

Article

# A Multi-Criteria Framework to Evaluate the Sustainability of Renewable Energy: A 2-Tuple Linguistic Grey Relation Model from the Perspective of the Prospect Theory

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**Abstract:** The unique resources and environmental advantages of renewable energy make it an essential component of energy strategies and a meaningful way to achieve “carbon neutrality”. However, due to limitations relating to ecological factors and geographical locations, renewable energy power generation faces many problems, including instability, resulting in unsustainable development. Few studies have been conducted on the sustainability of renewable energy. Therefore, a multi-criteria decision-making (MCDM) framework for evaluating renewable energy sustainability is put forward. Based on a 2-tuple linguistic grey relation model and the prospect theory, the MCDM framework can comprehensively analyze the factors that may influence renewable energy sustainability in terms of resources, the environment, society, technology, and the economy. The combination of the 2-tuple linguistic model and the prospect theory can improve the objectivity of decision making. Taking China as the research object, this study finds that the profit–loss ratios for the four alternatives considered are {0.969, 0.432, 0.395, 0.369} for solar photovoltaic power, wind power, hydropower, and biomass power, respectively, ranked from best to worst. Based on the sensitivity analysis, the MCDM framework can change its parameters based on the relevant psychological characteristics and then establish a suitable system for decision making. The MCDM framework proposed in this study can provide investors with decision-making references and help governmental agencies formulate renewable energy policies.

**Keywords:** renewable energy; sustainability; multi-criteria framework; 2-tuple linguistic grey relation model prospect theory



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## 1. Introduction

Greenhouse gas emissions are increasing and further driving global climate change [1]; in response, the Intergovernmental Panel on Climate Change (IPCC) has proposed that the goal of “carbon neutrality” be achieved by limiting the global temperature increase to less than 1.5 °C by the end of this century. CO<sub>2</sub> emissions mainly come from fossil fuel consumption, and developing renewable energy can reduce fossil fuel energy consumption. In a word, building a low-carbon energy system is essential for achieving “carbon neutrality” [2]. In addition, the sharp increase in electricity demand has triggered a shortage of fossil fuel energy [3], making renewable energy a necessary option for alleviating energy shortages [4].

Moreover, renewable energy can be leveraged to formulate poverty-alleviating projects in some countries [5]. While improving energy sustainability, renewable energy can also enhance the sustainability of social and financial development [6]. Therefore, the development of renewable energy has been favored by various countries. Nevertheless, although

renewable energy is more abundant than fossil fuel energy, there are still some issues with it. On the one hand, the development of renewable energy is often limited by environmental conditions and geographical locations, so power generation faces significant issues related to intermittency and instability [7]. On the other hand, the construction of renewable energy projects impacts the ecosystem, so the question of how to mitigate its environmental impact is also a key consideration [8]. In addition, due to the instability of renewable energy, its connection to the grid affects the stable operation of whole power systems, which have to be re-designed accordingly for greater flexibility [7]. Currently, renewable energy technologies do not solve the above problems well enough to ensure the sustainability of renewable energy systems. Compared with fossil fuel energy projects, renewable energy projects entail a heavier upfront investment; the wasting of money and resources is a certain result if the sustainability of renewable energy itself is not carefully considered [9]. However, most attention is currently paid to the question of whether the energy industry is sustainable and what roles renewable energy can play in the energy industry, with little research on whether renewable energy itself is sustainable. Therefore, there is an urgent need for a multi-criteria decision-making (MCDM) framework to evaluate the sustainability of renewable energy.

### 1.1. Literature Review

There have been many studies evaluating energy systems, especially renewable energy, from different aspects. Santoyo-Castelazo and Azapagic [10] used MCDM to determine the most sustainable energy choices throughout the life cycle, including an analysis of the economic, social, and environmental costs and benefits. Chachi et al. [11] provided a systematic analysis of renewable energy performance using data envelopment analysis (DEA) to understand the diverging paths of renewable energy development for different countries. Fang et al. [12] focused on the potential approaches to evaluating and promoting the international competitiveness of the renewable energy industry of the Group of 20. Katre et al. [13] developed a framework for individually assessing the sustainability of specific models of energy access; it combines a multi-dimensional analysis of five sustainability dimensions with the Multi-Tier Framework (MTF) to assess technical sustainability. Wang et al. [14] presented a hybrid methodology that combines the data envelopment analysis (DEA) Window model and the fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS) to evaluate the capabilities of 42 countries in terms of their renewable energy production potential. Wang et al. [15] proposed an approach to offshore wind power station site selection using a two-stage MCDM-based spherical fuzzy set approach. The above studies mainly focus on the MCDM framework of renewable energy performance, production capacity, competitiveness, and site optimization. However, there is no assessment of the sustainability of renewable energy itself.

Only a few scholars have evaluated renewable energy sustainability. A comprehensive “Renewable Energy Sustainability Index” was proposed for renewable energy sustainability evaluation and related development stages [16]. By enhancing the indexes of positive impacts and mitigating the indexes of negative impacts, some solutions for developing renewable energy sustainability were proposed. By combining the pursuit algorithm projection and the genetic algorithm, which is real-coded accelerated, Wang and Zhan quantitatively evaluated the sustainable development of renewable energy [17]. However, the above studies did not consider the characteristics of different renewable energy sources. In addition, the construction of indicators under the goal of “carbon neutrality” needs to be improved. To sum up, it is necessary to establish a hybrid MCDM framework for an evaluation of the sustainability of renewable energy itself.

At present, the standard decision-making methods are mainly AHP (Analytic Hierarchy Process), TOPSIS (Technique for Order Performance by Similarity to Ideal Solution), and VIKOR (VIsekriterijumska Optimizacija I Kompromisno Resenje), etc. Many scholars have combined one or more methods with other models and proposed various hybrid MCDM methods. Solangi et al. [18] proposed an integrated framework to assess sustainable energy planning based on fuzzy TOPSIS and AHP. Zhao et al. [19] proposed an integrated

MCDM model combining the entropy weight method, the superior language rating, and extended fuzzy-GRA to assess renewable energy. Çelikkilek and Tüysüz [20] proposed a grey MCDM framework to evaluate renewable energy; it integrates three methods, including DMATEL (Decision Making Trial and Evaluation Laboratory), VIKOR, and ANP (Analytic Network Process).

Some studies introduced novel and innovative theories, such as cloud models, 2-dimension certain linguistic variables (2DULVs), and spherical fuzzy sets. A hybrid approach was proposed to mix 2DULVs, the cloud model, and the extended TODIM to evaluate renewable energy performance [6]. Wu et al. [21] presented an MCDM technique based on a fuzzy theory and the cumulative prospect theory for determining the most suitable form of renewable energy power in China. Mahmood et al. [22] introduced the concept of the spherical fuzzy set (SFS) and the T-spherical fuzzy set (T-SFS) as generalizations of the conventional fuzzy set (FS), the intuitionistic fuzzy set (IFS), and the PFS. Neutrosophic statistics extend classical statistics and are applied when the data come from a complex process or an uncertain environment [23]. Aslam [24] used neutrosophic statistics to analyze wind power data using analysis of means, then made an evaluation. Currently, MCDM framework methods for renewable energy are mostly traditional or single models that need to be improved and innovated on using a new theory. Therefore, in this paper, we propose an MCDM framework suitable for assessing the sustainability of renewable energy and based on the 2-tuple linguistic model and the prospect theory.

### 1.2. Contributions

In this study, a grey relation of the 2-tuple linguistic MCDM system is developed, in combination with the prospect theory, to explore the sustainability of renewable energy. Its contributions and innovations include:

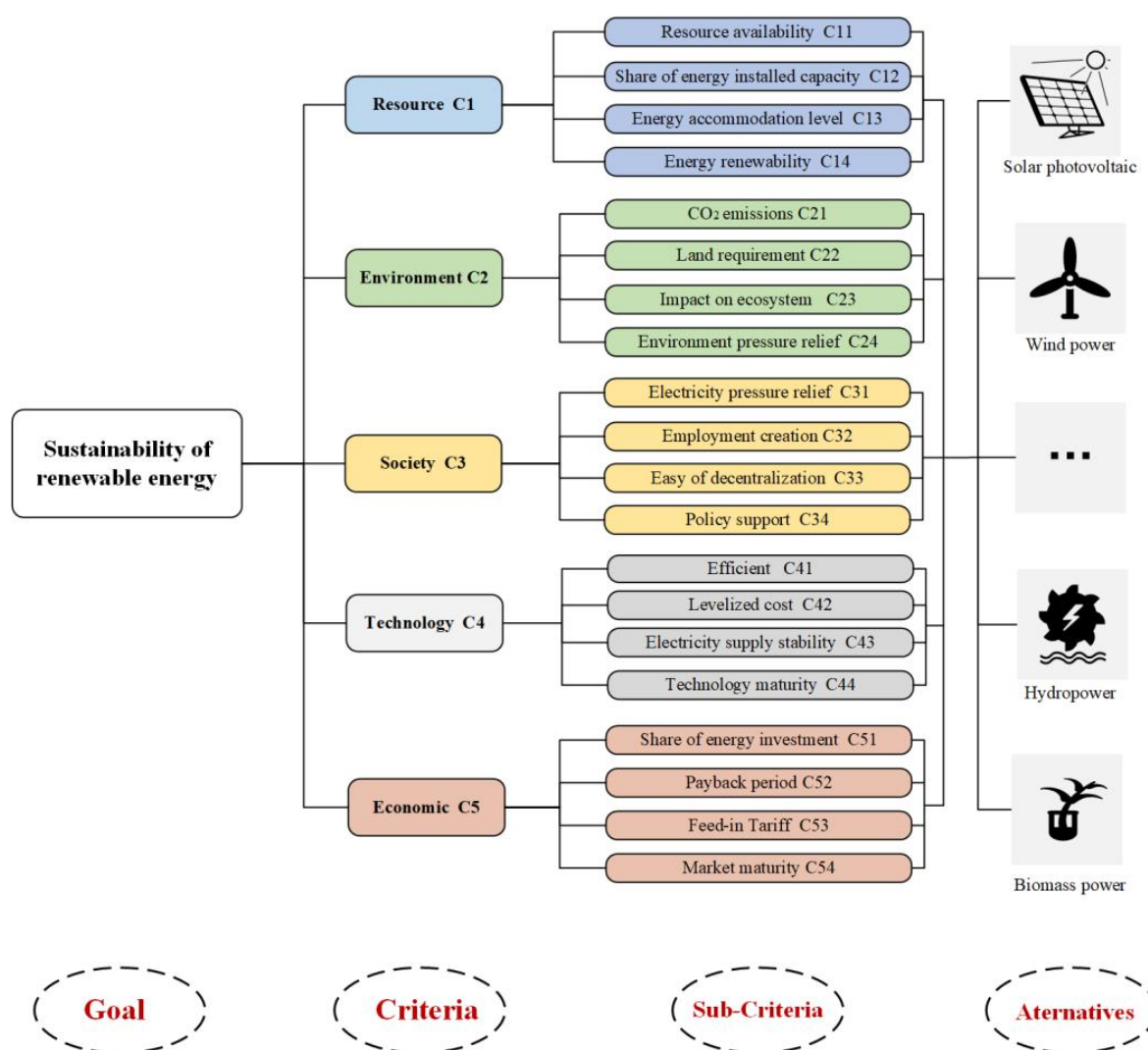
- (1) An MCDM framework for assessing the sustainability of renewable energy itself is established. Few existing studies have paid attention to renewable energy's sustainability. In this study, an evaluation system is designed with five dimensions: resources, the environment, society, technology, and the economy.
- (2) A 2-tuple linguistic model is introduced to the MCDM framework. The transformation 2-tuple linguistic model aims to process heterogeneous information; it effectively deals with the issues regarding multi-dimensional and non-normal data. Compared to general linguistic information, this 2-tuple linguistic model can effectively preserve information integrity and avoid the loss or distortion of information.
- (3) The grey relational analysis and the prospect theory are implemented in the MCDM framework. The prospect theory can take into consideration the psychological characteristics of decision makers and, when combined with the grey relational analysis, can boost the objectivity of the decision results.

