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New Energy-Driven Construction Industry: Digital Green Innovation Investment Project Selection of Photovoltaic Building Materials Enterprises Using an Integrated Fuzzy Decision Approach

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Abstract: In the context of carbon peak and carbon neutrality, digital green innovation development is becoming more and more important for enterprises. In order to effectively improve green competitiveness and increase profits, photovoltaic building materials enterprises must choose digital green innovation projects for investment. The purpose of this study is to build a reasonable investment project selection framework system and propose appropriate methods for photovoltaic building materials enterprises to help them correctly choose digital green innovation investment projects. This study firstly combines relevant theories and digital green innovation characteristics of target investment projects to build a framework system for photovoltaic building materials enterprises to select investment projects. Secondly, this study innovatively proposes a dynamic intuitionistic fuzzy multi-attribute group decision-making method considering the interaction between attributes. Finally, this study takes Yingli Group as the research object and conducts an empirical study on it to verify the scientific nature and reliability of the framework system and method selection. The results show that the framework system includes four aspects: external support system, commercialization expectation, project operation ability and project operation resources. Yingli Group should choose project A_3 for cooperation. The framework system and method proposed in this study are feasible and can help Yingli Group correctly choose digital green innovation investment projects. At the same time, this study also brings positive enlightenment to other photovoltaic building materials enterprises in the world when choosing digital green innovation investment projects.

Keywords: photovoltaic building materials; digital green innovation; selection of investment projects

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1. Introduction

In September 2020, China's carbon peak and carbon neutral goals were announced at the 75th session of the United Nations General Assembly, aiming to actively address climate change and achieve sustainable development [1]. As the main body of the market, enterprises are the main source of greenhouse gas emissions [2]. Enterprises undertake most of the tasks of carbon peak and carbon neutrality, and the low-carbon emission reduction behavior of enterprises is crucial to the realization of carbon peak and carbon neutral targets. At the same time, carbon peak and carbon neutral goals also promote the development of enterprises to a certain extent.

Green building materials refer to building materials that can reduce the consumption of natural resources and the impact on the ecological environment in the whole life cycle [3]. In the manufacturing process of green building materials, clean and pollution-free technology is mainly adopted to minimize the utilization of natural resources [4]. This can greatly reduce the pollution in the manufacturing process of building materials and the serious solid waste pollution faced by the realization of non-toxic and pollution-free emissions. This can achieve non-toxic and pollution-free emissions. This can greatly reduce the pollution caused by building materials during manufacturing and after they are discarded. At the same time, green building materials focus on the quality attributes of the material, including health and safety, high quality performance and comfort [5]. Green development has become the main focus of current economic development, and the field of green building materials has ushered in a new historic development opportunity [6]. However, in the process of development of green building materials, the energy source is ignored, and the energy supply depends on the outside, so the sustainable development of green building materials cannot be realized [7]. Photovoltaic power generation is a process in which light energy is directly converted into electricity by using the photogenerated volt effect generated by the semiconductor interface [8]. Photovoltaic power generation has the characteristics of low carbon energy-saving and green environmental protection and is one of the best sources of green energy [9]. Photovoltaic power itself consumes no fuel, emits no emissions, including greenhouse gases and other waste gases, and does not pollute the air or generate noise [10]. At present, with the deepening of the world's energy development and the growing shortage of resources, energy transformation is urgent [11]. Green and sustainable development has become the general tone of energy industry development in recent years. Photovoltaic is an inexhaustible renewable energy source worldwide [12]. From the perspective of cleanliness, security, extensiveness, maintenance-freedom or long-term sustainability, it is an extremely economical energy and occupies an important position in the long-term energy strategy of human beings.

Photovoltaic building materials combine green building materials technology and photovoltaic power generation technology, which is the integration of photovoltaic devices and green building materials [13]. Generally, exterior surfaces of buildings are painted, decorated with decorative tiles or installed with curtain wall glass for the purpose of protecting and decorating the building. If some building materials are replaced by photovoltaic devices, that is, photovoltaic modules are used to make the roof, exterior walls and windows of buildings, they can be used as building materials, as well as for power generation [14]. For a building with a frame structure, the whole envelope can be made into a photovoltaic array. Some photovoltaic modules can absorb both direct solar light and reflected solar light [15]. At present, large size color photovoltaic modules have been developed, which can achieve the above purpose and make the building appearance more attractive [16]. The photovoltaic system integrated with the building can be used as an independent power source or through grid-connected power supply. When the system is connected to the grid, a battery is not needed, but a grid device is needed. The photovoltaic module is installed on the roof or exterior wall of the building, and the leading end is connected to the public power grid through the controller to supply power to the photovoltaic array and the power grid in parallel to the user, which constitutes the grid-connected photovoltaic system. Grid-connected power generation is a new trend in photovoltaic applications [17]. Photovoltaic building materials have the following advantages and characteristics: first, photovoltaic building materials combine photovoltaic panels with buildings, which is more suitable for the requirements of green and sustainable development of buildings at this stage. Second, photovoltaic building materials can meet the requirements of low-energy buildings in terms of power generation, conversion rate, safety and aesthetics. They can reduce building energy consumption and realize building energy saving. Third, photovoltaic building materials do not need to occupy valuable land resources and can also save the support structure of the photovoltaic system. In addition, photovoltaic building materials can not only ensure electricity consumption in their own buildings, but also may supply power to the power grid under certain conditions, which alleviates the peak power demand and has great social benefits.

However, at present, the development of photovoltaic building materials enterprises is facing great challenges. First, the manufacturing technology of the enterprise is not perfect. Photovoltaic building materials are widely used in the building periphery, doors and windows [18]. This requires photovoltaic building materials to have strong weather resistance to withstand high temperatures and ultraviolet light [19]. Enterprises also need to further improve the application technology and improve the emergency treatment, surface rupture, leakage protection and other uncertain factors of the solution. At the same time, the enterprise also needs to increase the building materials' fire resistance, impact resistance and perform wind pressure testing. Second, the digitalization degree of photovoltaic building materials enterprises is low and the initial cost is high [20]. From the aspect of hardware cost reduction, digital and intelligent transformation is an indispensable step. In the current industry situation, the digital transformation of the photovoltaic building materials supply chain has not fully reached the optimization of the whole industrial chain. For example, at present, the industry has a shortage of photovoltaic glass, a backplane shortage and other supply problems. In reality, supply capacity is not the problem. The reason is that a lot of materials are piled up in warehouses and in transit, and there is excess processing of semi-finished products. If photovoltaic building materials enterprises can introduce digital and intelligent control in the entire industrial chain, the cost can be further reduced. In terms of non-hardware cost reduction, equipment automation, data informatization, intelligent operation and platform collaboration are the four stages of intelligent manufacturing development. After analysis, the collected big data can effectively improve the operation effect and the collaboration between the supply chain and business departments can also jointly promote the development of the whole enterprise. In terms of consumer demand, most photovoltaic building materials enterprises build universal products. However, different customer needs also require universal products to have personalized experience, and personalized experience is more realized through the personalized service of data transparency. If big data technology is applied to consumers, and users' product preferences are understood, the development of photovoltaic building materials enterprises can be reversely promoted [21]. In terms of management, the use of big data management can effectively improve management efficiency, and data visualization will help managers make decisions. At the same time, big data innovation can also effectively support management decisions, determine the market competitiveness of products and find the direction of product development [22]. Third, with the service life of photovoltaic building materials modules towards the end, ensuring the recycling of waste photovoltaic building materials is also an important issue that the industry needs to pay attention to [23]. To realize the sustainable development of the whole life cycle of the photovoltaic building materials industry, it is necessary to explore innovative application scenarios of photovoltaic building materials [24]. In the commercial application environment, commercial users and residential households should make more use of photovoltaic building materials.

Faced with the above problems, photovoltaic building materials enterprises need to choose digital green innovation investment projects to achieve rapid development. However, how to choose a project with great potential and high investment value is the key [25]. In recent years, the selection of investment projects to promote the development of enterprises has become a research hotspot. Aleskerova and Fedoryshyna (2018) argued that investing in real projects is a long-term process, and a comprehensive evaluation of the project must be carried out, taking into account all factors to the maximum [26]. Li Yan (2022) believed that project investment is an important way for state-owned enterprises to expand scale and increase income, and it is also the topic that requires attention in the process of internal control, in terms of operational risk [27]. With the spillover effect of technological innovation becoming more and more prominent, how to effectively choose digital green innovation investment projects has become a very important issue in the development of enterprises. In recent years, scholars have studied the selection of investment projects from the aspects of methods and index systems. At the methodological level, Coban (2020) explored the application of the analytic hierarchy process (AHP) in solar investment projects to determine the most suitable projects according to established criteria [28]. Fan (2017) thought that the AHP-fuzzy comprehensive evaluation method quantifies the qualitative factors that affect project investment decisions, and has good applicability for the investment of high-tech industry projects with many influencing factors that are difficult to quantify [29]. Ye (2017) used the TOPSIS method to provide a scientific investment decision analysis for small and medium-sized enterprises under the background of the Fujian Free Trade Zone [30]. Zhang and Su (2018) proposed the G1-entropy-TOPSIS evaluation method for new energy vehicle venture capital projects, and the evaluation results can take both subjective and objective evaluation information into account [31]. On the index level, Wu et al. (2017) constructed the evaluation index system of enterprise technology innovation projects from the aspects of profit and risk [32]. After the weight of each attribute is determined by the theory of cross information entropy and entropy weight, the attribute weight and the authority weight of the decision maker are fused with the interval intuitionistic fuzzy normalized matrix of the decision maker to obtain the comprehensive decision information value of the project to be evaluated, and the evaluation schemes are ranked and selected according to the score function value [32]. Liu (2020) enumerated the evaluation indicators of enterprise investment projects, including cash flow and discount rate, and carried out a dynamic evaluation of each indicator through case analysis [33]. The results of the comprehensive literature summary are shown in Table 1.

