

Feng Mei, Li Wenhua. Changes in primary energy consumption structure and high-quality economic development in New China in the past 70 years[J]. Economic Issues, 2019(07): 9-15. [in Chinese]

National Development and Reform Commission, National Energy Administration. "Energy Technology Revolution and Innovation Action Plan". 2016:513. http://www.nea.gov.cn/2016-06/01/c_135404377.htm [in Chinese]

Yan Lina (2019-09-17). The hydrogen source structure is characterized by "coal-based". China Coal News, 003. [in Chinese]

Chen Zizhan, Zhao Ting, Liu Chao & Zhou Fengying. (2017). Research on the status quo of coal hydrogen production industry and the choice of new energy development path in my country. China Mining (07), 35-40. doi:CNKI:SUN: ZGKA.0.2017-07-008. [in Chinese]

Zhang Yuanyuan. (2017). Research on the carbon emissions of modern coal chemical industry and its economic impact (PhD dissertation, China University of Mining and Technology (Beijing)). https://kns.cnki.net/KCMS/detail/ detail.aspx?dbname=CDFDLAST2018&filename=1017237807.nh [in Chinese]

Hu Bo & Han Yijie. (2016). Modeling of technical and economic evaluation of coal upstream industrial chain projects. Coal Economic Research (05), 49-54. doi:10.13202/j.cnki.cer.2016.05.011. [in Chinese]

Saaty, T. L. . (1994). How to make a decision: the analytic hierarchy process. European Journal of Operational Research.

Chen, C. T. . (2000). Extensions of the topsis for group decision-making under fuzzy environment. Fuzzy Sets & Systems, 114(1), 1-9.

Prince-Richard, S. , Whale, M. , & Djilali, N. . (2005). A techno-economic analysis of decentralized electrolytic hydrogen production for fuel cell vehicles. International Journal of Hydrogen Energy, 30(11), 1159-1179.

Konstantopoulou, P., Giannopoulos, D., & Founti, M. (2005, July). Multicriteria analysis of hydrogen production technologies. In Proceedings international hydrogen energy congress and exhibition IHEC.

Li Yiyang. (2010). Several hydrogen production methods of life cycle assessment studies (master's degree thesis, xian building university of science and technology). [in Chinese]

Luo, B., Zhou, Y., Yu, B., Xiao, R., & Yang, C. (2019). Comparison of chemical and biological hydrogen production processes.Ceramic (12), 23 to 28. [in Chinese]

Xie Xinshuo, Yang Weijuan, Shi Wei, Zhang Shengsheng, Wang Zhihua & Zhou Junhu.(2018).Progress in life cycle assessment of hydrogen production technology. Chemical Industry Progress (06),2147-2158. [in Chinese]

Niu J. (2007). Study on system evaluation system of hydrogen production technology (Master thesis, Beijing University of Chemical Technology). [in Chinese]

Deng Yuyong, Du Minghua & Lei Zhongmin. (2006). A review of model methods based on the energy-economy-environment (3E) system. Gansu Social Sciences (03), 209-212. doi:10.15891/j.cnki .cn62-1093/c.2006.03.053. [in Chinese]

Feng Wen. (2003). The fuel cell car hydrogen system evaluation and case study of Beijing (a master's degree thesis, tsinghua university). [in Chinese]

Table and Figure Caption

Table Captions

Table 1 Applicability,Reliability and Recognition

Table 2 External dependence of Technology

Table 3 Technology maturity

Table 4 Comprehensive evaluation index system of hydrogen production technology

Table 5 Criterion layer judgment matrix

Table 6 Weight value of comprehensive evaluation index of hydrogen production technology

Table 7 Energy dimension weighted normalization matrix

Table 8 Economic dimension weighted normalization matrix

Table 9 Environment dimension weighted normalization matrix

Table 10 Technical dimension weighted normalization matrix

Table 11 Social dimension weighted normalization matrix

Table 12 Sequence of difference between weighted normalized matrix and positive ideal solution

Table 13 Dimensionless processing results

Table 14 Comprehensive evaluation and ranking table of hydrogen production technical scheme