### 1.3. The Structure of the Paper

The paper is structured as follows. Section 2 discusses an MCDM framework that evaluates the sustainability of renewable energy. A 2-tuple linguistic grey relation model based on the prospect theory is introduced in Section 3. Section 4 talks about a case study, and Section 5 presents our conclusions.

## 2. MCDM System

The key to MCDM is to establish an evaluation system. To assess the sustainability of renewable energy itself, the paper demonstrates an MCDM model with five aspects, as shown in Figure 1.



**Figure 1.** An MCDM framework for evaluating the sustainability of renewable energy.

### 2.1. Resources

The “resources” dimension mainly considers the impact of the availability, renewable capacity, and utilization on the sustainable development of renewable energy itself.

- Resource availability ( $\text{kWh}/\text{m}^2/\text{year}$ ). Resource availability reflects the natural character of each form of renewable energy, such as solar radiation, water flow speed, and wind speed. Availability is an essential criterion for renewable energy generation capacity.
- Share of energy installed capacity (%) [25]. The percentage of energy installed capacity represents the proportion of the renewable energy capacity installation compared to the total power installation capacity, reflecting the level of renewable energy utilization in terms of power generation equipment. The data are from “The China Energy Statistics Yearbook.”
- Energy accommodation level [26]. The energy accommodation level represents the accommodation of electricity generated from renewable energy sources on the demand side, especially whether there is the abandonment of wind and solar.
- Energy renewability [26]. Energy renewability represents the ability of renewable energy sources to re-attain their original level after they have been consumed; for example, with hydropower, this represents the ability to restore the power supply after the water flow has dried up.

## 2.2. The Environment

The “environment” dimension mainly considers renewable energy’s positive and negative influences on the ecological environment, including carbon emissions and land use, and conducts a life-cycle assessment. Our study assesses the sustainability of other renewable energy sources’ development based on environmental carrying capacity.

- CO<sub>2</sub> emissions (tCO<sub>2</sub> equivalent/MKW) [27,28]. CO<sub>2</sub> emissions represent the emitted CO<sub>2</sub> per MKW of renewable energy generation during the life cycle. For example, solar photovoltaic power involves the production, installation, maintenance, and recovery of solar panels.
- Land requirements (km<sup>2</sup>/GW) [29,30]. Land resources are required to build power plants. This is not only a cost that must be paid; it also affects the landscape.
- Impacts on the ecosystem [6,27,31]. The impact on the ecosystem represents the impact of renewable energy projects on the surroundings and the interactions with the ecosystem during the life cycle.
- Environmental pressure relief [32]. In contrast with fossil fuel resources, renewable energy contributes to alleviating environmental pressure and encouraging environmental friendliness.

## 2.3. Society

The “society” dimension involves two aspects. First, the contribution of renewable energy power to social development is considered. Second, social support for renewable energy is considered.

- Electricity pressure relief (%). Electricity pressure relief represents the share of renewable energy power in society’s total consumption of electricity.
- Employment creation (Jobs/MW) [33,34]. Whether fossil-fuel-based or renewable, an energy supply system needs to hire many employees for functions including construction, operations, and shutting down.
- Ease of decentralization [27]. A key advantage of renewable energy is the development of energy supply distribution. Various renewable energy sources offer easy decentralization, which builds more distributed electricity near users, thereby supporting flexible and long-term adaptation to the grid with lower energy losses.
- Policy support [6,27,35]. Policy support represents the government’s support for each form of RE, which influences the long-term development of RE.

## 2.4. Technology

The “technology” dimension mainly represents the efficiency, cost, and reliability of renewable energy generation and the maturity of the technology.

- Efficiency (%) [34,36,37]. Efficiency represents the useful energy that can be converted into electricity as a percentage of the total energy generated from renewable sources.
- Levelized cost (USD/kWh) [38]. Levelized cost refers to the value of the unit cost of electricity over the lifetime of an energy-generating asset.
- Electricity supply stability [27,39]. RE is greatly affected by natural conditions. The stability of the power supply is a significant technical criterion for evaluating the long-term development of RE.
- Technological maturity [27,28]. Technological maturity refers to the popularity of key renewable energy technologies and whether there is still room for improvement. It is an important element in assessing risk.

## 2.5. The Economy

The “Economy” dimension evaluates the economic feasibility and sustainability of renewable energy from the point of view of investors, including the investment proportion, the payback period, on-grid tariffs, and market developments.



- Share of energy investment (%) [38]. The share of energy investment is the proportion of various renewable energy investments as compared to total investment in power. The data are from “The China Energy Statistics Yearbook”.
- Payback period (Years) [36,40–42]. The payback period refers to the time required for the total income obtained from the project to be equal to the entire original project investment.
- Feed-in Tariff (yuan/kWh). The feed-in tariff refers to the metered price paid by the grid company when sources of renewable energy generation are connected to the power grid. It reflects the degree of policy support for renewable energy projects.
- Market maturity [34,43]. Market maturity refers to whether the market mechanisms related to renewable energy generation, transmission, and sales are complete and whether the market can coordinate with renewable energy development.

### 3. Methodology

#### 3.1. Basic Concept and Theory

##### 3.1.1. The Method of 2-Tuple Fuzzy Linguistic Representation

2-tuple fuzzy linguistic information is a kind of linguistic information that has emerged in recent years. Different types of linguistic information are transformed into 2-tuple linguistic information through mathematical models. It preserves the integrity of the original information to the greatest extent, avoids the distortion and loss of information, and can effectively solve multi-dimensional and non-normal data. Therefore, it is applied to unify heterogeneous information in this paper.

**Definition 1** [44]. The 2-tuple linguistic model refers to the transfer of symbols and  $(s_d, \alpha_d)$  is used to replace the natural language evaluation information given by DMs.  $s_i \in S = \{s_0, s_1, \dots, s_t\}$  represents a kind of symbol transfer value in the symbolic interpretation of the linguistic term  $S$ .  $\alpha_d \in [-0.5, 0.5)$  refers to the error between the evaluation result and  $s_d$ . Let  $s_d \in S$  be a linguistic term, and the function can obtain the equivalent 2-tuple representation:

$$\begin{aligned} o : S &\rightarrow S \times [-0.5, 0.5) \\ o(s_d) &= (s_d, \alpha_d), s_d \in S \end{aligned} \quad (1)$$

**Definition 2** [44]. Let  $S = \{s_0, s_1, \dots, s_t\}$  be a linguistic term set and  $\phi \in [0, t]$  be a value representing the outcome of the operation of a symbolic aggregation. It can be obtained with function  $\Delta$  and  $\Delta^{-1}$ :

$$\begin{aligned} \Delta : [0, t] &\rightarrow S \times [-0.5, 0.5) \\ \Delta(\phi) &= (s_d, \alpha_d) = \left\{ \begin{array}{l} s_d, d = \text{round}(\phi) \\ \alpha_d = \phi - i, \alpha_d \in [-0.5, 0.5) \end{array} \right\} \end{aligned} \quad (2)$$

$$\Delta^{-1}(s_d, \alpha_d) = i + \alpha_d = \phi \quad (3)$$

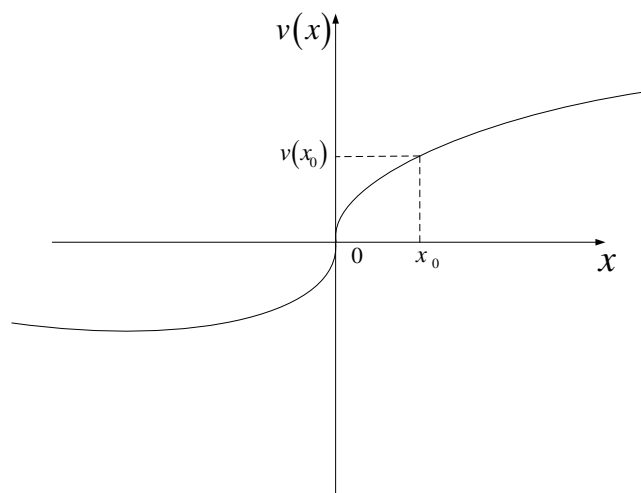
##### 3.1.2. Prospect Theory

Traditional decision-making methods are based on the assumption of a “completely rational person”, but the results may differ from the actual situation. The prospect theory is a decision-making theory based on “Limited Psychology”. The prospect theory considers the psychological characteristics of decision makers. According to the prospect theory, the prospect value  $V$  consists of the value function  $v(\Delta x)$  and the weight function  $w(p)$ , as shown in Figure 2. The value function refers to the risk preference. After many experiments, Tversky and Kahneman proposed a value function based on a power function [45]. They are obtained with the following function:

$$V = \sum_{i=1}^n w(p_i) v(\Delta x_i) \quad (4)$$

$$v(\Delta x) = \begin{cases} (\Delta x)^\alpha, \Delta x \geq 0 \\ -\theta(-\Delta x)^\beta, \Delta x < 0 \end{cases} \quad (5)$$

where  $x$  denotes the losses or gains.  $x < 0$  refers to the losses, and  $x \geq 0$  stands for the gains.  $0 \leq \alpha \leq \beta \leq 1, \theta > 1$ .



**Figure 2.** Prospect Theory.

The weight functions  $w(p)$  for gains and losses, respectively, are:

$$w^+(p) = \frac{p^\varphi}{(p^\varphi + (1-p)^\varphi)^{1/\varphi}}, \Delta x \geq 0 \quad (6)$$

$$w^-(p) = \frac{p^\delta}{(p^\delta + (1-p)^\delta)^{1/\delta}}, \Delta x \leq 0 \quad (7)$$

### 3.1.3. The Grey Relation Analysis

The grey correlation analysis analyzes the correlation between reference sequences  $R^* = [r_1^*, r_2^* \dots r_m^*]^T$  and comparison sequences  $R^j = [r_{1j}, r_{2j} \dots r_{mj}]^T$  [46]. The grey correlation coefficient is calculated as follows:

$$\zeta_i^j = \frac{\min_j \min_i |r_i^* - r_{ij}| + \rho \max_j \max_i |r_i^* - r_{ij}|}{|r_i^* - r_{ij}| + \rho \max_j \max_i |r_i^* - r_{ij}|} \quad (8)$$

where  $\rho$  is the resolution coefficient,  $\rho \in (0, 1)$ .

### 3.2. Decision Framework

There are two critical issues in the evaluation of the sustainability of renewable energy. (1) How to unify all kinds of information. Due to the many factors influencing renewable energy, the question of how to unify heterogeneous information is a problem that must be solved. This study introduces the method of 2-tuple fuzzy linguistic representation to address the nonlinearity of multi-dimensional data. (2) How to increase the objectivity of the results of decision making. For one thing, the abilities of experts have a significant impact on the results, and the question of how to improve the objectivity of qualitative indicators is an issue. 2-tuple fuzzy linguistic information includes multiple levels that can retain the original information to the greatest extent. Additionally, many evaluation studies are based on the hypothesis of “completely rational people.” How to consider the psychological characteristics of decision makers (DMs) is another issue. Therefore, this study applies the prospect theory to consider DMs’ risk preferences. This study proposes

a 2-tuple linguistic grey relation model combined with the prospect theory, as shown in Figure 3.