Table 1. Summary of comprehensive literature review.

Factors	Specific Applications	Reference Source
Analytic hierarchy process (AHP)	Investment decision for solar projects	[28]
AHP-fuzzy comprehensive evaluation method	Investment decision of high-tech industry project	[29]
TOPSIS	Project investment decision of small and medium enterprises	[30]
G1- entropy -TOPSIS evaluation method	New energy vehicle investment project evaluation	[31]
The aspects of profit and risk	Enterprise technology innovation project decision	[32]
Cash flow and discount rate	Enterprise investment project economic income evaluation	[33]
Resource-based view	The unique resources of the project itself	[34–36]
Project-related industry clustering advantage	The project is influenced by the advantages of industrial agglomeration	[37–40]
Social digital innovation environment	Project agency costs and information advantages	[41,42]
Financial market environment	The market environment for borrowing money and financing, dealing with various instruments and securities trading activities	[43–45]
Commercialization expectation	Whether the project has a market and competitiveness	[46]
Green market competition	The competitive situation of the project entering the green market needs attention	[47–50]
Digital service differentiation degree	Bring a competitive edge to the project	[51]

In order to solve the above problems, the purpose of this study is to establish a set of indicators system, adopt scientific methods to conduct research, correctly select digital green innovation investment projects and promote the development of enterprise digital green innovation. Firstly, this research combines relevant theories and target project characteristics to construct an index system. Secondly, a dynamic intuitionistic fuzzy multi-attribute group decision-making method considering the interaction between attributes is proposed. Finally, this study verifies the correctness of the system and method by analyzing the investment projects selected by Yingli Group.

The rest of this article is as follows. Section 2 is the theoretical basis and index system of investment project selection. The research methodology will be clarified in Section 3. Section 4 is the empirical study. The conclusion and future prospects will be introduced in Section 5.

2. Theoretical Basis and Index System

2.1. Theoretical Basis

The environment is divided into the external environment and internal environment. In the analysis of the external environment, the common theories include the PESTEL analysis model and Porter's five forces model. In the analysis of the internal environment, this study focuses on the theory of resource view and the theory of capability composition. In this study, relevant theories of internal and external environment are applied to project evaluation. Through the analysis of theoretical elements to determine the evaluation of the project index system.

The PESTEL analysis model is one of the strategic analysis tools [34]. In this study, the PESTEL analysis model is applied to project analysis. The PESTEL analysis model can not only analyze the external environment of the project but can also identify all the forces that have an impact on the project, including the potential risks and opportunities in the process of project implementation. The PESTEL analysis model is a method to investigate the external influencing factors of project implementation. Each letter of PESTEL represents a factor and can be divided into six major factors: political environmental factors, economic environmental factors, social and cultural environmental factors, technological environmental factors, environmental factors and legal factors. The political environmental factors of a project refer to the political forces and related policies that have actual and potential impacts on the implementation of a project. Common political factors include government regulation and government procurement scale and policy. The economic and environmental factors of the project refer to the external economic structure, industrial layout, resource situation, economic development level and future economic trend of the project department. Common economic factors include disposable income levels, economies of scale in interest rates and consumption patterns. The socio-cultural environment factors of the project refer to the values, education level and customs of the project implementation team. Common social factors include education level and so on. The technical environment of the project includes not only the inventions that cause revolutionary changes, but also the emergence and development trends and application prospects of new technologies, new processes and new materials related to the project. The natural environmental factors of the project refer to the elements that can interact with the environment in the activities, products or services of the project. The legal environmental factors of a project refer to the comprehensive system composed of laws, regulations, judicial conditions and citizens' legal consciousness outside the project.

Porter's five forces model is a theory put forward by Michael Porter in the early 1980s [35]. This model is a widely used model that can be used to focus analysis on the competitive environment of a project. In this study, Porter's five forces model is applied to project analysis. In the process of project development, there are five forces that determine the scale and degree of competition. These five forces together affect the attractiveness of the project and the competitive strategic decision of the existing project. The five forces are the threat of potential entrants, the bargaining power of buyers, the threat of substitutes, the bargaining power of suppliers and the competitiveness of existing competitors.

The resource-based view, which emerged in the 1980s, holds that business activities are based on their own resource endowments. In order to obtain and maintain competitive advantages, the main body of activities should seek and develop its own unique resources in strategic management and constantly maintain and strengthen them [36]. Internal resources are the sum of various factors that can be owned or controlled by the subject itself. In general, a single resource does not bring a competitive advantage to the subject itself. In fact, a competitive advantage is usually based on a differential combination of several resources. Internal resources are divided into tangible resources, intangible resources and human resources. This study applies resource theory to project selection of enterprises. Tangible resources of the project refer to the tangible assets included in the project, such as the production equipment, sales center and information system. Intangible resources of the project are those assets that are rooted in the history of the project and are accumulated over time. Intangible resources exist in unique ways and are usually not easily understood, analyzed and imitated by competitors. Knowledge, the project team relationship, management ability, organizational system, scientific research ability, innovation ability and brand are all intangible resources. Human resources of the project refer to the sum of the knowledge, skills, experience, judgment ability, insight ability and decision-making ability of the workers that can provide productive services for the implementation of the project.

Project implementation capability refers to the ability of the project team to coordinate resources and play their productive and competitive roles [37]. These capabilities exist in the daily work of the project team. Project implementation capabilities are often diverse and multi-level. Project implementation capacity consists of research and development capacity, production capacity, marketing capacity, organizational capacity, etc.

This study sorted out the theories and found that photovoltaic building materials enterprises can choose digital green innovation investment projects based on the above theories. These theories have good adaptability in photovoltaic building materials enterprises to choose digital green innovation investment projects. The framework system of enterprise project investment can be constructed by analyzing the factors that affect the internal and external environment of enterprises using relevant theories. The theoretical basis for photovoltaic building materials enterprises to choose digital green innovation investment projects is shown in Figure 1.