Table 1

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

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（A_1）	Resource suitability（b_{11}）
		Hydrogen production efficiency（b_{12}）
		The proportion of end-user energy consumption changes（b_{13}）
		Increased share of clean energy consumption（b_{14}）
	Economic（A_2）	The cost per unit of hydrogen production（b_{21}）
		Investment costs（b_{22}）
		Gross domestic product（b_{23}）
	Environment（A_3）	Wastewater emissions（b_{31}）
		Slag emissions（b_{32}）
		CO_2 emissions（b_{33}）
		NO_X emissions（b_{34}）
	Technology（A_4）	Technical reliability（b_{41}）
		Hydrogen purity（b_{42}）
		The proportion of researchers（b_{43}）
		External dependence of technology（b_{44}）
		Technical maturity（b_{45}）
	Social（A_5）	Policy applicability（b_{51}）
		Social recognition（b_{52}）

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

Table 6

Goal level	Criterion level(A)	Weight （W_i）	Factor level(B)	Weight (W_{ii})	Comprehensive weights
Comprehensive evaluation	A_1	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
	A2	0.1651	b_{21}	0.7003	0.1156
			b_{22}	0.2230	0.0368
			b_{23}	0.0767	0.0127
	A3	0.2854	b_{31}	0.2014	0.0575
			b_{32}	0.1559	0.0445
			b_{33}	0.3535	0.1009
			b_{34}	0.2892	0.0825
	A4	0.1074	b_{41}	0.2810	0.0302
			b_{42}	0.2828	0.0304
			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	The proportion of end-user energy consumption changes	Increased 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	0.0000	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	0.0000	0.0054
Electrolytic water	0.0000	0.0000	0.0361	0.0360	0.1156	0.0050	0.0119	0.0575	0.0445
Solar	0.0712	0.1278	0.0370	0.0428	0.0634	0.0368	0.0127	0.0165	0.0000

Scheme	CO_2 emissions	NOX emissions	Technical reliability	Hydrogen purity	The proportion of researchers	External dependence of technology	Technical maturity	Policy applicability	Social recognition
Coal gasification	0.0341	0.0275	0.0023	0.0304	0.0074	0.0088	0.0000	0.0242	0.0000
Coke oven gas	0.0145	0.0074	0.0302	0.0069	0.0059	0.0000	0.0297	0.0461	0.0242
Electrolytic water	0.1009	0.0825	0.0000	0.0000	0.0012	0.0097	0.0031	0.0413	0.0242
Solar	0.0000	0.0000	0.0210	0.0000	0.0000	0.0055	0.0203	0.0000	0.0119