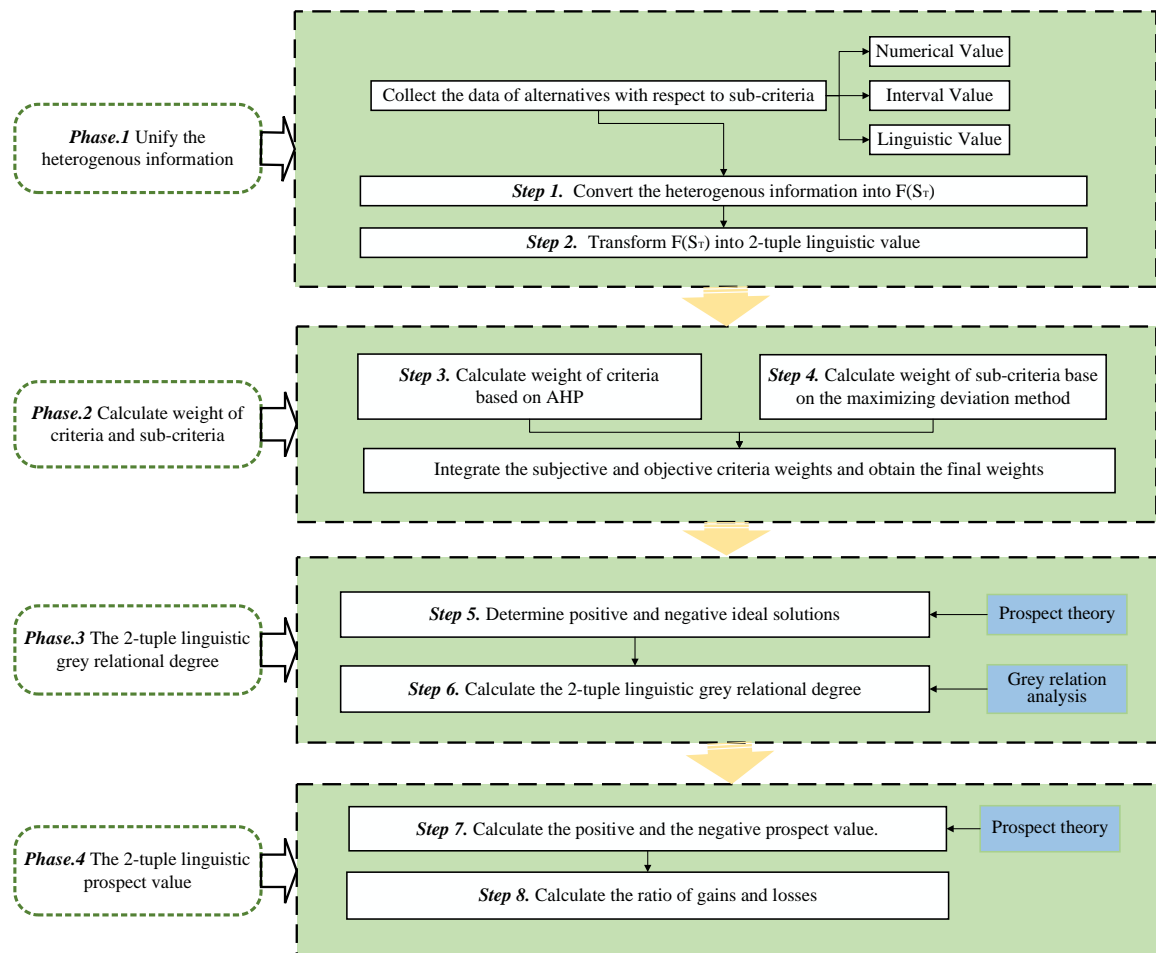


Figure 3. Decision framework.

Phase 1. Unify the heterogeneous information.

Step 1. Convert the heterogeneous information into  $F(S_T)$ .

This step uses a basic linguistic term set  $S_T = \{s_0, s_1, \dots, s_t\}$ , shown in Figure 4, denoted as  $F(S_T)$ .  $S_T = \{s_0, s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}, s_{12}, s_{13}, s_{14}\}$  is selected as the basic linguistic term, with 15 terms symmetrically arranged.

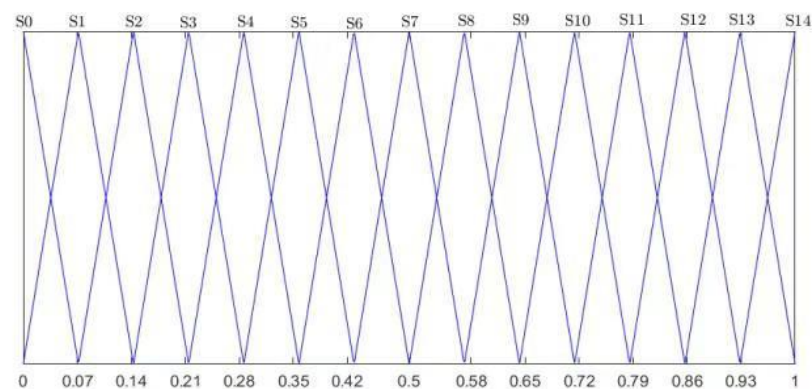


Figure 4. The basic linguistic term.



1. Transform numerical value  $\varsigma \in [0, 1]$  into  $F(S_T)$  [47].  
The function  $\tau_N$  converts a numerical value  $\varsigma$  into  $F(S_T)$  in,

$$\tau_N : \varsigma \in [0, 1] \rightarrow F(S_T) \quad \tau_N(\varsigma) = \{(s_0, \gamma_0), (s_1, \gamma_1), \dots, (s_t, \gamma_t)\}, \quad (9)$$

$$s_d \in S_T, d \in \{0, 1, \dots, t\}$$

$$\gamma_d = \mu_{sd}(\varsigma) = \begin{cases} 0 & , \text{ if } \varsigma \notin \text{support}(\mu_{sd}(x)) \\ (\varsigma - m_d)/(n_d - m_d) & , \text{ if } m_d \leq \varsigma \leq n_d \\ 1 & , \text{ if } n_d \leq \varsigma \leq p_d \\ (p_d - \varsigma)/(p_d - q_d) & , \text{ if } p_d \leq \varsigma \leq q_d \end{cases} \quad (10)$$

2. Transform interval value  $I = [\bar{i}, i]$  in  $[0, 1]$  into  $F(S_T)$  [47].

The function  $\tau_I$  transforms an interval value  $I = [\bar{i}, i]$  into  $F(S_T)$  in,

$$\tau_I : I \in [0, 1] \rightarrow F(S_T)$$

$$\tau_I(I) = \{(s_0, \gamma_0), (s_1, \gamma_1), \dots, (s_t, \gamma_t)\}, \quad (11)$$

$$s_d \in S_T, d \in \{0, 1, \dots, t\}$$

$$\mu_I(\varepsilon) = \begin{cases} 0 & , \text{ if } \varepsilon < \bar{i} \\ 1 & , \text{ if } \bar{i} \leq \varepsilon \leq i \\ 0 & , \text{ if } i < \varepsilon \end{cases} \quad (12)$$

$$\gamma_i = \maxmin\{\mu_I(y), \mu_{sd}(y)\} \quad (13)$$

3. Transform linguistic terms  $S = \{l_0, l_1 \dots l_p\}$  into  $F(S_T)$  [47].

The function  $\tau_L$  transforms linguistic terms  $S = \{l_0, l_1 \dots l_p\}$  into  $F(S_T)$  in,

$$\tau_L : l_d \in S \rightarrow F(S_T)$$

$$\tau_L(l_d) = \{(s_0, \gamma_0), (s_1, \gamma_1), \dots, (s_t, \gamma_t)\}, \quad (14)$$

$$s_d \in S_T, i \in \{0, 1, \dots, t\}$$

$$\gamma_i = \maxmin\{\mu_{ld}(y), \mu_{sd}(y)\} \quad (15)$$

This paper selects  $S = \{l_0, l_1, l_2, l_3, l_4\}$  as expert evaluation linguistic terms that are denoted in linguistic terms as {very low, low, fair, high, very high}, as shown in Figure 5.

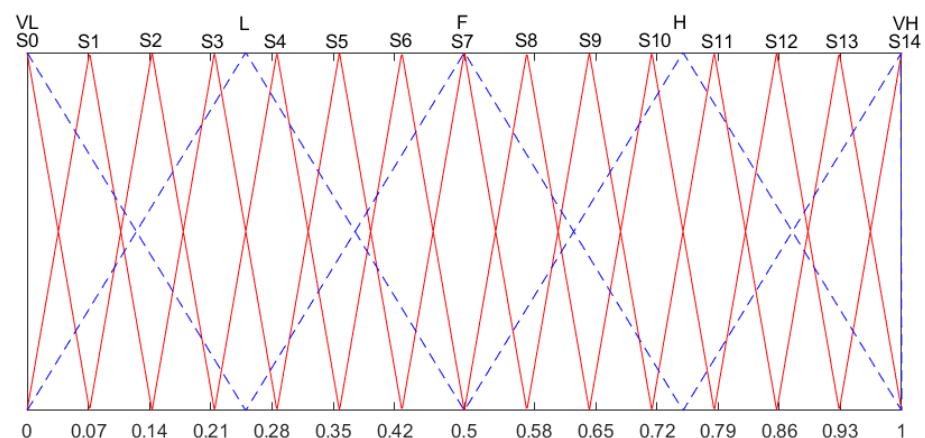


Figure 5. The basic linguistic term and expert evaluation linguistic term.

Step 2. Transform  $F(S_T)$  into 2-tuple linguistic value [47].

$$\chi : F(S_T) \rightarrow [0, t]$$

$$\chi(F(S_T)) = \chi(\{(s_d, \gamma_d), d = 0, 1, \dots, t\}) = \frac{\sum_{d=0}^t i\gamma_d}{\sum_{d=0}^t \gamma_d} = \phi \quad (16)$$

Therefore, using the function  $\Delta$ , we can obtain a collective preference relation, and then it can be expressed with linguistic 2-tuples:

$$\Delta(\chi(F(S_T))) = \Delta(\phi) = (s_d, \alpha), s_d \in S_T \quad (17)$$

Phase 2. Calculate criteria and sub-criteria weight.

Step 3. Calculate the weight of criteria based on AHP [48].

Experts judge the significance of one criterion relative to another. The weights  $\lambda_k$  can be obtained, where  $k = 1, 2, 3, 4, 5$ .

Step 4. Calculate the weight of sub-criteria based on the method of maximizing deviation.

Maximizing deviation was proposed by Qu et al. [49] to determine criteria weights. The more the criteria  $C_j$  significantly differ between the evaluation values of alternatives, the greater the weight. The optimization model is as follows:

$$\begin{cases} \max D(\omega) = \sum_{q=1}^p \sum_{i=1}^m \sum_{l=1}^m \omega_j |S_{iq} - S_{lq}| \\ \text{s.t. } \sum_{j=1}^n (\omega_j)^2 = 1, \omega_j > 0, q = 1, 2, \dots, p \end{cases} \quad (18)$$

where  $S_{iq} - S_{lq} = \Delta^{-1}(d((s_d, \alpha_d)_{iq}, (s_d, \alpha_d)_{lq}))$  represents the total deviation of all alternatives from other alternatives.

The Lagrange function is used to solve the optimization model, as follows:

$$\omega_j = \sum_{i=1}^m \sum_{l=1}^m |S_{iq} - S_{lq}| / \sqrt{\sum_{q=1}^p \left[ \sum_{i=1}^m \sum_{l=1}^m |S_{iq} - S_{lq}| \right]^2} \quad (19)$$

$$(\omega_q)^* = \omega_q / \sum_{q=1}^p \omega_q, q = 1, 2, \dots, p \quad (20)$$

Finally, the comprehensive weight of sub-criteria  $\omega_j$  based on AHP and maximizing deviation method is calculated as follows:

$$\omega_j = (\omega_q)^* \lambda_k, j = 1, 2, \dots, n, q = 1, 2, \dots, p, k = 1, 2, 3, 4, 5 \quad (21)$$

Phase 3. The 2-tuple linguistic grey relational degree.

Step 5. Determine the positive and negative ideal solutions.

According to the prospect theory, measuring losses or gains requires a decision reference point, so the gains or losses obtained at different reference points are different.

The paper takes the ideal solutions, including the positive and negative ones, as the reference point for decision making. The principle for selecting such solutions is as follows:

$$(s_d^+, \alpha_d^+)_j = \begin{cases} \max_i (s_d, \alpha_d)_{ij}, \text{ benefit criteria } C_j \\ \min_i (s_d, \alpha_d)_{ij}, \text{ cost criteria } C_j \end{cases} \quad (22)$$

$$(s_d^-, \alpha_d^-)_j = \begin{cases} \min_i (s_d, \alpha_d)_{ij}, \text{ benefit criteria } C_j \\ \max_i (s_d, \alpha_d)_{ij}, \text{ cost criteria } C_j \end{cases} \quad (23)$$

where  $i = 1, 2, \dots, m, j = 1, 2, \dots, n$ .