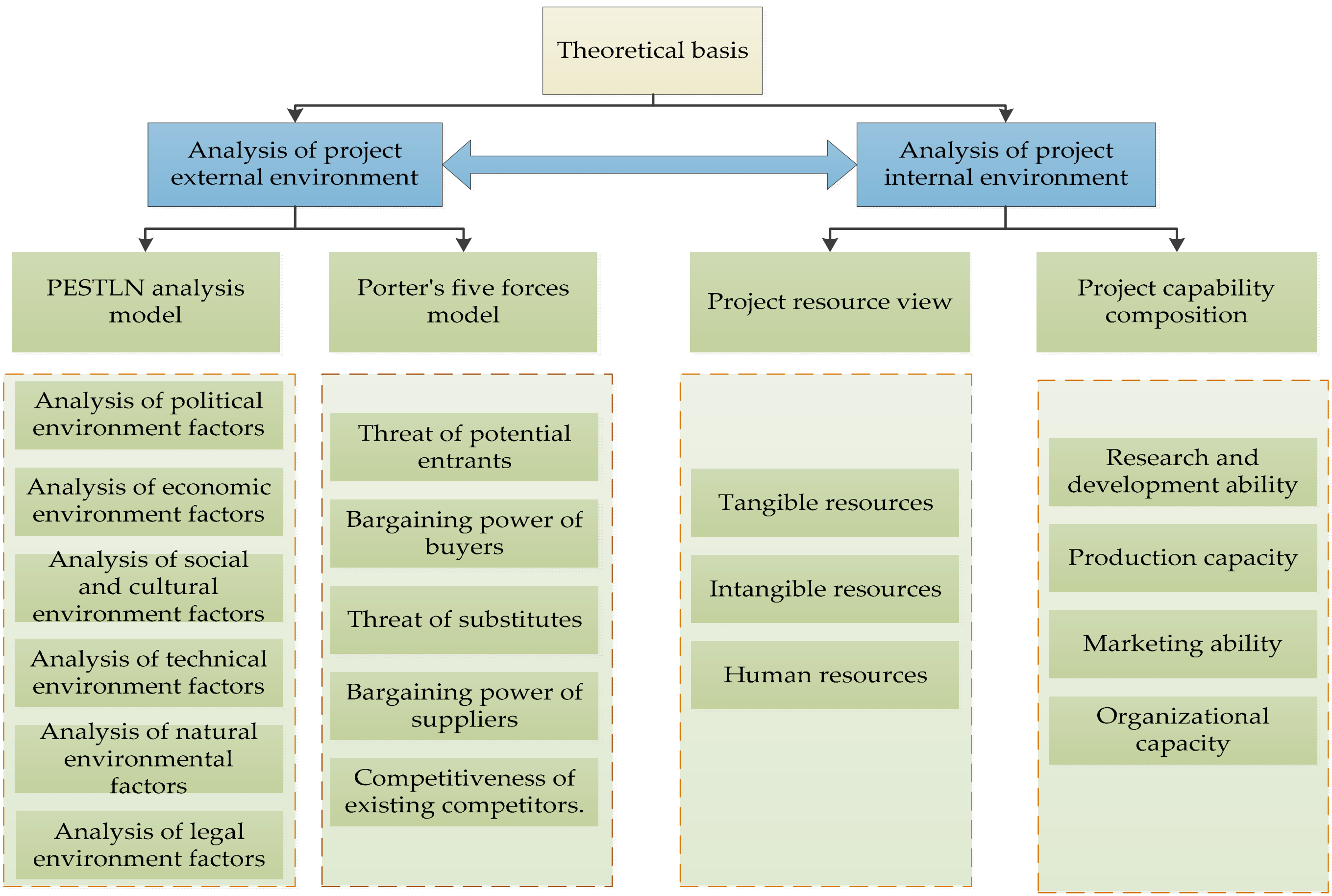

Figure 1. Theoretical basis for photovoltaic building materials enterprises to choose digital green innovation investment projects.

2.2. Index System

The criteria by which enterprises choose investment projects are important. Enterprises should consider two aspects when choosing investment in digital green innovation projects. On the one hand, the internal and external environment of the project itself, on the other hand, the degree of digital green innovation of the project. This study fully considers these two aspects when constructing the evaluation index system of project selection. According to the theoretical basis, the index system constructed in this study is divided into four first-level indicators: external support system, commercialization expectation, project operation ability and project operation resources.

The external support system mainly reflects the external environment of the project [38]. In the external support system, the secondary indicators selected in this study include green policy support, project-related industry clustering advantage, social digital innovation environment, project location advantage, project industrial chain maturity, financial market environment and intellectual property protection system support. Among them, green policy support takes into account the political environment outside the project. This refers to the degree to which the project is supported by the government's environmental protection, and other relevant preferential, policies [39]. Innovative projects are characterized by a high degree of localized agglomeration effects, which may come from the aggregation of capital, more talents, good communication networks or geographical advantages. Investment is an important driver of innovation. When choosing investment projects, enterprises will inevitably consider the project-related industry clustering advantage of project-related industries [40]. The social digital innovation environment takes into account the technical environment outside the project [41]. There is a huge information asymmetry in the process of project investment, and the main reason for this information asymmetry is that the process contains a lot of soft information. Soft information is specific information that is difficult to record, store and transmit. This requires more close contact between enterprises and project teams, and local investment can reduce agency costs and information advantages. In addition, some companies invest in a particular area to win the competition, while others may relax the geographical location criterion. Therefore, this study takes the location advantage of the project into account when selecting the evaluation indicators [42]. Project industrial chain maturity reflects the degree of technical and economic correlation between various industrial sectors [43]. The financial market environment is the market environment for the realization of currency borrowing and financial financing and the transaction of various bills and securities [44]. The intellectual property protection system is an inevitable requirement in the era of the knowledge economy. A perfect intellectual property protection system is conducive to the development and perfection of the market economy [45]. This study selects the index of intellectual property protection system support.

Commercialization expectation mainly refers to the existence of the market and competitiveness of the project [46]. In the commercialization expectation system, the secondary indicators selected in this study are green market competition, consumer green demand, smart and green logistics, green technology research and development strength, digital service differentiation degree and whether products or technologies are protected by patents. Project entry into a market needs to pay attention to the competition, as competition intensity will have a significant impact on the profitability of the project. Environmental protection and sustainable development are the world trend and this study selects green market competition as a secondary index [47]. A product or service to meet the market demand is the basic purpose of project production and the size of the demand determines the future development space of the project. This study pays special attention to the green demand of consumers [48]. Smart green logistics refers to the digital green degree of the logistics of raw materials or products transportation [49]. Green technology research and development strength represents the future competitiveness of the project [50]. Strong green technology research and development strength can not only make the project occupy the commanding heights of the market, but also can obtain sustainable development. Therefore, green technology research and development strength has an important impact on the selection of projects. The differentiation of products or services can bring a competitive advantage to the project and gain more consumers' favor, thus bringing more profits [51]. Intellectual property is the asset that a project has a competitive advantage, which can make the project continue. Therefore, this study selects whether the product or technology is protected by patents [52].

Project operation ability is mainly necessary for the continuous operation of the project [53]. Under the project operation capability system, the secondary indicators selected in this study include intellectualization degree of the process, digital technical proficiency of employees, green awareness of technicians, proportion of green research and development personnel, digital marketing network, green research and development investment and number of patents applied. Intellectualization degree of process refers to the digitalization and intellectualization degree of the production process of project products [54]. The digital technical proficiency of employees greatly affects the efficiency of the whole project. Therefore, the intellectualization degree of the process and the digital technical proficiency of employees are selected to represent the production capacity of the project. Green awareness of technicians refers to the environmental protection consciousness and sustainable development consciousness of project technicians, which reflects the green degree of the project to a certain extent [55]. Digital marketing network refers to the digital environment of project product marketing, which represents the marketing ability of the project [56]. Proportion of green research and development personnel refers to the proportion of personnel responsible for green technology to the total staff of the project [57]. Green research and development investment refers to the investment in green technology research and development for sustainable development of the project [58]. Number of patents applied refers to the number of patents applied for the implementation of the project [59]. Proportion of green research and development personnel, green research and development investment and number of patents applied represent the research and development capability of the project.

Project operation resources are mainly the resources necessary for the continuous operation of the project [60]. Under the project operation resource system, the secondary indicators selected in this study include project green culture, digital knowledge of the team, current ratio, inventory turnover, return on equity and growth rate of total assets. One of them, project green culture, refers to the soul of project sustainable development and is one of the important factors of project development [61]. Digital knowledge of the team reflects how digital the project is [62]. Current ratio refers to the ratio of current assets to current liabilities [63]. Inventory turnover ratio refers to the ratio of project selling cost to the average inventory capital occupied in a certain period [64]. Return on equity refers to the ratio of after-tax profit and net assets of a project [65]. Growth rate of total assets refers to the ratio between the growth amount of total assets of the project this year and the total assets at the beginning of the year [66]. Current ratio, inventory turnover, return on equity and growth rate of total assets, respectively, represent the project's solvency, operating ability, profitability and development ability.

Based on the above analysis, this paper constructs a framework system for photovoltaic building materials enterprises to choose digital green innovation investment projects, as shown in Figure 2.