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

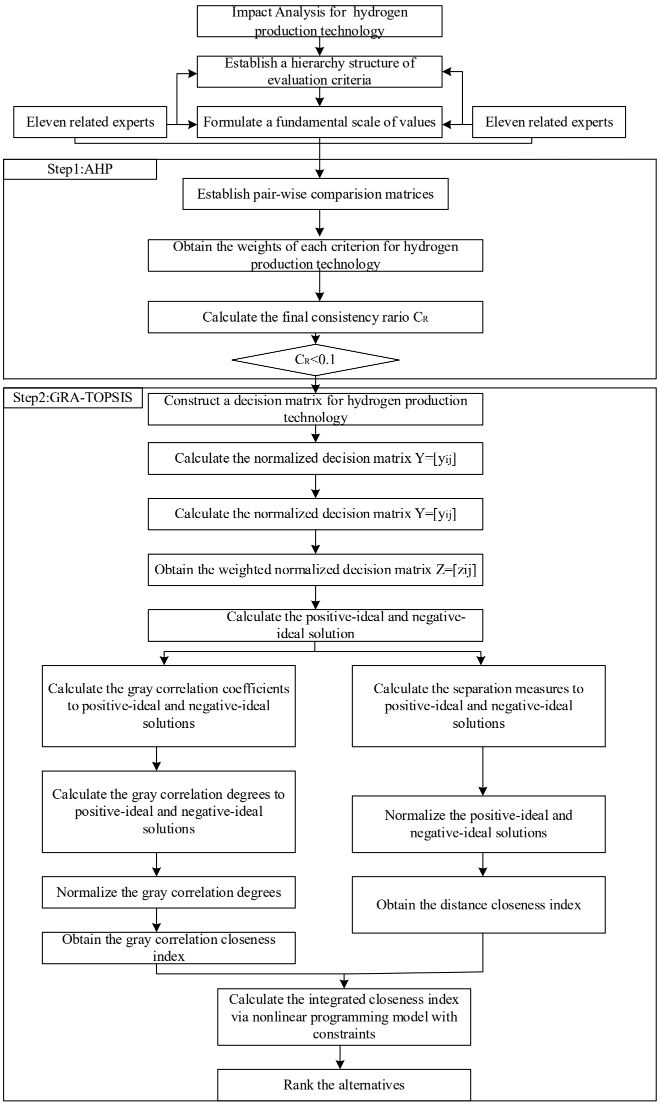
Impact Analysis for hydrogen production technology
Establish a hierarchy structure of evaluation criteria
Eleven related experts
Formulate a fundamental scale of values
Eleven related experts
Step1:AHP
Establish pair-wise comparision matrices
Obtain the weights of each criterion for hydrogen production technology
Calculate the final consistency rario CR
CR<0.1
Step2:GRA-TOPSIS
Construct a decision matrix for hydrogen production technology
Calculate the normalized decision matrix Y=[yij]
Calculate the normalized decision matrix Y=[yij]
Obtain the weighted normalized decision matrix Z=[zij]
Calculate the positive-ideal and negative-ideal solution
Calculate the gray correlation coefficients to positive-ideal and negative-ideal solutions
Calculate the separation measures to positive-ideal and negative-ideal solutions
Calculate the gray correlation degrees to positive-ideal and negative-ideal solutions
Normalize the positive-ideal and negative-ideal solutions
Normalize the gray correlation degrees
Obtain the distance closeness index
Obtain the gray correlation closeness index
Calculate the integrated closeness index via nonlinear programming model with constraints
Rank the alternatives

Fig. 1

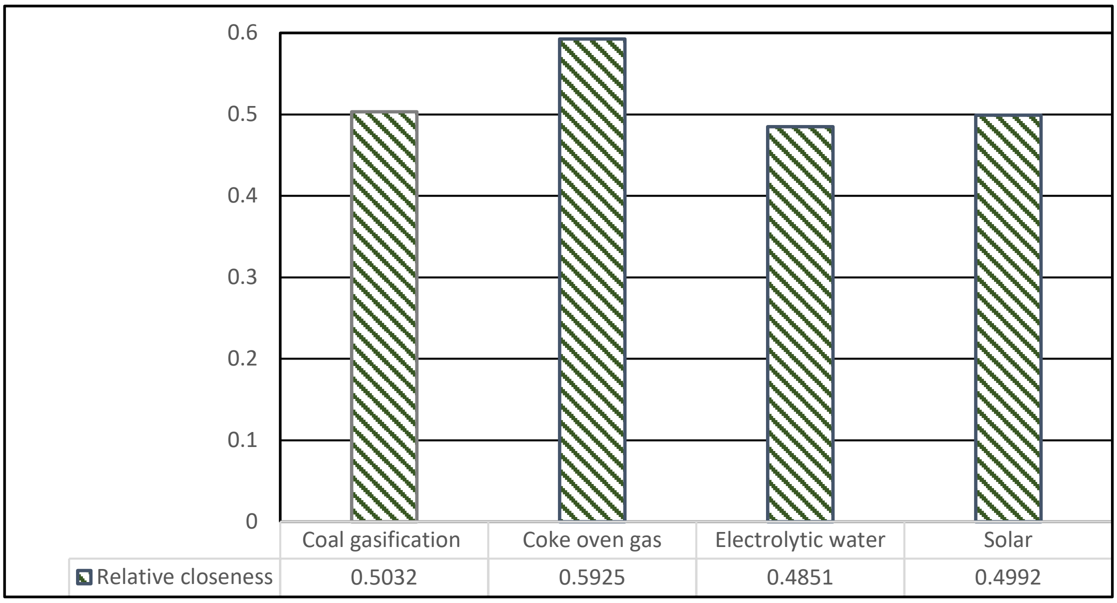
0.6
0.5
0.4
0.3
0.2
0.1
0
Coal gasification
Coke oven gas
Electrolytic water
Solar
Relative closeness
0.5032
0.5925
0.4851
0.4992