Step 6. Calculate the 2-tuple linguistic grey relational degree.

$$(\xi_d^+, \eta_d^+)_{ij} = \Delta \left( \frac{\min_i \min_j D_{ij}^+ + \rho \max_i \max_j D_{ij}^+}{D_{ij}^+ + \rho \max_i \max_j D_{ij}^+} \right) \quad (24)$$

$$(\xi_d^-, \eta_d^-)_{ij} = \Delta \left( \frac{\min_i \min_j D_{ij}^- + \rho \max_i \max_j D_{ij}^-}{D_{ij}^- + \rho \max_i \max_j D_{ij}^-} \right) \quad (25)$$

where  $D_{ij}^+ = |\Delta^{-1}(s_d, \alpha_d)_{ij} - \Delta^{-1}(s_d^+, \alpha_d^+)_{ij}|$ ,  $D_{ij}^- = |\Delta^{-1}(s_d, \alpha_d)_{ij} - \Delta^{-1}(s_d^-, \alpha_d^-)_{ij}|$ ;  $\rho \in [0, 1]$ ,  $\rho$  generally takes 0.5.

Phase 4. The 2-tuple linguistic prospect value.

Step 7. Calculate the positive and negative prospect values.

Firstly, a prospect value function is constructed, as follows:

$v_{ij}^+ = \left(1 - \Delta^{-1}(\xi_d^-, \eta_d^-)_{ij}\right)^\alpha$  represents the deviation of the substitute from the negative ideal solution, shown as a gain value function;  $v_{ij}^- = -\theta \cdot \left[-\Delta^{-1}((\xi_d^+, \eta_d^+)_{ij} - 1)\right]^\beta$  represents the deviation of the replacement from the positive ideal solution, denoted as a loss value function.

Then, calculate the positive and the negative prospect values, as follows:

$$V_i^+ = \sum_{j=1}^n v_{ij}^+ \left(\Delta^{-1}(\xi_d^-, \eta_d^-)_{ij}\right) w^+(p_j) = \sum_{j=1}^n \left[\left(1 - \Delta^{-1}(\xi_d^-, \eta_d^-)_{ij}\right)\right]^\alpha \times \frac{\omega_j^\gamma}{\left(\omega_j^\gamma + (1 - \omega_j)^\gamma\right)^{1/\gamma}} \quad (26)$$

$$V_i^- = \sum_{j=1}^n v_{ij}^- \left(\Delta^{-1}(\xi_d^+, \eta_d^+)_{ij}\right) w^-(p_j) = \sum_{j=1}^n \left(-\theta \left(-1 - \Delta^{-1}(\xi_d^+, \eta_d^+)_{ij}\right)\right)^\beta \times \frac{\omega_j^\delta}{\left(\omega_j^\delta + (1 - \omega_j)^\delta\right)^{1/\delta}} \quad (27)$$

$V_i^+$  and  $V_i^-$  represent the 2-tuple linguistic prospect value of the alternative;  $V_i^+$  represents the positive prospect value, shown as benefits, and  $V_i^-$  represents the negative prospect value, denoted as losses.

Step 8. Calculate the ratio of gains and losses.

$$R_i = |V_i^+ / V_i^-|, i = 1, 2, \dots, m \quad (28)$$

Sort the alternatives according to the ratio of gains and losses  $R_i$ , and the optimal alternative can be obtained.

## 4. Case Study

### 4.1. Background Information

As the largest country in Asia, China has a significant ability to develop renewable energy. The year 2018 witnessed an installed renewable energy capacity in China that reached 729.86 million kW, 38.4% [25]. This paper selects China as a case study. For one thing, China is rich in solar, wind, and water resources. The installed capacity of various forms of renewable energy is among the highest globally, so there is enough material to study the sustainability of each form of renewable energy. In addition, natural resources and electricity demand in China are inversely distributed. Developing renewable resources sustainably while coordinating the relationship between supply and demand is a challenge. The distribution of solar photovoltaic power, hydropower, wind power, and biomass power in China is shown in Figure 6.



**Figure 6.** The distribution of renewable energy in China.

#### 4.2. Results and Discussions

Renewable energy in China is the research object of this paper. The quantitative data mainly come from statistical data and the literature. Experts from three energy industries are asked to rate the qualitative indicators, and the three experts all have equal weight. Initial data are shown in Appendix A.

In Phase 1, heterogeneous information relating to twenty indicators is unified into the 2-tuple linguistic value. It is shown in Table 1.

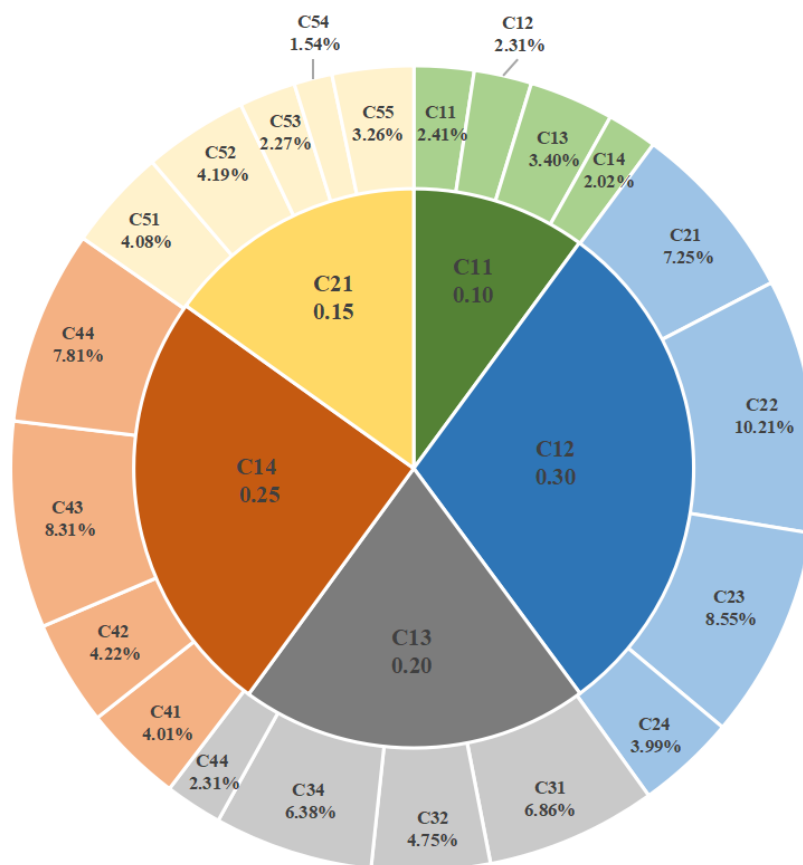
##### 4.2.1. Discussion of the Weights

Based on Phase 2, the final weights of the sub-criteria are obtained, as shown in Figure 7. Out of the weights for the five criteria, the weight of “resources” is the largest at 30%, followed by “society”, “the environment”, “technology”, and “the economy”. This shows that the resources criterion has the most significant influence on the sustainability of renewable energy, and the impact of economics is small.

From the ranking of the sub-criteria weights (Figure 8), the order of the weights is as follows: share of installed energy capacity (C11) > energy accommodation level (C12) > ease of decentralization (C33) > policy support (C34). First, renewable energy is more plentiful than fossil fuel energy, so renewable energy’s sustainability relies mainly on the level of renewable energy development in terms of installed equipment and the electricity accommodation level on the demand side. Second, a great advantage of renewable energy is its capacity for building distributed power generation systems. The distances between the power generation station and the user are significantly decreased, which is more convenient and economical. Third, compared with traditional power, the profitability of renewable energy projects is not advantageous. Encouraging investors to invest in renewable energy projects is another issue that determines sustainability. In this process, the government’s incentive policy plays a big role.

**Table 1.** The decision matrix of the 2-tuple linguistic value.

Sub-Criteria	Type	Solar Photovoltaic Power	Wind Power	Hydropower	Biomass Power
Resource availability	benefit	$(S_{14}, 0)$	$(S_3, -0.340)$	$(S_7, -0.420)$	$(S_0, 0)$
Share of installed energy capacity	benefit	$(S_{14}, 0)$	$(S_4, 0.200)$	$(S_3, -0.060)$	$(S_0, 0)$
Energy accommodation level	benefit	$(S_8, -0.020)$	$(S_0, 0)$	$(S_{14}, 0)$	$(S_{14}, 0)$
Energy renewability	benefit	$(S_{13}, 0.200)$	$(S_{13}, -0.033)$	$(S_8, -0.275)$	$(S_6, 0.316)$
CO <sub>2</sub> emissions	cost	$(S_{14}, 0)$	$(S_3, -0.340)$	$(S_0, 0)$	$(S_6, -0.190)$
Land requirements	cost	$(S_1, -0.402)$	$(S_2, 0.095)$	$(S_{13}, 0.064)$	$(S_9, -0.457)$
Impacts on the ecosystem	cost	$(S_5, -0.092)$	$(S_9, 0.316)$	$(S_{13}, -0.033)$	$(S_{11}, -0.092)$
Environmental stress relief	benefit	$(S_{13}, -0.500)$	$(S_{11}, -0.092)$	$(S_8, -0.275)$	$(S_9, 0.316)$
Electrical pressure relief	benefit	$(S_{11}, -0.500)$	$(S_{14}, 0)$	$(S_1, 0.400)$	$(S_0, 0)$
Employment creation	benefit	$(S_7, 0)$	$(S_1, 0.035)$	$(S_1, 0.441)$	$(S_8, 0.475)$
Ease of decentralization	benefit	$(S_{13}, 0.200)$	$(S_8, -0.275)$	$(S_5, -0.092)$	$(S_{13}, -0.500)$
Policy support	benefit	$(S_{13}, 0.200)$	$(S_{13}, -0.033)$	$(S_8, -0.275)$	$(S_{13}, -0.500)$
Efficiency	cost	$(S_1, 0.225)$	$(S_2, 0.339)$	$(S_7, 0)$	$(S_{12}, -0.036)$
Levelized cost	cost	$(S_{13}, -0.225)$	$(S_5, -0.331)$	$(S_1, 0.225)$	$(S_4, 0.116)$
Electricity supply stability	benefit	$(S_{13}, 0.200)$	$(S_{10}, -0.450)$	$(S_{11}, 0.142)$	$(S_{13}, -0.500)$
Technological maturity	benefit	$(S_{13}, 0.200)$	$(S_{10}, -0.450)$	$(S_{11}, 0.142)$	$(S_{13}, -0.500)$
Share of energy investment	benefit	$(S_4, 0.340)$	$(S_{14}, 0)$	$(S_{13}, -0.40)$	$(S_0, 0)$
Payback period	cost	$(S_6, 0.366)$	$(S_{12}, 0.092)$	$(S_3, 0.164)$	$(S_3, 0.260)$
Feed-in tariff	benefit	$(S_{10}, -0.182)$	$(S_6, -0.114)$	$(S_3, -0.182)$	$(S_8, -0.406)$
Market maturity	benefit	$(S_{13}, -0.500)$	$(S_9, 0.316)$	$(S_{13}, -0.033)$	$(S_4, 0.142)$

**Figure 7.** The weights of the criteria and sub-criteria.

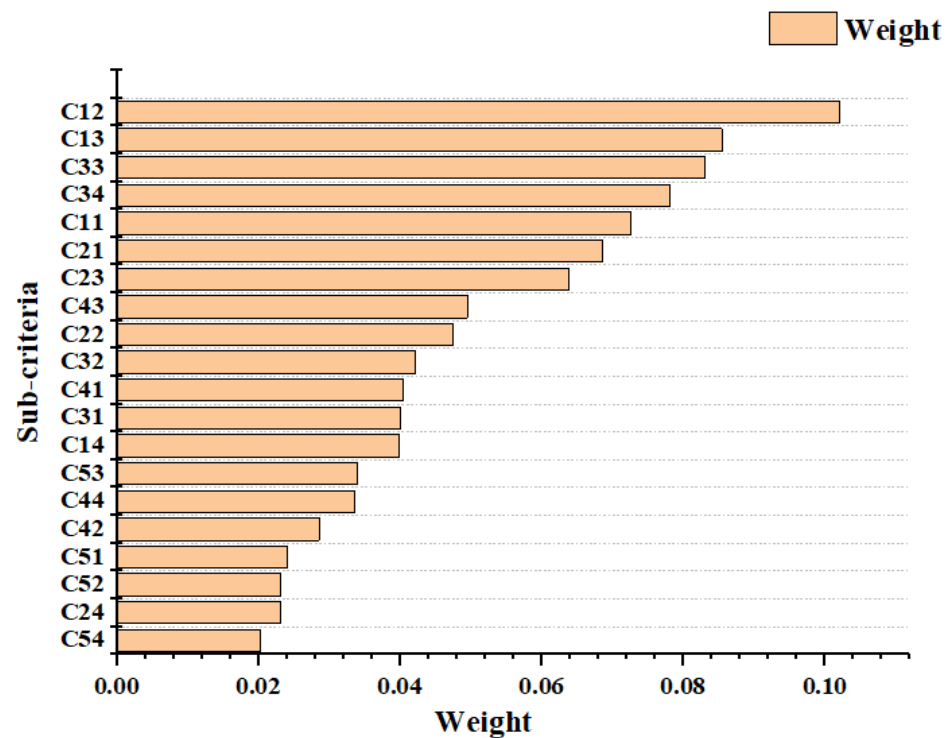


Figure 8. The ranking of the sub-criteria weights.