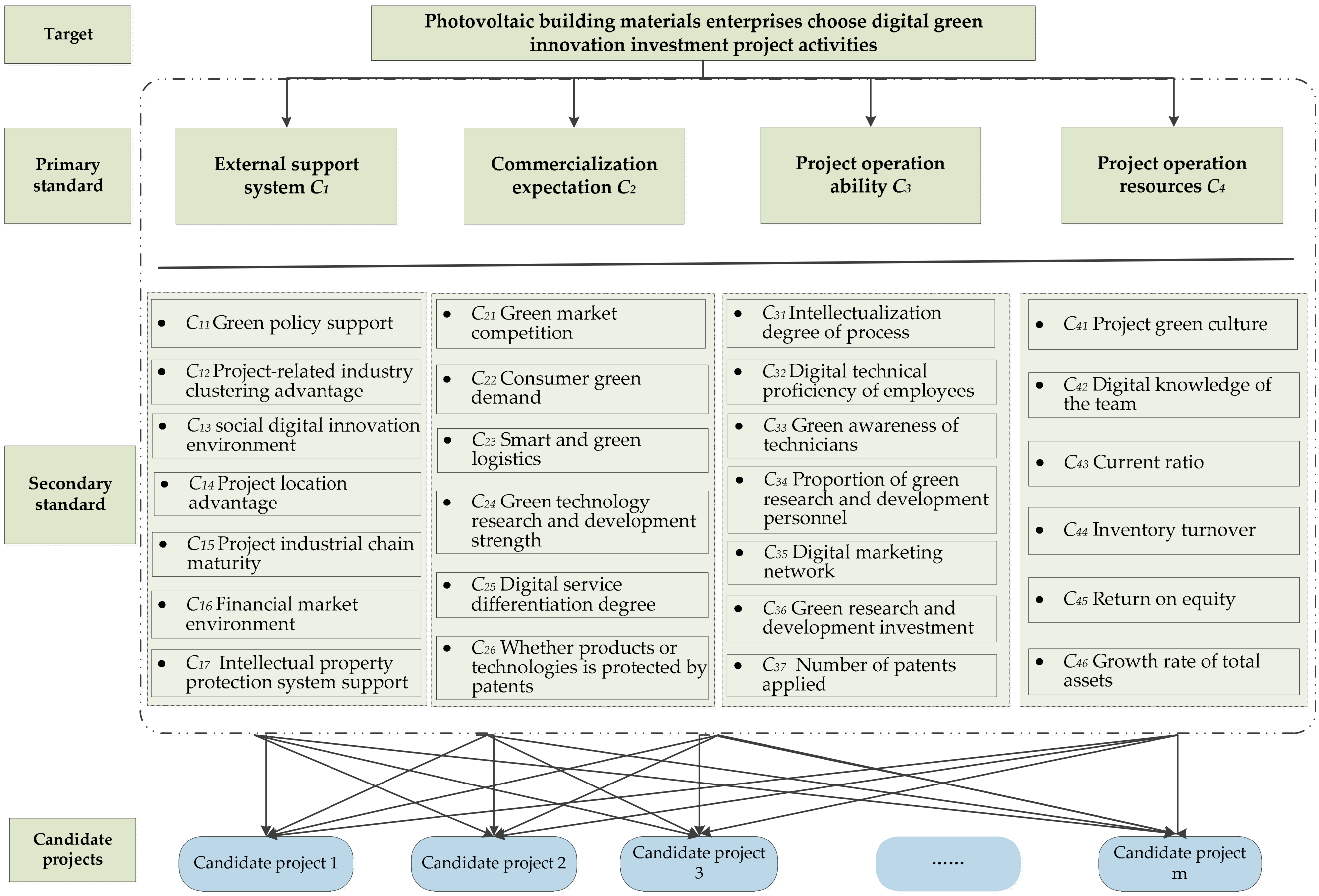

Figure 2. Frame system for photovoltaic building materials enterprises to choose digital green innovation investment projects.

3. Methodology

Since the advent of fuzzy sets, they have been widely used in data processing, pattern recognition and other fields. However, the membership function in fuzzy sets is only a single valued function, which have difficulty describing the uncertainty in the cognitive process. The intuitionistic fuzzy set was proposed by Atanassov in 1986 [67]. It is a kind of extension and supplement to fuzzy set. On the basis of fuzzy set, it introduces two class attribute parameters, non-membership degree and hesitancy degree, in order to describe the class fuzziness more carefully.

3.1. Related Concepts of Intuitionistic Fuzzy Sets

Definition 1 ([67]). *Let X be a nonempty set and be $X = (x_1, x_2 \cdots, x_m)$, then we call X the intuitionistic fuzzy set $A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in X\}$. Where $\mu_A(x), v_A(x) \in [0,1]$, the former is the membership degree of element x in X belonging to X, while the latter is the non-membership degree and satisfies condition $0 \leq \mu_A(x) + v_A(x) \leq 1$. At the same time, we call $\pi_A(x) = 1 - \mu_A(x) - v_A(x)$ the uncertainty or hesitation degree of element x in X belonging to X. When $\pi_A(x) = 0$, the intuitionistic fuzzy set degenerated into the traditional fuzzy set.*

Different from fuzzy sets, intuitionistic fuzzy sets have three eigenvalues of membership degree, non-membership degree and hesitation degree, and satisfy $\mu_A(x_i) + \gamma_A(x_i) + \pi_A(x_i) = 1$. They are extended from the two-dimensional expression of ordinary sets to the three-dimensional spatial expression. The spatial distribution of intuitionistic fuzzy sets is shown in Figure 3.

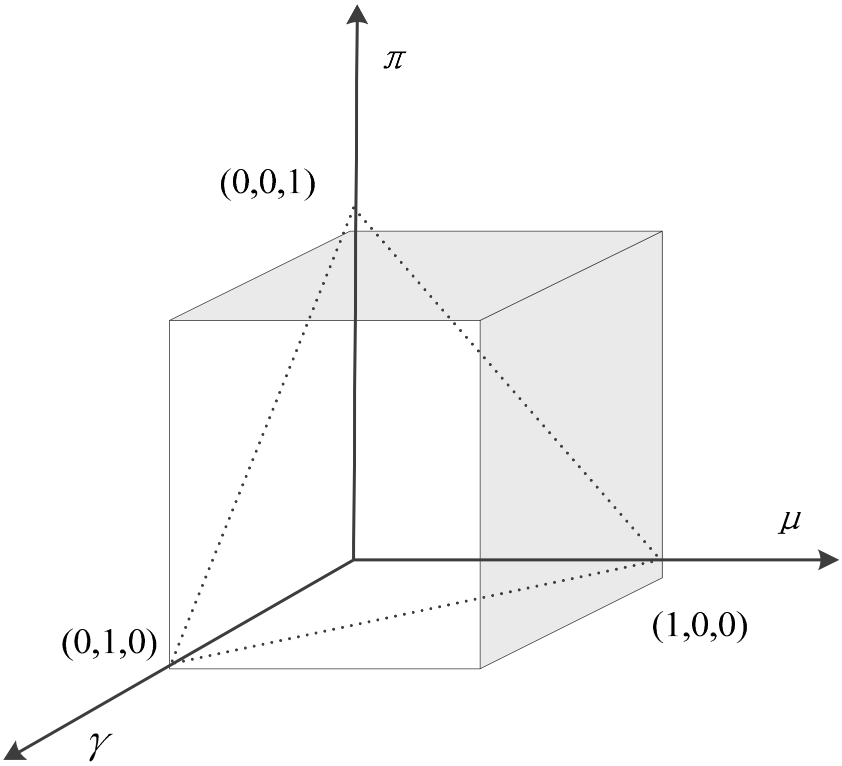

Figure 3. Intuitive fuzzy set.

Definition 2 ([68,69]). *Let $a = \langle \mu_A(x), v_A(x) \rangle$ be an intuitionistic fuzzy number in X, then define $S(a) = \mu_A(x) - v_A(x)$ as the score function of a, the larger the value of $S(a)$, the higher the score of $a = \langle \mu_A(x), v_A(x) \rangle$. $H(a) = \mu_A(x) + v_A(x)$ is the accuracy function of a. Similarly, the higher the value of $H(a)$, the higher the accuracy of $a = \langle \mu_A(x), v_A(x) \rangle$.*

If $S(a_1) < S(a_2)$, it is $a_1 < a_2$.

If $S(a_1) = S(a_2)$, when $H(a_1) < H(a_2)$, then $a_1 < a_2$. When $H(a_1) = H(a_2)$, then $a_1 = a_2$.

Definition 3 ([70]). *Let there be intuitionistic fuzzy number $a = \langle \mu_A(x), v_A(x) \rangle$ in domain X, and $a_1 = \langle \mu_{A1}(x), v_{A1}(x) \rangle$, $a_2 = \langle \mu_{A2}(x), v_{A2}(x) \rangle$, $\lambda > 0$ are any real numbers, then its operation rule is as follows:*

(i) $\lambda a = \left\langle 1 - (1 - \mu_A(x))^\lambda, v_A(x)^\lambda \right\rangle$;

(ii) $a^\lambda = \left\langle \mu_A(x)^\lambda, 1 - (1 - v_A(x))^\lambda \right\rangle$

(iii) $a_1 \oplus a_2 = \langle \mu_{A1}(x) + \mu_{A2}(x) - \mu_{A1}(x)\mu_{A2}(x), v_{A1}(x)v_{A2}(x) | \forall x \in X \rangle$

(iv) $a_1 \otimes a_2 = \langle \mu_{A1}(x)\mu_{A2}(x), v_{A1}(x) + v_{A2}(x) - v_{A1}(x)v_{A2}(x) | \forall x \in X \rangle$

Definition 4 ([71]). *Let $p \geq 0, q \geq 0$ and p, q be zero at different times and $a_i (i = 1, 2, \ldots, n)$ be a set of non-negative numbers. If*

$$\mathrm{GHM}^{p,q}(a_1, a_2, \ldots, a_n) = \frac{1}{p+q} \left(\prod_{i=1,j=1}^{n} (pa_i + qa_j)^{2/n(n+1)} \right) \quad (1)$$

holds, then GHM is called geometric heronian average.

Definition 5 ([72]). *Let $\beta_{ij} = \left(\left[t_{\beta_{ij}}, f_{\beta_{ij}}\right]\right)(i, j = 1, 2, \ldots, n)$ be an intuitionistic fuzzy set and the β_{ij} operator can be represented as*

$$\bigotimes_{i=1,j=1}^{n} \beta_{ij}^{2/n(n+1)} = \left(\prod_{i=1,j=1}^{n} t_{\beta_{ij}}^{2/n(n+1)}, 1 - \prod_{i=1,j=1}^{n} \left(1 - f_{\beta_{ij}}\right)^{2/n(n+1)}\right) \tag{2}$$

where $t_{\beta_{ij}}$ represents the degree of membership of β_{ij} and $f_{\beta_{ij}}$ represents the degree of non-membership of β_{ij}.