Fig. 2

Figures

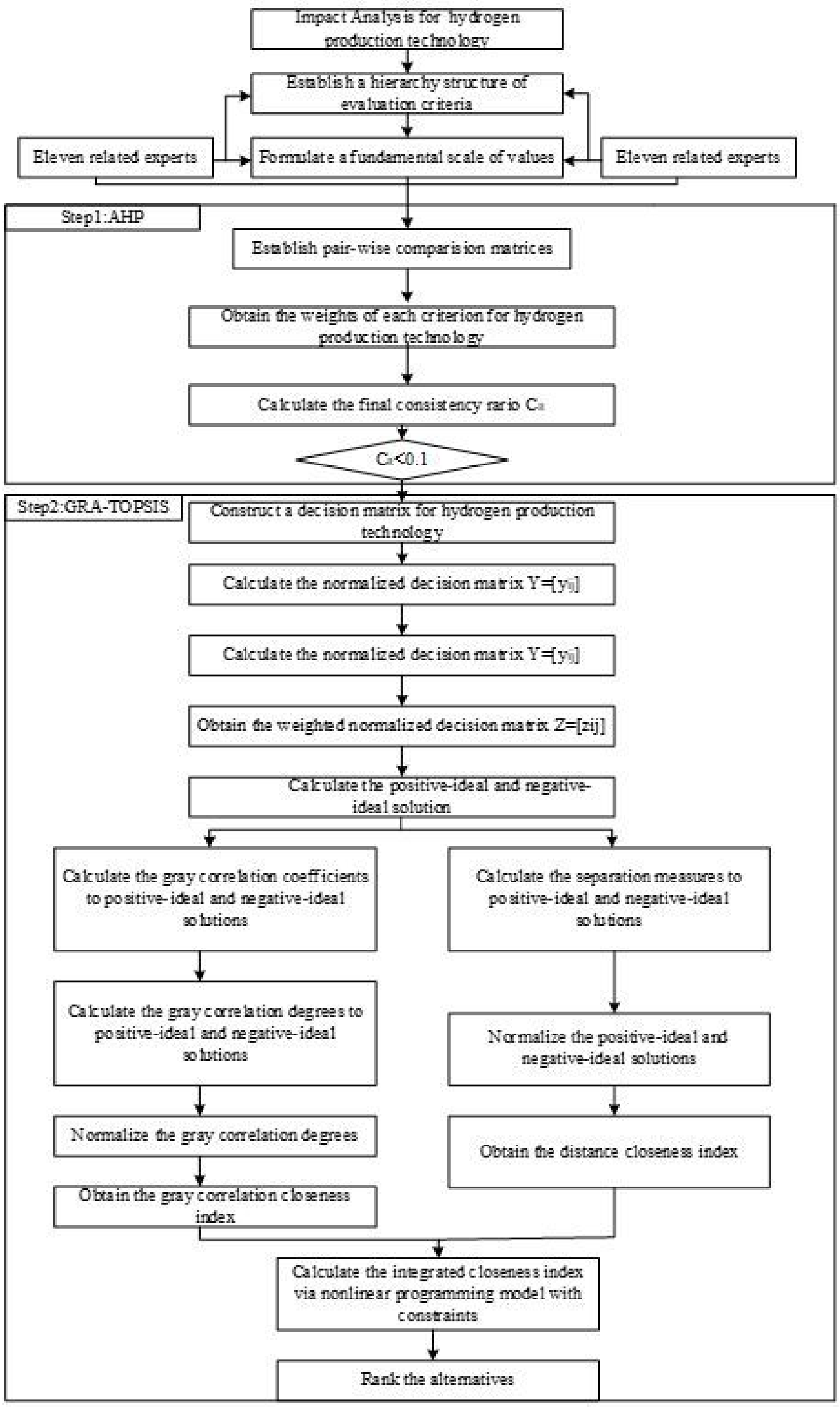

Figure 1

Model frame diagram

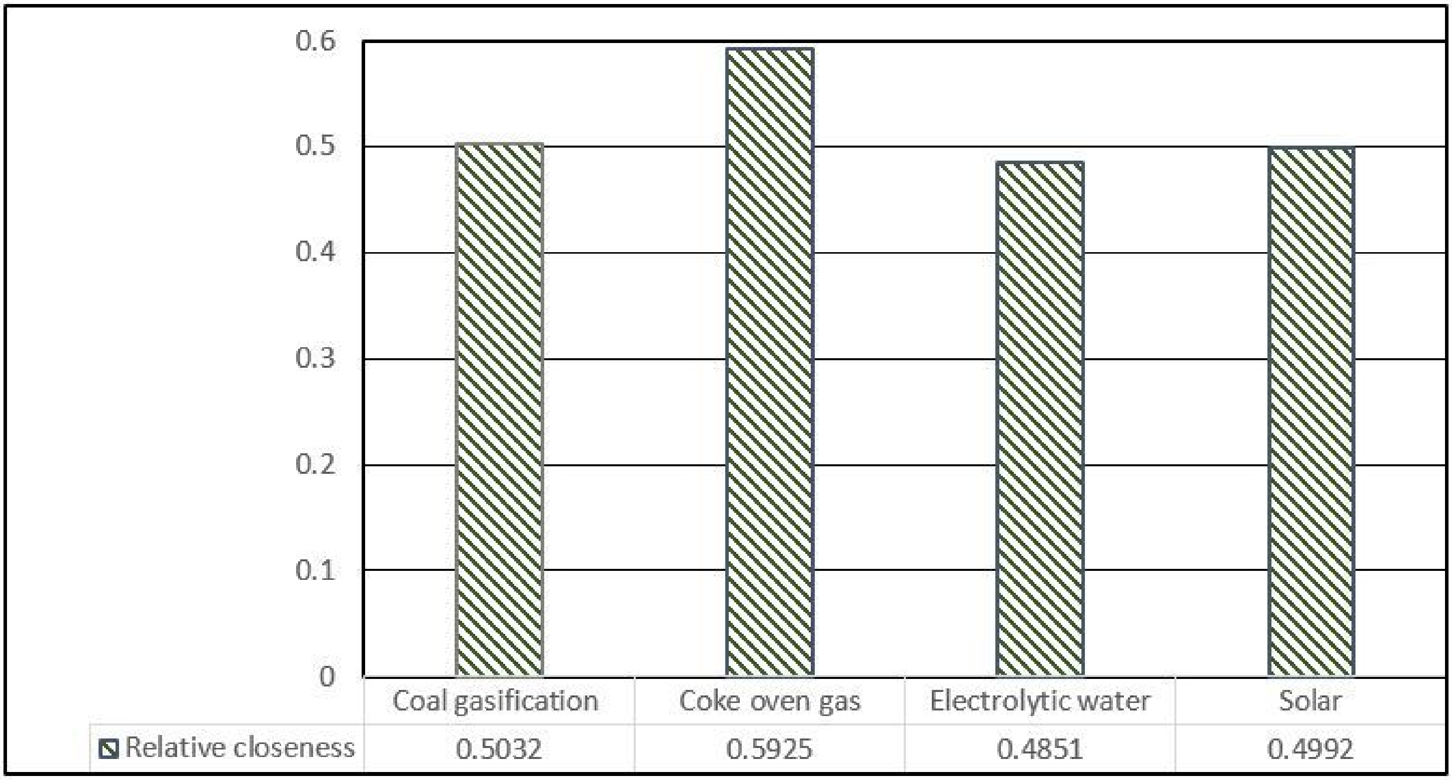

Figure 2

Relative closeness of comprehensive evaluation of hydrogen production technology