#### 4.2.2. Discussion of the Ideal Solutions

Based on Phase 3, the ideal solutions for the prospect theory are obtained. The positive ideal solution is as follows:

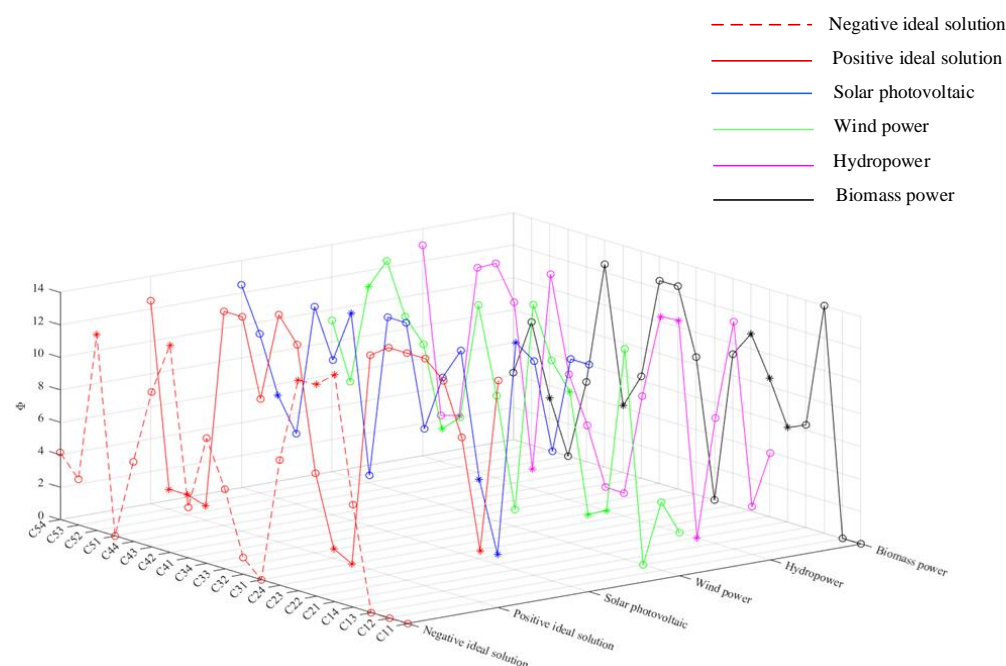
$$(s_d^+, \alpha_d^+) = \begin{pmatrix} (s_{14}, 0) & (s_{14}, 0) & (s_{14}, 0) & (s_{13}, 0.2) \\ (s_0, 0) & (s_1, -0.402) & (s_5, -0.092) & (s_{13}, -0.5) \\ (s_{14}, 0) & (s_8, 0.475) & (s_{13}, 0.2) & (s_{13}, 0.2) \\ (s_{14}, -0.451) & (s_1, 0.225) & (s_{13}, -0.5) & (s_{13}, 0.2) \\ (s_{14}, 0) & (s_3, 0.164) & (s_{10}, -0.182) & (s_{13}, -0.033) \end{pmatrix}$$

The negative ideal solution is as follows:

$$(s_d^-, \alpha_d^-) = \begin{pmatrix} (s_0, 0) & (s_0, 0) & (s_0, 0) & (s_6, 0.316) \\ (s_{14}, 0) & (s_{13}, 0.062) & (s_{13}, -0.033) & (s_8, -0.275) \\ (s_0, 0) & (s_1, 0.035) & (s_5, -0.092) & (s_8, -0.275) \\ (s_3, 0.115) & (s_{13}, -0.225) & (s_{10}, -0.450) & (s_5, -0.092) \\ (s_0, 0) & (s_{12}, 0.092) & (s_3, -0.182) & (s_4, 0.142) \end{pmatrix}$$

We compare the four alternatives with the ideal solution, as shown in Figure 9, where the dots represent the benefit-type indicators and the asterisks denote the cost-type indicators. For the positive ideal solution, the  $\phi$  of the benefit-type indicators is at a relatively high level, while the  $\phi$  of the cost-type indicators is at a relatively low level. The negative ideal solution is just the opposite. By comparing the alternatives with the positive and negative ideal solutions, each alternative's strengths and weaknesses can be obtained.



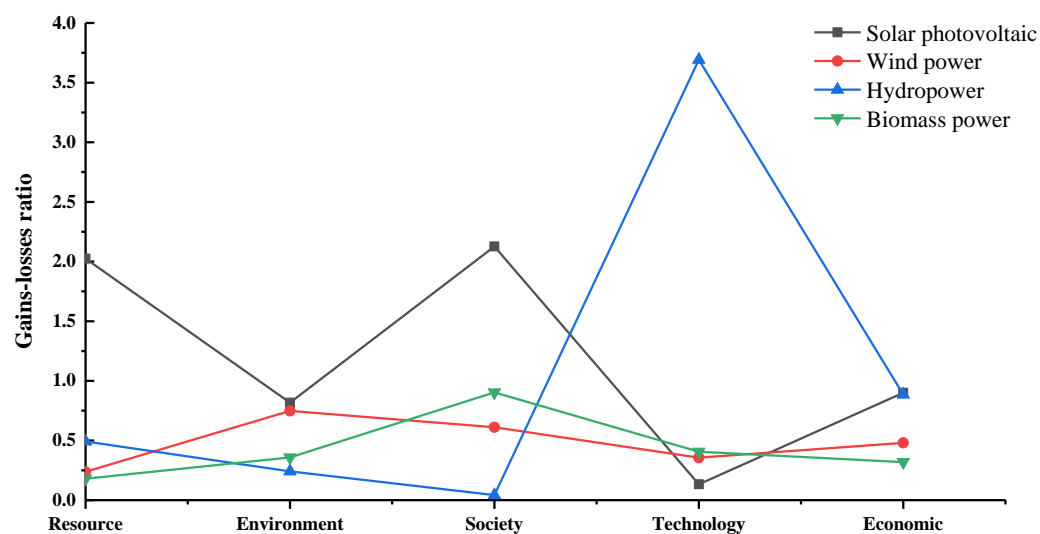


**Figure 9.** The comparison of alternatives with the positive ideal solution and the negative ideal solution.

Taking biomass power as an example, we see that when compared to other forms of power generation, the popularity of biomass power in China is low; therefore, the installed capacity, the proportion of investment, and the power generation capacity of biomass power generation are low. However, biomass power is at a high level in terms of stability and employment creation. Compared with methods that generate intermittent power, such as small-scale hydropower, solar photovoltaic power, and wind power, it has a superior power quality and high reliability. It can also provide a large amount of stable employment.

#### 4.2.3. Discussion of the Rankings

Based on Phase 4, this study obtains the profit–loss ratio of each alternative  $R_i = \{ 0.96863567, 0.431756841, 0.39474594, 0.368916558 \}$ , as shown in Figure 10. The final ranking is solar photovoltaic power  $\succ$  wind power  $\succ$  hydropower  $\succ$  biomass power.



**Figure 10.** The gain–loss ratio of each alternative for each criterion.

In addition, each alternative's positive and negative prospect values for each criterion are obtained, as shown in Figure 11. Taking hydropower as an example, the “resources” criterion displays the best performance. On the one hand, China has abundant water resources and development potential; on the other hand, hydropower developed earlier and therefore has a large installed capacity. It is worth mentioning that hydropower also performs well under the “technology” criterion because its technological maturity and efficiency are high. Additionally, its levelized cost is low. Hydropower performed the worst in the “society” criterion. Hydropower depends on geographical conditions, and the distribution of suitable sites is concentrated. Hydropower is mainly distributed in the southwestern region of China, so it is not suitable for distributed power generation. As a result, the distance to users is relatively long. Secondly, as a mature form of power generation, the government's support is relatively small, which is also a primary reason affecting hydropower sustainability. In response to these problems, the state should encourage the development of small hydropower generation projects, accelerate hydropower development in various places, and improve the price mechanism and incentive policies.

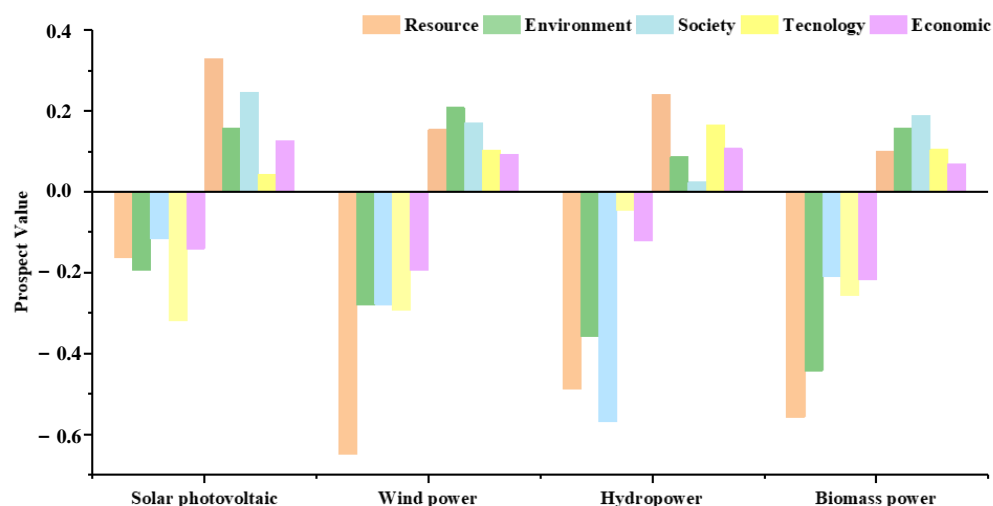


Figure 11. Positive and negative prospect values of alternatives under each criterion.

#### 4.3. Sensitive Analysis

##### 4.3.1. Change in Psychological Characteristics

$\alpha$ ,  $\beta$  are the risk attitude parameters in the prospect theory and represent the unevenness of the gain and loss in the value function, respectively. The larger the value of  $\alpha$ , the greater the likelihood that DMs pursue risk when facing gains; the larger the value of  $\beta$ , the greater the possibility that DMs pursue risk when facing losses. Conversely, as  $\alpha$  and  $\beta$  decrease, DMs are more conservative in the face of risk. According to Kahneman and Tversky, when  $\alpha = \beta = 0.88$ , the behavior of DMs is more consistent with the actual situation. The study set  $\alpha, \beta \in [0.2, 1]$  for sensitivity analysis, as shown in Figures 12 and 13.