Definition 6 ([73]). *Let $a_j = \langle \mu_{Aj}(x), v_{Aj}(x) \rangle$, where $j = 1, 2, \cdots, n$, be the intuitionistic fuzzy number on domain X, $\omega_j = (\omega_1, \omega_2 \cdots \omega_n)^T$, and $\sum_{j=1}^{n} \omega_j = 1$. Definition $IFWA : Q^n \to Q$, when*

$$IFWA_{\omega}(a_1, a_2 \cdots, a_n) = \sum_{j=1}^{n} a_j \omega_j = \left(1 - \prod_{j=1}^{n} (1 - \mu_{Aj}(x))^{\omega_j}, \prod_{j=1}^{n} \gamma_{Aj}(x)^{\omega_j}\right) \tag{3}$$

is satisfied, then $IFWA$ is called multi-dimensional intuitionistic fuzzy weighted average operator.

Definition 7 ([74]). *Let $a(t) = \left\langle \mu_{A(t)}(x), v_{A(t)}(x) \right\rangle$ be the intuitionistic fuzzy number, where t is the temporal variable, $\mu_{A(t)}(x)$ and $v_{A(t)}(x)$ belong to $[0, 1]$, and $\mu_{A(t)}(x) + v_{A(t)}(x) \leq 1$. If $t = t_1, t_2 \cdots, t_n$, the intuitionistic fuzzy sets with different time sequences are represented as $a(t_1), a(t_2), \cdots, a(t_p)$.*

Definition 8 ([75]). *Let $a_{tk} = \langle \mu_{tk}(x), v_{tk}(x) \rangle$ be the intuitionistic fuzzy number of time series t_k, and $\varphi(t_k) = (\varphi(t_1), \varphi(t_2), \cdots, \varphi(t_n))^T$ be the weight vector of time series t_k, $\varphi(t_k) \in [0, 1]$ and $\sum_{k=1}^{p} \varphi(t_k) = 1$, then*

$$DIFWG_{\varphi(tk)}(a_{t1}, a_{t2} \cdots, a_{tp}) = \prod_{j}^{p} a_{tk}^{\varphi(tk)} = \left(\prod_{j}^{p} a_{tk}^{\varphi(tk)}, 1 - \prod_{j}^{p} (1 - \gamma_{tk})^{\varphi(tk)}\right) \tag{4}$$

is called the dynamic intuitionistic weighted geometric operator.

3.2. Integration Operator and Weight Vector Based on Interaction between Attributes

3.2.1. Intuitionistic Fuzzy Weighted Geometric Heronian Average Operator Based on the Interaction between Attributes

On the basis of Equation (1), let $\tilde{a}_i = \langle a_i, b_i \rangle (i = 1, 2, \ldots, n)$ be a set of intuitionistic fuzzy sets and $p \geq 0, q \geq 0$, then the intuitionistic fuzzy geometric heronian average (IFGHM) operator can be written as follows:

$$\text{IFGHM}^{p,q}(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_n) = \frac{1}{p+q}\left(\bigotimes_{i=1,j=1}^{n} \left((p\tilde{a}_i \oplus q\tilde{a}_j)^{2/n(n+1)}\right)\right) \tag{5}$$

Equation (2) is introduced for intuitionistic fuzzy ensemble operator:

$$\bigotimes_{i=1,j=1}^{n} \beta_{ij}^{2/n(n+1)} = \left(\prod_{i=1,j=1}^{n} t_{\beta_{ij}}^{2/n(n+1)}, 1 - \prod_{i=1,j=1}^{n} (1 - f_{\beta_{ij}})^{2/n(n+1)}\right) \tag{6}$$

Through the intuitionistic fuzzy algorithm, we have:

$$p\tilde{a}_i \oplus q\tilde{a}_j = \left[1 - (1 - a_i)^p (1 - a_j)^q, (b_i)^p (b_j)^q\right] \tag{7}$$

Then replace β_{ij}, $t_{\beta_{ij}}$ and $f_{\beta_{ij}}$ with $p\tilde{a}_i \oplus q\tilde{a}_j$, $1-(1-a_i)^p(1-a_j)^q$ and $(b_i)^p(b_j)^q$, respectively. It can be obtained as follows:

$$\underset{i=1.j=1}{\overset{n}{\otimes}}(p\tilde{a}_i \oplus q\tilde{a}_j)^{2/n(n+1)} = \left[\prod_{i=1,j=1}^{n}\left(1-(1-a_i)^p(1-a_j)^q\right)^{2/n(n+1)}, \right. \\ \left. 1-\prod_{i=1,j=1}^{n}\left(1-(b_i)^p(b_j)^q\right)^{2/n(n+1)}\right] \tag{8}$$

According to the above derivation, let $\tilde{a}_i = \langle a_i, b_i\rangle (i = 1, 2, \ldots, n)$ be a set of intuitionistic fuzzy sets and $p \geq 0, q \geq 0$, then Equation (5) is still an intuitionistic fuzzy set after integration, and the IFGHM integration operator can be obtained as follows:

$$\mathrm{IFGHM}^{p,q}(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_n) = \frac{1}{p+q}\left(\underset{i=1,j=1}{\overset{n}{\otimes}}\left((p\tilde{a}_i \oplus q\tilde{a}_j)^{2/n(n+1)}\right)\right) \\ = \left(1-\left(1-\prod_{i=1,j=1}^{n}\left(1-(1-a_i)^p(1-a_j)^q\right)^{2/n(n+1)}\right)^{1/p+q}, \right. \\ \left. 1-\left(1-\prod_{i=1,j=1}^{n}\left(1-(b_i)^p(b_j)^q\right)^{2/n(n+1)}\right)^{1/p+q}\right) \tag{9}$$

Since each attribute has different effects on the target value, the weight of each attribute is introduced into Equation (9) based on the IFGHM ensemble operator considering the interaction between attributes, so as to form the IFGWHM operator.

Let $\tilde{a}_i = \langle a_i, b_i\rangle (i = 1, 2, \ldots, n)$ be a set of intuitional fuzzy sets and $p \geq 0, q \geq 0$, $w = (w_1, w_2, \ldots, w_n)^{\mathrm{T}}$ be attribute weight vectors satisfying $0 \leq w_j \leq 1, \sum_{j=1}^{n} w_j = 1$, then the IFGWHM operator is:

$$\mathrm{IFGWHM}^{p,q}(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_n) = \frac{1}{p+q}\left(\underset{i=1,j=1}{\overset{n}{\otimes}}\left(\left((p\tilde{a}_i)^{w_i} \oplus (q\tilde{a}_j)^{w_j}\right)^{2/n(n+1)}\right)\right) \tag{10}$$

Similarly, according to the principle of Equations (5)–(9), the IFGWHM operator can be deduced as follows:

$$\mathrm{IFGWHM}^{p,q}(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_n) = \frac{1}{p+q}\left(\underset{i=1,j=1}{\overset{n}{\otimes}}\left(\left((p\tilde{a}_i)^{w_i} \oplus (q\tilde{a}_j)^{w_j}\right)^{2/n(n+1)}\right)\right) \\ = \left(1-\left(1-\prod_{i=1,j=1}^{n}\left(1-\left(1-(a_i)^{w_i}\right)^p\left(1-(a_j)^{w_j}\right)^q\right)^{2/n(n+1)}\right)^{1/p+q}, \right. \\ \left. \left(1-\prod_{i=1,j=1}^{n}\left(1-\left(1-(1-b_i)^{w_i}\right)^p\left(1-(1-b_j)^{w_j}\right)^q\right)^{2/n(n+1)}\right)^{1/p+q}\right) \tag{11}$$

3.2.2. Time Sequence Weight Vector and Target Attribute Weight Vector Based on Time Entropy

(i) Determination of time series weight vector based on time entropy

Compared with a traditional intuitionistic fuzzy multi-attribute group decision-making problem, dynamic multi-attribute intuitionistic fuzzy group decision-making needs to consider the influence of time more [76]. In the process of real group decision-making, the decision maker does not fully grasp the existing information and the information distribution is not clear. In order to fully reflect the timeliness of intuitionistic fuzzy information, this study draws on the idea of stressing the present rather than the past. In other words, the closer the intuitionistic fuzzy information is, the stronger its timeliness is, and the closer it is to the true value of the target attribute, the larger the weight coefficient is given, which reflects the characteristics of attaching importance to new information and paying attention to effectiveness. Therefore, this paper adopts the method of stressing the present rather than the past. Based on time entropy, the algorithm is as follows [77].

Let the time entropy $I = -\sum_{k=1}^{p} w_k \ln w_k$ objectively reflect the amount of intuitionistic fuzzy information under different time sequences contained in the time weight. If the amount of information is less, the time entropy will be greater. Set $\lambda = \sum_{k=1}^{p} \frac{p-k}{p-1}\eta_k$, then λ is called the time degree of $\eta = \{\eta_1, \eta_2, \cdots, \eta_p\}$. $\lambda = 0$ at that time indicates that the decision maker only attaches importance to the current moment information, which is called the positive time weight vector. When λ= 1, it indicates that the decision maker only attaches importance to the oldest information, which is called the negative time weight vector. λ= 0.5, $V = \left\{\frac{1}{p}, \frac{1}{p}, \cdots, \frac{1}{p}\right\}$ at that time, indicating that decision makers attach equal importance to information at all times.