For  $\alpha$ , as  $\alpha$  increases, the gain–loss ratio of each alternative decreases, which shows that the more likely DMs are to pursue risk, the less likely they are to invest in the alternative. From the choice of alternatives, the difference in the investment probability of DMs for each scheme is reduced. However, the ranking is the same as when  $\alpha = 0.88$ . For  $\beta$ , the changing trend is precisely the opposite of  $\alpha$ . Compared with the ranking of the various schemes when  $\beta = 0.88$ , solar photovoltaic power is still the optimal selection for DMs, followed by wind power, hydropower, and biomass power.

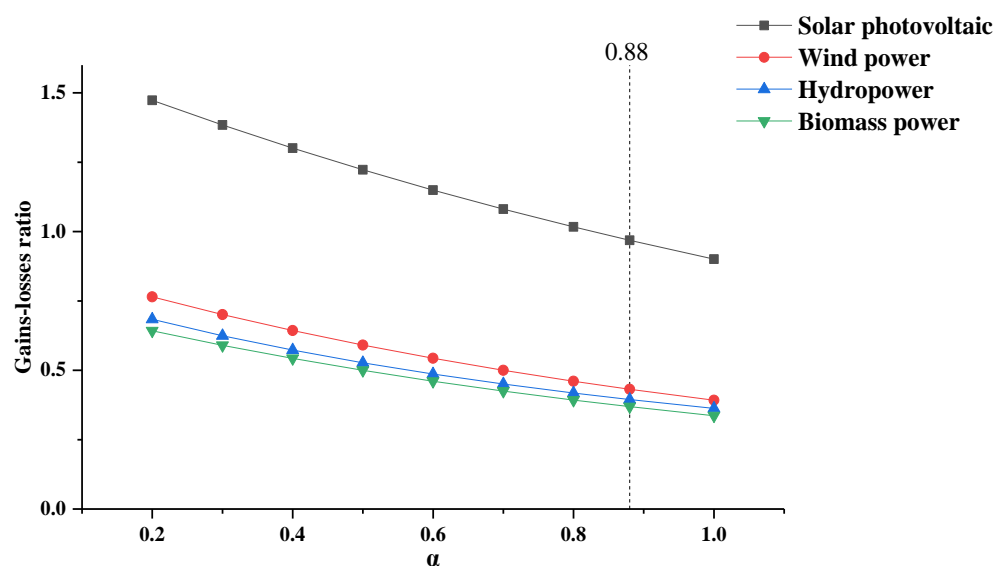


Figure 12. The sensitivity analysis of  $\alpha$ .

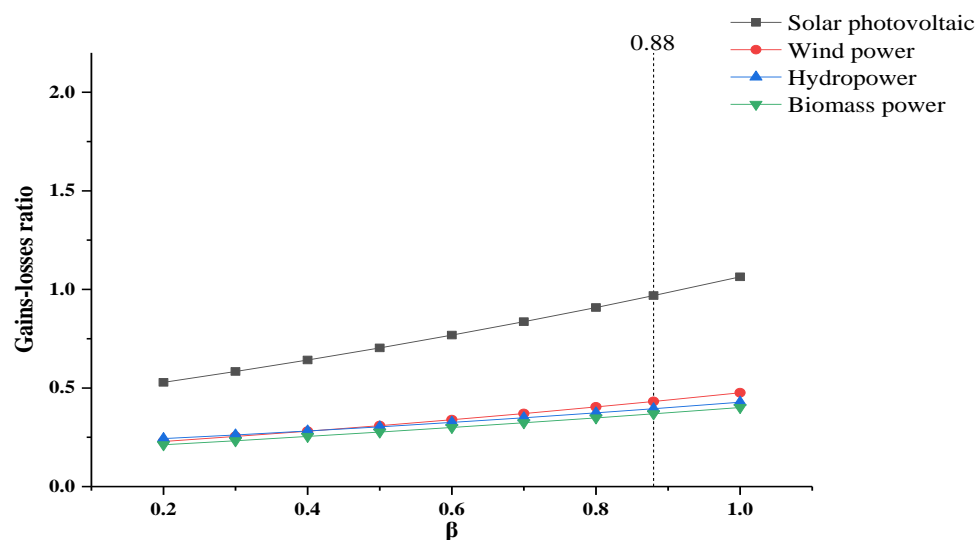


Figure 13. The sensitivity analysis of  $\beta$ .

$\theta$  is the loss aversion parameter of the prospect theory and indicates the sensitivity to loss. The larger the value of  $\theta$ , the higher the sensitivity to loss. According to Kahneman and Tversky, when  $\theta = 0.88$ , the behavior of DMs is more consistent with the actual situation. The study set  $\theta \in [1.5, 3.5]$  for the sensitivity analysis is shown in Figure 14. As  $\theta$  increases, the gain–loss ratio of each alternative decreases. When DMs are more sensitive to losses, they are less likely to invest in each alternative. From the choice of alternatives, the difference in the investment probability of DMs for each scheme is reduced. In addition, the ranking is not changed.

A change in the parameters affects the gain–loss ratio, but the ranking of the four alternatives does not change. The psychological characteristics of DMs affect their evaluation value of each alternative to a certain extent. Still, fluctuations within a certain range do not affect the results, proving the evaluation framework’s stability. Based on the prospect theory, the MCDM framework can adjust the parameters according to the psychological characteristics of different DMs and then establish a suitable system to refer to decisions.

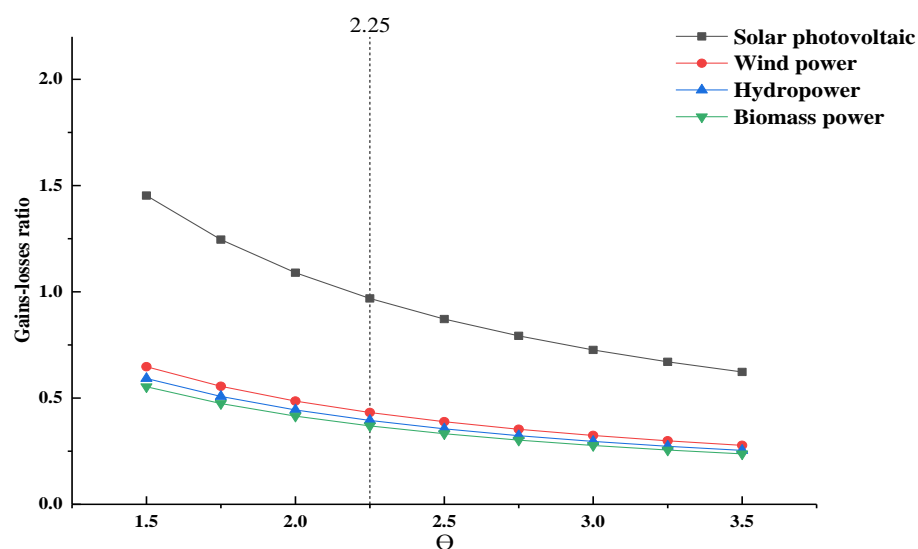


Figure 14. The sensitivity analysis of  $\theta$ .

#### 4.3.2. Change in Development Goals

Sustainable development refers to both current growth and long-term future development and the goal of meeting human needs without exceeding the carrying capacity of society or the environment. Therefore, when considering the sustainability of renewable energy, environmental capacity and social needs are the two most important factors besides renewable energy itself. This section aims to analyze different development goals. Based on the baseline scenario, we establish the following three sets: matching criteria, higher environment criterion, and higher society criterion (as shown in Table 2).

Table 2. The weight of criteria in different scenarios.

	Baseline Scenario	Scenario 1	Scenario 2	Scenario 3
Resources	0.30	0.2	0.1	0.1
Environment	0.20	0.2	0.6	0.1
Society	0.24	0.2	0.1	0.6
Technology	0.15	0.2	0.1	0.1
Economy	0.10	0.2	0.1	0.1

Scenario 1. It is assumed that the four criteria are equally important, as shown in Figure 15. It is also found that the ranking is not changed. The difference between the profit and loss ratios for the four scenarios under Scenario 1 is smaller than under the baseline scenario, which indicates that the gap in renewable energy sustainability can be reduced when the four standard weights are equal. In addition, the gain-loss ratios of solar photovoltaic power and wind power are smaller than in the baseline scenario, which indicates that when the weights of the resources, environmental, and social criteria decrease, it is not conducive to the sustainability of solar photovoltaic power and wind power.

Scenario 2. It is assumed that more emphasis is placed on the various renewable energy influences on the environment, increasing the weight of the environmental criterion, as shown in Figure 16. It is found that the ranking does not change. However, the gain-loss ratio of wind power increases, and the gain-loss ratios of solar photovoltaic power and hydropower decrease; of the two, wind power is the most sensitive. When the weight of the environmental criterion increases, it helps facilitate the sustainability of wind power.

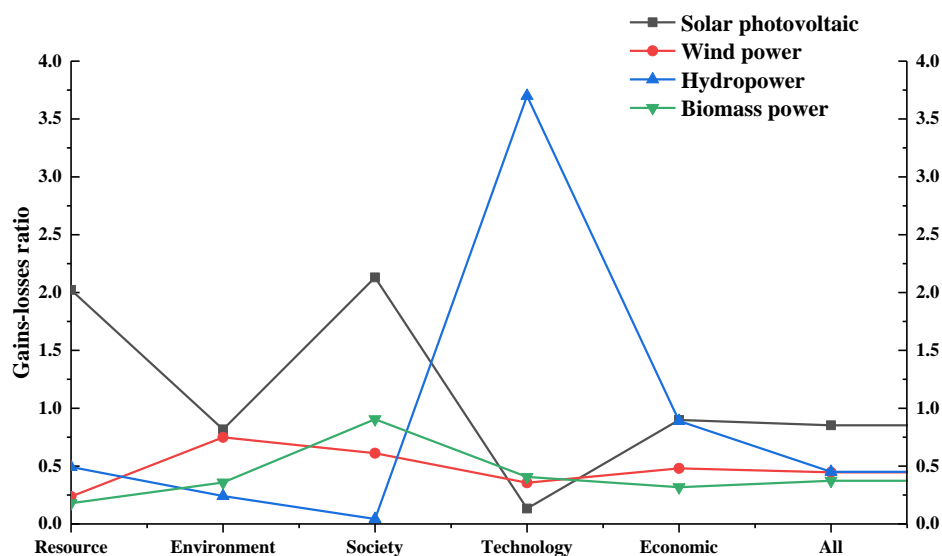


Figure 15. The gain-loss ratio of alternatives under various criteria in scenario 1.

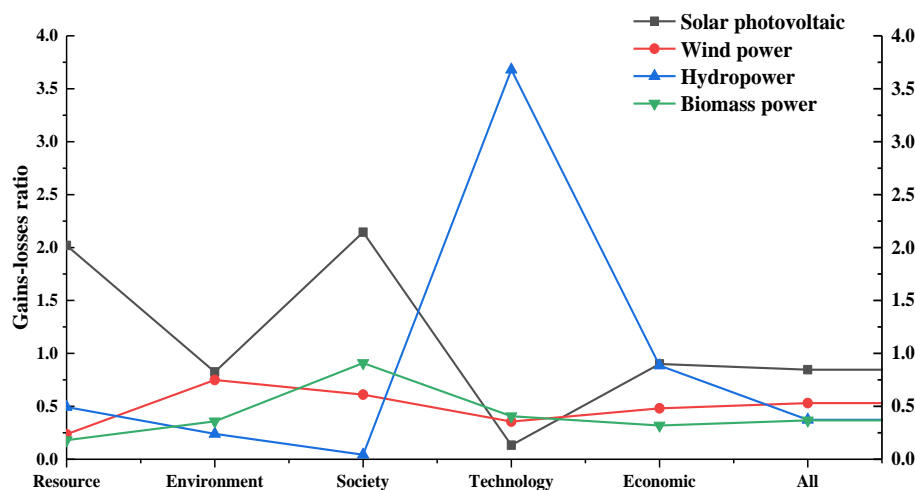


Figure 16. The gain-loss ratio of alternatives under various criteria in scenario 2.

Scenario 3. It is assumed that more attention is paid to whether renewable energy can develop in harmony with society, that is, to increase the weight of the social criterion, as shown in Figure 17.

It is found that the ranking of the four alternatives becomes solar photovoltaic power  $\succ$  wind power  $\succ$  biomass power  $\succ$  hydropower, but the ranking under each criterion has not changed. Therefore, to facilitate social sustainability, biomass power is better than hydropower. The policy support for biomass power is more significant, and more job opportunities are created. Additionally, biomass power is less affected by natural conditions and is more suitable for developing distributed power networks. Similarly, if it is desirable to facilitate hydropower sustainability, DMs should pay more attention to social acceptance, such as developing more small hydropower projects according to local conditions to adapt in harmony with the sustainable development of society.

The ranking comparison of the four scenarios is shown in Figure 18. Solar photovoltaic power is the best choice in all four scenarios, and wind power is second. Under the baseline scenario, Scenario 1, and Scenario 2, hydropower is better than biomass power, but biomass power is better than hydropower in Scenario 3. DMs can adjust the weights of the criteria according to different sustainable development goals to obtain renewable energy rankings.

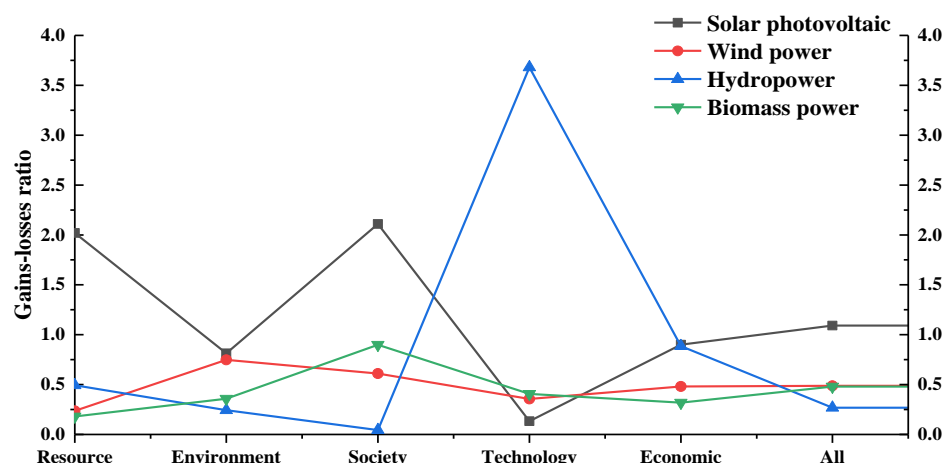


Figure 17. The gain-loss ratio of alternatives under various criteria in scenario 3.

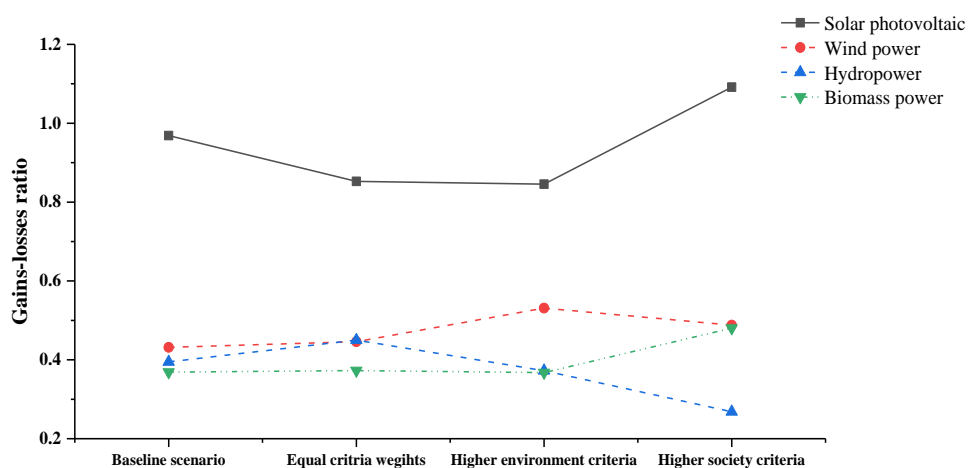


Figure 18. The gain-loss ratio of each alternative in the four scenarios.

#### 4.4. Comparative Analysis

To verify the results, two traditional methods (TOPSIS [42] and VIKOR [50]) are compared with our proposed model, as shown in Table 3. The outcomes of TOPSIS and VIKOR are the same as this paper's ranking; this shows the practicality of the 2-tuple linguistic value grey relation MCDM framework following the prospect theory. Moreover, both TOPSIS and VIKOR assume that the DMs are “completely rational people”, without considering the psychological characteristics of the DMs. Our model uses the grey relation method to associate the 2-tuple linguistic value with the prospect theory. DMs can adjust parameters in the prospect theory to reflect their risk preference, so it is innovative.

Table 3. The decision results of TOPSIS and VIKOR.

Alternatives	TOPSIS		VIKOR			
	Close Degree	Ranking Orders	$S_i$	$R_i$	$Q_i$	Ranking Orders
Solar photovoltaic	0.6473	1	0.271125	0.06859	0.5	1
Wind power	0.4972	2	0.581539	0.083053	0.784317	2
Hydropower	0.4397	3	0.517528	0.102118	0.396893	3
Biomass power	0.4227	4	0.527107	0.085474	0.660537	4

#### 5. Conclusions and Future Work

The question of the sustainability of renewable energy is often overlooked due to its adequacy and renewability. Different regional development levels lead to different



sustainable development capabilities related to renewable energy. The question of how to make renewable energy sustainable is worth exploring. This study proposes a 2-tuple linguistic grey relation MCDM model based on the prospect theory, selecting China as the research object.

Specifically, the profit–loss ratios of each alternative are  $\{0.969, 0.432, 0.395, 0.369\}$  for solar photovoltaic power, wind power, hydropower, and biomass power, respectively, ranked from best to worst. Sensitivity analyses show that changes in the parameters affect the gain–loss ratios. Still, the ranking of the four alternatives shows no change, thus proving the MCDM framework’s stability. On the one hand, DMs such as governments and investors can facilitate the sustainability of renewable energy according to the weights and the performance under different criteria; on the other hand, DMs can highlight different risk preferences and development goals by adjusting the parameters in the model. Finally, a comparison of the MCDM model with TOPSIS and VIKOR verifies the accuracy and innovativeness of the model.

This study proposes a ranking of different forms of renewable energy, but does not offer more specific planning recommendations. In the future, the structure of renewable energy can be designed and optimized based on deeper analyses for different development goals, and further practical suggestions can be put forward. In addition, new MCDM theories could potentially be applied, such as spherical fuzzy sets [22].

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Nomenclature

$(s_d, \alpha_d)$	A 2-tuple
$\phi$	Result of a symbolic aggregation operation
$\alpha$	Exponential parameters related to gains
$\beta$	Exponential parameters related to losses
$\theta$	The risk aversion parameter
$\varphi$	Attitude coefficient of risk gains
$\delta$	Attitude coefficient of risk losses
$\rho$	The resolution coefficient in grey theory
$\zeta_i^j$	The grey correlation coefficient
$\zeta$	The numerical value
$I$	The interval value
$F(S_T)$	The fuzzy sets define in Sr
$\mu_I(\bullet)$	The membership functions associated with $I$
$\gamma$	Membership function
$\lambda_k$	The weights obtained by AHP
$\omega_j$	The initial weights of sub-criteria
$(\omega_j)^*$	The normalized weights of sub-criteria
$\bar{\omega}_j$	The final weights of sub-criteria
$(s_d^+, \alpha_d^+)_j$	The positive ideal solutions
$(s_d^-, \alpha_d^-)_j$	The negative ideal solutions

$(\xi_d^-, \eta_d^-)_{ij}$	The 2-tuple linguistic grey relational degree
$v_{ij}^+$	The gain value function
$v_{ij}^-$	The loss value function
$V_{ij}^+$	The positive prospect value
$V_{ij}^-$	The negative prospect value
$R_i$	The ratio of gains and losses
$\mu_{sd}(\bullet)$	The membership functions associated with $sd$
$\tau$	Conversion function
$\chi$	Conversion function of 2-tuple linguistic value

## Appendix A

**Table A1.** Basic data.

Sub-Criteria	Type	Solar Photovoltaic Power	Wind Power	Hydropower	Biomass Power
Resource availability	benefit	2130	570	1100	200
Share of energy installed capacity	benefit	41.02%	13.21%	9.89%	1.57%
Energy accommodation level	benefit	97%	93%	100%	100%
CO <sub>2</sub> emissions	cost	0.46	0.12	0.04	0.18
Land requirements	cost	30–65	65–75	70–750	533–1000
Electrical pressure relief	benefit	12.80%	15.96%	4.67%	3.45%
Employment creation	benefit	0.7–25	0.9–4.0	0.9–1.2	11.2–19.7
Efficiency	cost	9.5–12	30–40	75–85	25–50
Levelized cost	cost	0.13–0.15	0.06–0.08	0.03–0.05	0.05–0.08
Share of energy investment	benefit	9.83%	23.48%	21.45%	3.62%
Payback period	cost	7–13	13–16	5–10	6–9.5
Feed-in tariff	benefit	0.55–0.75	0.44–0.58	0.3–0.5	0.70–0.80

**Table A2.** Expert 1.

Sub-Criteria	Type	Solar Photovoltaic Power	Wind Power	Hydropower	Biomass Power
Energy renewability	benefit	VH	VH	F	L
Impact on ecosystem	cost	L	F	VH	F
Environmental stress relief	benefit	H	H	F	F
Ease of decentralization	benefit	VH	F	L	H
Policy support	benefit	VH	VH	F	H
Electricity supply stability	benefit	F	F	VH	H
Technological maturity	benefit	H	H	VH	F
Market maturity	benefit	H	F	H	F

**Table A3.** Expert 2.

Sub-Criteria	Type	Solar Photovoltaic Power	Wind Power	Hydropower	Biomass Power
Energy renewability	benefit	VH	H	F	F
Impact on ecosystem	cost	L	F	H	H
Environmental stress relief	benefit	H	H	F	H
Ease of decentralization	benefit	VH	F	L	H
Policy support	benefit	VH	VH	F	H
Electricity supply stability	benefit	F	F	H	H
Technological maturity	benefit	H	F	VH	L
Market maturity	benefit	H	H	LH	L

Table A4. Expert 3.

Sub-Criteria	Type	Solar Photovoltaic Power	Wind Power	Hydropower	Biomass Power
Energy renewability	benefit	VH	VH	F	F
Impact on ecosystem	cost	F	H	VH	H
Environmenta stress relief	benefit	H	F	F	F
Ease of decentralization	benefit	VH	F	F	H
Policy support	benefit	VH	H	F	H
Electricity supply stability	benefit	VH	VH	F	H
Technological maturity	benefit	H	H	VH	L
Market maturity	benefit	H	F	VH	VL