Under the condition of given time degree λ, the time weight $\eta_k (k = 1, 2, \cdots, p)$ is determined by the criterion of time entropy maximization, then the following nonlinear programming model can be obtained:

$$\begin{cases} \max I = -\sum_{k=1}^{p} w_k \ln w_k \\ s.t.\ \lambda = \sum_{k=1}^{p} \frac{p-k}{p-1}\eta_k, \sum_{k=1}^{p} \eta_k = 1, \eta_k \in [0,1] \end{cases} \tag{12}$$

The timing weight vector can be obtained by solving this model.

(ii) Determination of target attribute weight vector

At different moments, decision makers attach different importance to each attribute of the target, so it is necessary to determine the weight of each attribute of the target in different time series. In this paper, based on probability theory, the intuitionistic fuzzy entropy method (IFE) of measuring information is used to obtain the weights of target attributes under different time series, so as to reduce the influence of subjective weights on uncertain information and measure the dynamic intuitionistic information more scientifically and reasonably. The specific steps of the algorithm are as follows [78]:

Let the intuitionistic fuzzy number $a_{ij}(t_k) = \langle \mu_{ij}(t_k)(x), \gamma_{ij}(t_k)(x) \rangle$, $\mu_{ij}(t_k)(x)$ represents the membership degree of the i scheme belonging to the j attribute at time t_k, and $\gamma_{ij}(t_k)(x)$ represents the non-membership degree of the i scheme belonging to the j attribute at time t_k. Then the hesitancy degree is $\pi_{ij}(t_k) = 1 - \mu_{ij}(t_k)(x) - \gamma_{ij}(t_k)(x)$. When t_k is defined, the intuitionistic fuzzy entropy of the target attribute is:

$$E_j(t_k) = \frac{1}{m}\sum_{i=1}^{m}\left\{1 - \sqrt{\left(1 - \pi_{ij}(t_k)^2\right) - \mu_{ij}(t_k)(x)\gamma_{ij}(t_k)(x)}\right\} \tag{13}$$

Let the weight of target attribute be $\omega_j(t_k)$ when t_k, then the optimization model of target attribute weight is:

$$\begin{cases} \min \sum_{j=1}^{n} \omega_j(t_k)^2 E_j(t_k) \\ s.t.\ \sum_{j=1}^{n} \omega_j(t_k) = 1 \end{cases} \tag{14}$$

The Lagrangian function constructed from the above equation is: $L(\omega_j(t_k), \delta) = \sum_{j=1}^{n} \omega_j(t_k)^2 E_j(t_k) + 2\delta\left(\sum_{j=1}^{n} \omega_j(t_k) - 1\right)$. Take the partial derivatives of $\omega_j(t_k)$ and δ, respectively, and set the partial derivatives equal to 0, then:

$$\begin{cases} \frac{\partial L(\omega_j(t_k),\delta)}{\partial \omega_j(t_k)} = 2\omega_j(t_k)E_j(t_k) + 2\delta = 0 \\ \frac{\partial L(\omega_j(t_k),\delta)}{\partial \delta} = 2\left(\sum_{j=1}^{n} \omega_j(t_k) - 1\right) = 0 \end{cases} \tag{15}$$

The attribute weight vector can be obtained by solving this model, then the target attribute weight is:

$$\omega_j(t_k) = \frac{(E_j(t_k))^{-1}}{\sum_{j=1}^{n} (E_j(t_k))^{-1}} \tag{16}$$

3.3. Dynamic Intuitionistic Fuzzy Multi-Attribute Group Decision-Making Steps

Based on the properties of interactions between the IFGWHM operator, in a time sequence of entropy weight vector and target properties, on the basis of weight vector for weights being a completely unknown attribute weight and time dynamic intuitionistic fuzzy multiple attribute group decision-making problems, this paper proposes a considering interaction in a dynamic intuitionistic fuzzy multiple attribute group decision-making method. The running logic of this method is shown in Figure 4.

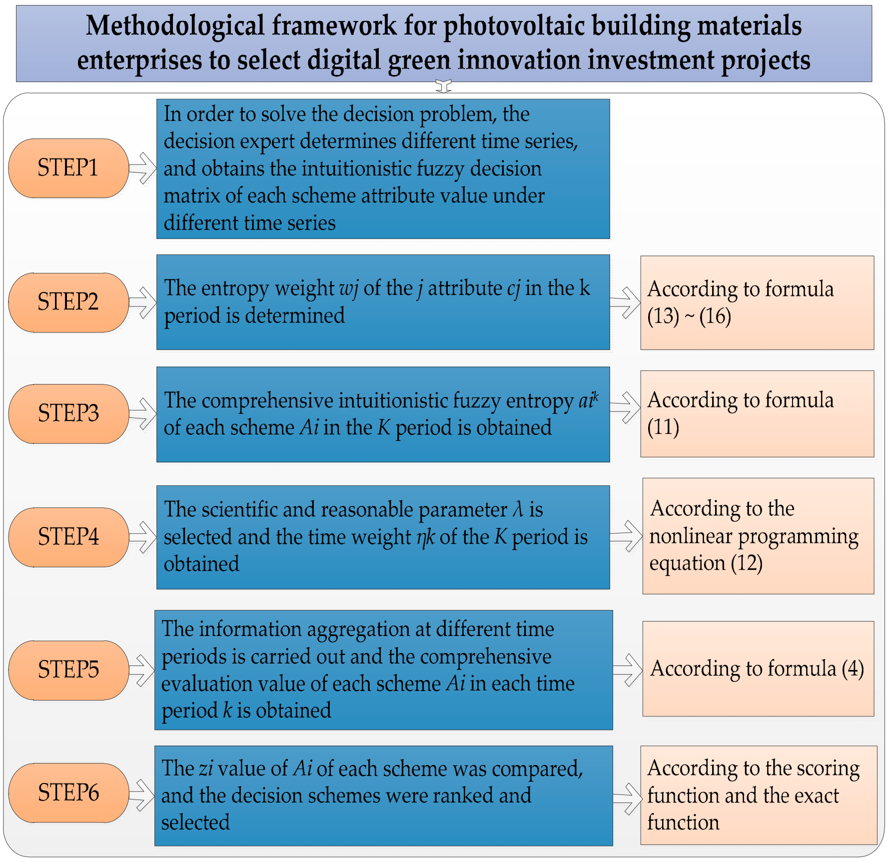

Figure 4. Methodology framework for photovoltaic building materials enterprises to select digital green innovation investment projects.

Figure 4 shows the process of dynamic selection of digital green innovation investment projects by photovoltaic building materials enterprises. The specific steps are as follows.

Step 1: For a group of decision problems, the relevant decision evaluation experts are invited and each decision expert determines the different timing sequence. Intuitionistic fuzzy evaluation is carried out on the attribute values of each scheme under different time series. After multiple rounds of comprehensive feedback and decision expert evaluation, the results of decision expert evaluation are consistent and the intuitionistic fuzzy decision matrix of attribute values of each scheme under different time series is $G(t_k) = \left(g_{ij}(t_k)\right)_{m\times n}$.

Step 2: The intuitionistic fuzzy entropy method formulas (13) to (16) of measure information are used to determine the entropy weight w_j of the j attribute c_j in the k period.

Step 3: Formula (11) is used to obtain the comprehensive intuitionistic fuzzy value a_i^k of each scheme A_i in the k period.

Step 4: According to the advice of decision makers and relevant decision experts, it is necessary to select a scientific and reasonable parameter of time degree λ, solve the nonlinear programming Equation (12) and obtain the time weight η_k of the k period.

Step 5: Formula (4) is used to gather information in different periods, and the comprehensive evaluation value $z_i(i = 1, 2, \cdots, n)$ of each scheme A_i in k period is obtained.

Step 6: The score function and the exact function are used to compare the magnitude of the z_i value of each scheme A_i and to rank and select the best decision scheme.

4. Empirical Example Analysis

4.1. Application Background

Yingli Group was founded in 1987 and entered the photovoltaic field in 1993. The enterprise is a collection of photovoltaic module manufacturing, photovoltaic green building materials product development and application and green logistics as one of the comprehensive industrial groups. Headquartered in Baoding, Hebei Province, Yingli Group has 21 provincial-level companies and 1156 authorized service outlets nationwide, with branches in key regions, such as Beijing–Tianjin–Hebei, Yangtze River Delta and Greater Bay Area. Its business scope covers the UK, Germany, the Netherlands, the Middle East and other countries and regions around the world. Up to now, Yingli has accumulated more than 25 gigawatts of photovoltaic products to serve the world, an average annual power generation of 23 billion KWH and an annual emissions reduction of 18.75 million tons of greenhouse gas. By cultivating multiple sub-brands and forming a diversified industrial sequence system, Yingli Group extends zero carbon to every corner of urban life and contributes to the construction of quality life. With the global attention to low-carbon environmental protection production and life, the development of enterprises increasingly needs to improve the competitiveness and profit of digital green innovation. In order to further improve the sustainable development ability of Yingli Group, the enterprise will be committed to the selection of digital green innovation investment projects.