## References

- Volkart, K.; Weidmann, N.; Bauer, C.; Hirschberg, S. Multi-Criteria Decision Analysis of Energy System Transformation Pathways: A Case Study for Switzerland. *Energy Policy* **2017**, *106*, 155–168. [\[CrossRef\]](#)
- Zheng, F.; Zhou, X.; Rahat, B.; Rubbaniy, G. Carbon Neutrality Target for Leading Exporting Countries: On the Role of Economic Complexity Index and Renewable Energy Electricity. *J. Environ. Manag.* **2021**, *299*, 113558. [\[CrossRef\]](#) [\[PubMed\]](#)
- Chang, R.-D.; Zuo, J.; Zhao, Z.-Y.; Zillante, G.; Gan, X.-L.; Soebarto, V. Evolving Theories of Sustainability and Firms: History, Future Directions and Implications for Renewable Energy Research. *Renew. Sustain. Energy Rev.* **2017**, *72*, 48–56. [\[CrossRef\]](#)
- Zhang, B.; Wang, B.; Wang, Z. Role of Renewable Energy and Non-Renewable Energy Consumption on EKC: Evidence from Pakistan. *J. Clean. Prod.* **2017**, *156*, 855–864. [\[CrossRef\]](#)
- Wang, Z.; Li, J.; Liu, J.; Shuai, C. Is the Photovoltaic Poverty Alleviation Project the Best Way for the Poor to Escape Poverty?—A DEA and GRA Analysis of Different Projects in Rural China. *Energy Policy* **2020**, *137*, 111105. [\[CrossRef\]](#)
- Zhang, L.; Xin, H.; Yong, H.; Kan, Z. Renewable Energy Project Performance Evaluation Using a Hybrid Multi-Criteria Decision-Making Approach: Case Study in Fujian, China. *J. Clean. Prod.* **2019**, *206*, 1123–1137. [\[CrossRef\]](#)
- Wang, H.; Yan, Z.; Xu, X.; He, K. Evaluating Influence of Variable Renewable Energy Generation on Islanded Microgrid Power Flow. *IEEE Access* **2018**, *6*, 71339–71349. [\[CrossRef\]](#)
- Santoyo-Castelazo, E.; Azapagic, A. Sustainability Assessment of Energy Systems: Integrating Environmental, Economic and Social Aspects. *J. Clean. Prod.* **2014**, *80*, 119–138. [\[CrossRef\]](#)
- Sequeira, T.N.; Santos, M.S. Renewable Energy and Politics: A Systematic Review and New Evidence. *J. Clean. Prod.* **2018**, *192*, 553–568. [\[CrossRef\]](#)
- Boran, F.E.; Boran, K.; Menlik, T. The Evaluation of Renewable Energy Technologies for Electricity Generation in Turkey Using Intuitionistic Fuzzy TOPSIS. *Energy Sources Part B Econ. Plan. Policy* **2012**, *7*, 81–90. [\[CrossRef\]](#)
- Mohd Chachuli, F.S.; Ahmad Ludin, N.; Mat, S.; Sopian, K. Renewable Energy Performance Evaluation Studies Using the Data Envelopment Analysis (DEA): A Systematic Review. *J. Renew. Sustain. Energy* **2020**, *12*, 062701. [\[CrossRef\]](#)
- Fang, K.; Zhou, Y.; Wang, S.; Ye, R.; Guo, S. Assessing National Renewable Energy Competitiveness of the G20: A Revised Porter's Diamond Model. *Renew. Sustain. Energy Rev.* **2018**, *93*, 719–731. [\[CrossRef\]](#)
- Katre, A.; Tozzi, A. Assessing the Sustainability of Decentralized Renewable Energy Systems: A Comprehensive Framework with Analytical Methods. *Sustainability* **2018**, *10*, 1058. [\[CrossRef\]](#)
- Wang, C.-N.; Dang, T.-T.; Tibo, H.; Duong, D.-H. Assessing Renewable Energy Production Capabilities Using DEA Window and Fuzzy TOPSIS Model. *Symmetry* **2021**, *13*, 334. [\[CrossRef\]](#)
- Wang, C.-N.; Nguyen, N.-A.-T.; Dang, T.-T. Offshore Wind Power Station (OWPS) Site Selection Using a Two-Stage MCDM-Based Spherical Fuzzy Set Approach. *Sci. Rep.* **2022**, *12*, 4260. [\[CrossRef\]](#) [\[PubMed\]](#)
- Çelikkilek, Y.; Tüysüz, F. An Integrated Grey Based Multi-Criteria Decision Making Approach for the Evaluation of Renewable Energy Sources. *Energy* **2016**, *115*, 1246–1258. [\[CrossRef\]](#)
- Wang, Q.; Zhan, L. Assessing the Sustainability of Renewable Energy: An Empirical Analysis of Selected 18 European Countries. *Sci. Total Environ.* **2019**, *692*, 529–545. [\[CrossRef\]](#)
- Solangi, Y.A.; Tan, Q.; Mirjat, N.H.; Ali, S. Evaluating the Strategies for Sustainable Energy Planning in Pakistan: An Integrated SWOT-AHP and Fuzzy-TOPSIS Approach. *J. Clean. Prod.* **2019**, *236*, 117655. [\[CrossRef\]](#)
- Zhao, H.; Guo, S. External Benefit Evaluation of Renewable Energy Power in China for Sustainability. *Sustainability* **2015**, *7*, 4783–4805. [\[CrossRef\]](#)
- Saeedpoor, M.; Vafadarnikjoo, A. Corrigendum to “Multicriteria Renewable Energy Planning Using an Integrated Fuzzy VIKOR & AHP Methodology: The Case of Istanbul”. *Energy* **2015**, *79*, 536–537. [\[CrossRef\]](#)
- Wu, Y.; Xu, C.; Zhang, T. Evaluation of Renewable Power Sources Using a Fuzzy MCDM Based on Cumulative Prospect Theory: A Case in China. *Energy* **2018**, *147*, 1227–1239. [\[CrossRef\]](#)
- Mahmood, T.; Ullah, K.; Khan, Q.; Jan, N. An Approach toward Decision-Making and Medical Diagnosis Problems Using the Concept of Spherical Fuzzy Sets. *Neural Comput. Appl.* **2019**, *31*, 7041–7053. [\[CrossRef\]](#)

23. Aslam, M.; Bantan, R.A.R.; Khan, N. Design of a New Attribute Control Chart Under Neutrosophic Statistics. *Int. J. Fuzzy Syst.* **2019**, *21*, 433–440. [\[CrossRef\]](#)
24. Aslam, M. Analyzing Wind Power Data Using Analysis of Means under Neutrosophic Statistics. *Soft Comput.* **2021**, *25*, 7087–7093. [\[CrossRef\]](#)
25. REN21 Renewables 2019 Global Status Report. Available online: <https://www.ren21.net/gsr-2019> (accessed on 27 March 2020).
26. Liu, G. Development of a General Sustainability Indicator for Renewable Energy Systems: A Review. *Renew. Sustain. Energy Rev.* **2014**, *31*, 611–621. [\[CrossRef\]](#)
27. Al Garni, H.; Kassem, A.; Awasthi, A.; Komljenovic, D.; Al-Haddad, K. A Multicriteria Decision Making Approach for Evaluating Renewable Power Generation Sources in Saudi Arabia. *Sustain. Energy Technol. Assess.* **2016**, *16*, 137–150. [\[CrossRef\]](#)
28. Chen, Y.; Wang, Z.; Zhong, Z. CO<sub>2</sub> Emissions, Economic Growth, Renewable and Non-Renewable Energy Production and Foreign Trade in China. *Renew. Energy* **2019**, *131*, 208–216. [\[CrossRef\]](#)
29. Ahmad, S.; Tahar, R.M. Selection of Renewable Energy Sources for Sustainable Development of Electricity Generation System Using Analytic Hierarchy Process: A Case of Malaysia. *Renew. Energy* **2014**, *63*, 458–466. [\[CrossRef\]](#)
30. Amer, M.; Daim, T.U. Selection of Renewable Energy Technologies for a Developing County: A Case of Pakistan. *Energy Sustain. Dev.* **2011**, *15*, 420–435. [\[CrossRef\]](#)
31. Diakoulaki, D.; Karangelis, F. Multi-Criteria Decision Analysis and Cost-Benefit Analysis of Alternative Scenarios for the Power Generation Sector in Greece. *Renew. Sustain. Energy Rev.* **2007**, *11*, 716–727. [\[CrossRef\]](#)
32. Liu, G.; Rasul, M.G.; Amanullah, M.T.O.; Khan, M.M.K. Sustainability Indicator of Renewable Energy System Based on Fuzzy Multi-Criteria Decision Making Methods. *AMR* **2011**, *361–363*, 1263–1273. [\[CrossRef\]](#)
33. Chatzimouratidis, A.I.; Pilavachi, P.A. Multicriteria Evaluation of Power Plants Impact on the Living Standard Using the Analytic Hierarchy Process. *Energy Policy* **2008**, *36*, 1074–1089. [\[CrossRef\]](#)
34. Kahraman, C.; Kaya, İ.; Cebi, S. A Comparative Analysis for Multiattribute Selection among Renewable Energy Alternatives Using Fuzzy Axiomatic Design and Fuzzy Analytic Hierarchy Process. *Energy* **2009**, *34*, 1603–1616. [\[CrossRef\]](#)
35. Cîrstea, S.; Moldovan-Teseliu, C.; Cîrstea, A.; Turcu, A.; Darab, C. Evaluating Renewable Energy Sustainability by Composite Index. *Sustainability* **2018**, *10*, 811. [\[CrossRef\]](#)
36. Kaya, T.; Kahraman, C. Multicriteria Renewable Energy Planning Using an Integrated Fuzzy VIKOR & AHP Methodology: The Case of Istanbul. *Energy* **2010**, *35*, 2517–2527. [\[CrossRef\]](#)
37. Nigim, K.; Munier, N.; Green, J. Pre-Feasibility MCDM Tools to Aid Communities in Prioritizing Local Viable Renewable Energy Sources. *Renew. Energy* **2004**, *29*, 1775–1791. [\[CrossRef\]](#)
38. Environment, U.N. Global Trends in Renewable Energy Investment 2019. Available online: <http://www.unep.org/resources/report/global-trends-renewable-energy-investment-2019> (accessed on 27 March 2020).
39. Georgopoulou, E.; Lalas, D.; Papagiannakis, L. A Multicriteria Decision Aid Approach for Energy Planning Problems: The Case of Renewable Energy Option. *Eur. J. Oper. Res.* **1997**, *103*, 38–54. [\[CrossRef\]](#)
40. Çolak, M.; Kaya, İ. Prioritization of Renewable Energy Alternatives by Using an Integrated Fuzzy MCDM Model: A Real Case Application for Turkey. *Renew. Sustain. Energy Rev.* **2017**, *80*, 840–853. [\[CrossRef\]](#)
41. Haddad, B.; Liazid, A.; Ferreira, P. A Multi-Criteria Approach to Rank Renewables for the Algerian Electricity System. *Renew. Energy* **2017**, *107*, 462–472. [\[CrossRef\]](#)
42. Şengül, Ü.; Eren, M.; Eslamian Shiraz, S.; Gezder, V.; Şengül, A.B. Fuzzy TOPSIS Method for Ranking Renewable Energy Supply Systems in Turkey. *Renew. Energy* **2015**, *75*, 617–625. [\[CrossRef\]](#)
43. Beccali, M.; Cellura, M.; Mistretta, M. Decision-Making in Energy Planning. Application of the Electre Method at Regional Level for the Diffusion of Renewable Energy Technology. *Renew. Energy* **2003**, *28*, 2063–2087. [\[CrossRef\]](#)
44. Wang, J.-H.; Hao, J. A New Version of 2-Tuple Fuzzy Linguistic Representation Model for Computing with Words. *IEEE Trans. Fuzzy Syst.* **2006**, *14*, 435–445. [\[CrossRef\]](#)
45. Tversky, A.; Kahneman, D. Advances in Prospect Theory: Cumulative Representation of Uncertainty. *J. Risk Uncertain.* **1992**, *5*, 297–323. [\[CrossRef\]](#)
46. Xiong, W.; Liu, L.; Xiong, M. Application of Gray Correlation Analysis for Cleaner Production. *Clean Technol. Environ. Policy* **2010**, *12*, 401–405. [\[CrossRef\]](#)
47. Martinez, L.; Herrera, F. A 2-Tuple Fuzzy Linguistic Representation Model for Computing with Words. *IEEE Trans. Fuzzy Syst.* **2000**, *8*, 746–752. [\[CrossRef\]](#)
48. Li, W.; Yu, S.; Pei, H.; Zhao, C.; Tian, B. A Hybrid Approach Based on Fuzzy AHP and 2-Tuple Fuzzy Linguistic Method for Evaluation in-Flight Service Quality. *J. Air Transp. Manag.* **2017**, *60*, 49–64. [\[CrossRef\]](#)
49. Qu, J.F.; Bi, Y.; Xiao, W.B. Integrated Evaluation of Ship Maneuverability Based on the Method of Maximizing Deviation. *AMR* **2012**, *524–527*, 3888–3895. [\[CrossRef\]](#)
50. Chang, T.-H. Fuzzy VIKOR Method: A Case Study of the Hospital Service Evaluation in Taiwan. *Inf. Sci.* **2014**, *271*, 196–212. [\[CrossRef\]](#)