At present, there are four digital green innovation projects for enterprises to choose from. Yingli Group needs to choose one of the investment projects, and these projects are willing to cooperate with Yingli Group. Yingli Group has some experience in selecting investment projects, but how to choose the best investment project from multiple options is still a difficult problem.

4.2. The Experience Element

4.2.1. Formulation of Evaluation Criteria

Based on the theory, this study constructs a framework system for enterprises to choose digital green innovation investment projects. This system can meet the requirements of Yingli Group to select investment projects. In the context of digital green innovation, the system evaluation criteria for enterprises to select investment projects are divided into external support system, commercialization expectation, project operation capability and project operation resources. External support system includes green policy support, project-related industry clustering advantage, the social digital innovation environment, project location advantage, project industrial chain maturity, financial market environment and intellectual property protection system support. Commercialization expectation system includes green market competition, consumer green demand, smart and green logistics, green technology research and development strength, digital service differentiation degree and whether products or technologies are protected by patents. Project operation ability system includes the intellectualization degree of process, digital technical proficiency of employees, green awareness of technicians, proportion of green research and development personnel, digital marketing network, green research and development investment and number of patents applied. Project operation resources system includes project green culture, digital knowledge of the team, current ratio, inventory turnover, return on equity and growth rate of total assets.

The evaluation system established in this study is shown in Figure 2.

4.2.2. Data and Scenarios

Yingli Group is a photovoltaic building materials enterprise, committed to the development of digital green innovation direction. At present, the concept of low-carbon and energy-saving production and life is gradually paid attention to, and the government is also paying more and more attention to carbon emissions in production and life. Companies will face hefty fines from government departments if their total carbon emissions exceed government limits. How to improve the green competitiveness and profit of enterprises in the environment of low carbon emission reduction is an important issue. Yingli Group promotes enterprise development by investing in digital green innovation projects. In this case, Yingli Group needs to choose the best project from a large number of alternative projects to invest in. The criteria and methods presented in this paper are applicable to the selection of digital green innovation investment projects by light-volt building materials enterprises. The reason is that managers and participants understand that the weight of selection criteria for digital green innovation projects is in a vague state. After preliminary screening, there are four digital green innovation investment projects $P_i = \{P_1, P_2, P_3, P_4\}$ entered into the final selection range.

4.3. Results and Discussion

4.3.1. Results

Yingli Group is required to choose among four digital green innovation investment projects according to the suggested criteria and methods. The developed project selection criteria, shown in Figure 2, consist of four main criteria and 26 sub-criteria for the purpose of evaluating alternative projects. In this process, this study selected three time series sets $t_k = (t_1, t_2, t_3)$ of different periods. For the sake of simplicity, this paper only gives the calculation of four main criteria, denoted as attribute set $C_k = (C_1, C_2, C_3, C_4)$. Table 1 shows the indicator evaluations of four alternative partners over three different periods.

Step 1: Yingli Group selects projects based on the above four indicators and conducts market research. The enterprise initially determined four alternative projects, and invited ten relevant decision evaluation experts and each decision expert determined three different timing periods. Intuitionistic fuzzy evaluation was carried out by experts on the attribute values of each alternative project under different time series. After multiple rounds of comprehensive feedback and evaluation by decision experts, the evaluation results of decision experts were finally made consistent, and the intuitionistic fuzzy decision matrix of attribute values of each alternative project under three different time series was obtained as shown in Table 2.

Table 2. Intuitionistic fuzzy decision matrix under 3 different time series.

T_1	C_1	C_2	C_3	C_4
A_1	<0.3, 0.4>	<0.2, 0.4>	<0.3, 0.4>	<0.4, 0.5>
A_2	<0.4, 0.5>	<0.5, 0.1>	<0.6, 0.3>	<0.1, 0.8>
A_3	<0.4, 0.6>	<0.1, 0.3>	<0.4, 0.6>	<0.6, 0.2>
A_4	<0.1, 0.4>	<0.4, 0.5>	<0.6, 0.4>	<0.5, 0.4>
T_2	C_1	C_2	C_3	C_4
A_1	<0.5, 0.4>	<0.6, 0.4>	<0.2, 0.4>	<0.4, 0.5>
A_2	<0.4, 0.6>	<0.7, 0.3>	<0.5, 0.5>	<0.6, 0.4>
A_3	<0.7, 0.2>	<0.4, 0.5>	<0.4, 0.6>	<0.4, 0.3>
A_4	<0.4, 0.5>	<0.3, 0.4>	<0.1, 0.4>	<0.4, 0.6>
T_3	C_1	C_2	C_3	C_4
A_1	<0.3, 0.5>	<0.6, 0.4>	<0.2, 0.4>	<0.4, 0.5>
A_2	<0.5, 0.2>	<0.1, 0.3>	<0.2, 0.5>	<0.1, 0.2>
A_3	<0.4, 0.4>	<0.4, 0.2>	<0.4, 0.1>	<0.4, 0.4>
A_4	<0.6, 0.4>	<0.3, 0.5>	<0.6, 0.3>	<0.4, 0.4>

Step 2: According to the Intuitionistic Fuzzy entropy method formula (13) to (16), the attribute weights of the first period are determined as follows:

$$\begin{aligned} w_j^1 &= (0.2262, 0.2017, 0.2457, 0.3264) \\ w_j^2 &= (0.2773, 0.2574, 0.2170, 0.2483) \\ w_j^3 &= (0.2990, 0.2254, 0.2671, 0.2085) \end{aligned}$$

Step 3: According to Formula (11), the IFGWHM operator based on the interaction between attributes studied in this paper is used to aggregate the attribute information of each alternative project of Yingli Group and $p = q = 1$ is set in the process, so that the comprehensive intuitionistic fuzzy evaluation value of each alternative project in the $k(k = 1, 2, 3)$ period can be obtained as:

$$\begin{aligned} &a_1^1 =< 0.7424, 0.1333 >;\ a_2^1 =< 0.7406, 0.1810 >; \\ &a_3^1 =< 0.7672, 0.1354 >;\ a_4^1 =< 0.7687, 0.1280 >; \\ &a_1^2 =< 0.7984, 0.1299 >;\ a_2^2 =< 0.8552, 0.1448 >; \\ &a_3^2 =< 0.8265, 0.1244 >;\ a_4^2 =< 0.7250, 0.1528 >; \\ &a_1^3 =< 0.7610, 0.1402 >;\ a_2^3 =< 0.6656, 0.0917 >; \\ &a_3^3 =< 0.7953, 0.0824 >;\ a_4^3 =< 0.8286, 0.1201 > . \end{aligned}$$

Step 4: According to the suggestions of decision makers and relevant decision-making experts, and according to the opinions of experts related to the project research, in order to show the obvious emphasis on the recent data, take time degree $\lambda = 0.4$, solve the nonlinear programming Equation (12) and obtain the time weight of the $k(k = 1, 2, 3)$ period:

$$\eta_k(k = 1, 2, 3) = (0.2384, 0.3232, 0.4384)$$

Step 5: According to Equation (4), the dynamic intuitionistic weighted geometry operator is used to gather the time information, so that the overall intuitionistic fuzzy evaluation value of each alternative project based on the three time periods can be obtained as:

$$\begin{aligned} &z_1 =< 0.7683, 0.1352 >;\ z_2 =< 0.7404, 0.1309 >; \\ &z_3 =< 0.7984, 0.1089 >;\ z_4 =< 0.7795, 0.1327 > . \end{aligned}$$

Step 6: The score function $S(a)$ and the exact function $H(a)$ are used and the comprehensive score and accuracy of each alternative project is compared according to the ranking rule. The enterprise ranks and selects the best of the alternative projects, as shown in Table 3.

Table 3. Evaluation results of the IFGWHM operator considering the interaction between attributes.

	S	H	Ranking
A_1	0.6331	0.9036	3
A_2	0.6095	0.8713	4
A_3	0.6894	0.9073	1
A_4	0.6469	0.9122	2

As can be seen from Table 3, $S(A_3) > S(A_4) > S(A_1) > S(A_2)$, Yingli Group can choose projects in the order of pros and cons $A_3 \succ A_4 \succ A_1 \succ A_2$. Therefore, Yingli Group should choose project A_3 for digital transformation cooperation.

Yingli Group conducted research and planned to adopt this method to select digital green innovation investment projects and finally decided to choose project A_3 for investment cooperation.

4.3.2. Comparative Analysis of Evaluation Results

In the example, based on the evaluation of attribute values by decision evaluation experts on project related research and the selection of three time series stages, the attribute information with interaction is integrated through the weight of each attribute at different time series and the IFGWHM operator considering the interaction between attributes. The information of an intuitionistic fuzzy ensemble under different timings is integrated by timing weights and dynamic intuitionistic fuzzy weighted geometry (DIFWG) operators. Finally, the score function and exact function are used to rank and select the best decision schemes, so as to make a multi-attribute group decision for the project selection of Yingli Group. In order to verify the effectiveness and scientificness of the method proposed in this paper, the classical IFWA operator in Definition 6 and the temporal weight based on SUM function are compared and analyzed with the method as follows.

The classical IFWA operator of attribute information integration in reference [79] and the temporal weight based on SUM function in reference [74] are, respectively, compared and analyzed, and the evaluation and selection results are shown in Table 4.

Table 4. Evaluation and selection results of different attribute integration operators and timing weights.

	IFGWHM Operator			IFWA Operator		
Time	**S**	**H**	**Ranking**	**S**	**H**	**Ranking**
A_1	0.6331	0.9036	3	−0.0504	0.8210	4
A_2	0.6095	0.8713	4	0.0198	0.7317	2
A_3	0.6894	0.9073	1	0.1307	0.7467	1
A_4	0.6469	0.9122	2	−0.0025	0.8449	3
SUM Function	**S**	**H**	**Ranking**	**S**	**H**	**Ranking**
A_1	0.6352	0.9071	3	−0.0422	0.8327	4
A_2	0.6171	0.8474	4	0.0247	0.6945	2
A_3	0.6826	0.9023	1	0.1302	0.7198	1
A_4	0.6549	0.9170	2	0.0087	0.8450	3

(i) Time series weight comparison and analysis based on different operators

In the calculation example, under the IFGWHM operator, the selection results of temporal weight determined based on time entropy are shown in Table 3 and the good and bad order of selected items is $A_3 \succ A_4 \succ A_1 \succ A_2$. In the SUM function, if the parameter is 2, there is $Q(x) = x^2$ and the timing weight determined based on the SUM function is $\eta_k = (0.1111, 0.3333, 0.5556)$. The selection results are shown in Table 4 and the good and bad order of the selected items is $A_3 \succ A_4 \succ A_1 \succ A_2$. Although the selection results are consistent, the variance average method is further used to test the variance of the above two results. It can be concluded that the variance of the selection results based on time entropy and SUM function is $S^2_{mean\times 1} = 0.0336$ and $S^2_{mean\times 2} = 0.0281$, respectively, and, obviously, $S^2_{mean\times 1} > S^2_{mean\times 2}$. Similarly, under the classical IFWA operator, the selection results of temporal weight determined based on time entropy are shown in Table 4 and the good and bad order of selected items is $A_3 \succ A_2 \succ A_4 \succ A_1$. The timing weight is the same as that under the IFGWHM operator. The selection results are shown in Table 4 and the pros and disadvantages of the selected items are listed in $A_3 \succ A_2 \succ A_4 \succ A_1$. Then, $S^2_{mean\times 1}$ is still bigger than $S^2_{mean\times 2}$. It can be seen that the timing weight selection results based on time entropy have better discrimination, which can provide more clear and reliable decision information for decision makers. In addition, the temporal weight obtained based on SUM function depends on its own parameters and changes with the change of parameters, while the temporal weight determined based on time entropy is more stable, so the integrated information of temporal weight obtained is more scientific, and the result of group decision-making is more reasonable and effective.

(ii) Comparison and analysis of IFGWHM operator and classical IFWA operator

In the example, the results selected by the IFGWHM operator considering the interaction between attributes are shown in Table 4 and the good and bad order of the selected items is $A_3 \succ A_4 \succ A_1 \succ A_2$. The selection results of the classical IFWA operator are shown in Table 4. The selected items are in the order of $A_4 \succ A_2 \succ A_1 \succ A_3$. Although the selection results are consistent, the ranking is obviously different. The reason is that the attributes are often not independent and there are always certain interaction relations, such as complementarity, redundancy, preference relations, etc. The four attribute indexes of this example are external support system, commercialization expectation, project operation ability and project operation resources. For example, external support system, project operation capacity and project operation resources will affect the commercialization expectation. Project operation resources will inevitably affect the project operation ability. Therefore, it is more scientific and reasonable to use the IFGWHM operator, considering the interaction between attributes for group decision analysis.

Therefore, the method of this study is a dynamic intuitionistic fuzzy multi-attribute group decision-making method considering the interaction between attributes. In this method, the IFGWHM operator is used to aggregate the attribute information under different time series considering the interaction between attributes. It determines the scientific and stable time sequence weight by the method of stressing the present rather than the past, based on time entropy. At the same time, the DIFWG operator is used to integrate the intuitionistic fuzzy ensemble information under different time series. This study verifies the scientificity and effectiveness of the dynamic intuitionistic fuzzy multi-attribute group decision-making method considering the interaction between attributes through the example and comparative analysis.

5. Conclusions and Implications

5.1. Conclusions

With the background of carbon peak and carbon neutrality, it is the right choice for enterprises to invest in digital green innovation projects in order to improve their green competitiveness and increase profits. First of all, based on the theoretical analysis, this paper constructs the index system of the evaluation project. Secondly, an intuitionistic fuzzy multi-attribute group decision-making method is proposed. Finally, this study analyzes the process of Yingli Group in selecting digital green innovation investment projects. This practice has positive enlightenment significance for other photovoltaic building materials enterprises to make decisions in the selection of digital green innovation investment projects.

The conclusion of this study is as follows. First, this study innovatively established a project selection framework system based on the combination of relevant theories and project characteristics of expected investment. The framework system includes four aspects: external support system, commercialization expectation, project operation ability and project operation resources, which are scientific. Second, this study proposes a dynamic intuitionistic fuzzy multi-attribute group decision-making method considering the interaction between attributes. The method takes into account the interaction between attributes. Moreover, this method can determine the scientific and reasonable timing weight vector and improve the validity and stability of group decision-making results. This study shows that the above framework system and method can effectively help Yingli Group to make investment project decisions. At the same time, the framework system and method are also applied to other global photovoltaic building materials enterprises to select digital green innovation investment projects.

5.2. Implications

This research has important theoretical and managerial significance. It can bring positive enlightenment to other photovoltaic building materials enterprises when making choices in the activities of choosing digital green innovation projects.

In terms of theoretical significance, this study proposes a dynamic intuitionistic fuzzy multi-attribute group decision-making method considering the interaction between attributes. The method takes into account the interaction between the factors, and determines the scientific and reasonable timing weight vector, which can improve the effectiveness and stability of group decision-making results. On the basis of introducing the related concepts of intuitionistic fuzzy, this method firstly introduces the time entropy criterion, calculates the temporal weight according to the amount of information contained in the temporal weight, which fully reflects the timeliness of intuitionistic fuzzy information, and calculates the weight of each attribute under different temporal sequences based on the intuitionistic fuzzy entropy. Secondly, the method integrates the interacting attribute information through the IFGWHM operator considering the interaction between attributes and the weight of each attribute at different time series. Thirdly, the method integrates the intuitionistic fuzzy ensemble information of different timings by using temporal weights and DIFWG operators. Finally, the method ranks and chooses the best decision schemes by the score function and the exact function. On the one hand, the method fully takes into account the interaction relationship between attributes in different time series, such as complementarity, redundancy and preference relations, which is consistent with the fact that there are always different degrees of correlation between decision attributes. In this way, the unreasonable situation of information integration and the group decision-making result is avoided and the result of group decision-making is more realistic. On the other hand, under the premise of considering the subjective preference of time series made by experts, the subjective and objective weighting methods are integrated by mining the difference of time series information of time series samples, which effectively avoids the arbitrariness of subjective assignment of time series weight. The time sequence weight is determined by time entropy, which is more stable, avoids the unstable influence of some parameters in the time sequence weight function and the invalidity of some time sequence information caused by 0 weight and makes the group decision more scientific and reasonable.

In terms of management significance, this study innovatively constructs a research system for photovoltaic building materials enterprises in the selection of digital green innovation investment projects. The system selects four aspects: external support system, commercialization expectation, project operation ability and project operation resources, which fully reflect the characteristics of the internal and external environment of the project and are scientific. At the same time, the research framework and research system can be used to help other photovoltaic building materials enterprises make choices in the selection of digital green innovation projects. This makes the investment decision more efficient and accurate, and then reduces the management cost and promotes the development of enterprises.

5.3. Deficiencies and Future Prospects

There are still some limitations to this study that deserve further attention. First, artificial intelligence (AI) technology is gradually applied to decision-making problems, and the combination of resource complementarity and AI plays an important role in future enlightenment. Second, only one case study was conducted in this study, and future studies may include a large sample size from many photovoltaic building materials enterprises to verify the correctness of the framework system and the use of methods. Photovoltaic building materials enterprises can also be classified according to the scale of research and development or enterprise size. Third, in terms of system, the system established in this study is only effective for photovoltaic building materials enterprises and the future research system needs to make different adjustments according to different industries and fields. Fourth, at the method level, the time weight and attribute weight in this study are both objective weights. In the future, methods need to be developed to combine subjective and objective weights.

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