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A Hybrid Model to Explore the Barriers to Enterprise Energy Storage System Adoption

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Abstract: Using green energy is an important way for businesses to achieve their ESG goals and ensure sustainable operations. Currently, however, green energy is not a stable source of power, and this instability poses certain risks to normal business operations and manufacturing processes. The installation of energy storage equipment has become an indispensable accompaniment to facilitating green energy use for an enterprise. However, businesses may encounter significant barriers during the process of installing energy storage equipment. This study aims to explore and discern the key barrier factors that influence the assessment and decision-making process of installing energy storage equipment. A hybrid approach combining the Decision-making and Trial Evaluation Laboratory (DEMATEL) and Interpretive Structural Modeling (ISM) is developed to explore the causality relationships and degrees of influence among these key factors. The Z-number and Rough Dombi Weighted Geometric Averaging (RDWGA) methods are also utilized to integrate the experts' varied opinions and uncertain judgements. Finally, recommendations are provided based on the results to assist businesses to make informed decisions while evaluating the installation of energy storage equipment, to ensure a stable and uninterrupted supply of green energy for use in normal operations.

Keywords: corporate energy storage system; ESG; sustainability; MCDM; DEMATEL; ISM; RDWGA

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1. Introduction

The adoption of clean and renewable energy and a reduction in the consumption of fossil fuels are essential trends for the transformation of the global energy supply. The goal of controlling increases in global temperature is, or should be, the aim of concerted efforts in all countries [1]. Increased awareness of the needs for environmental protection and a reduction of carbon emissions are essential for the sustainable development of economies and businesses. The development of clean and renewable sources of energy is a crucial policy direction for sustainable development in all countries. Today, under the encouragement of governmental policies, the technological development and application of renewable energy such as solar energy [2], wind energy [3], ocean thermal energy [4], and biomass energy [3] have become widespread, allowing for the diversification and utilization of varied sources of renewable power. Despite its non-polluting characteristics, renewable energy still has some disadvantages, such as unstable power quality and supply due to its randomness, intermittency, and volatility [5]. For example, the production of solar power is limited by the hours of sunlight, the sunlight intensity, the amount of cloud cover, and the wind speed [6,7]. Wind power is limited by the season and changes in the weather, so it cannot be supplied stably over a long period of time [8,9]. Energy storage systems are a solution to instability in the supply of renewable energy bringing the advantages of backup power, voltage control, and power supply support [10]. However, in practice, the rate of businesses installing energy storage equipment is still low. A review of the current literature reveals that most of the research has been focused on energy storage technologies and materials, few have explored the factors which act as barriers to decisions to install or not to install energy storage equipment in the real world. There is no research discussing the obstacles of installing energy storage for enterprises. The objective of this study is to find out what the major barrier factors to the installation of energy storage systems in businesses are, as well as their causality and significance ranking, and the mutual influence relationships among the factors.

A review of the literature shows that many research methods have been successfully adapted to explore the interconnected influence relationships among factors, including Structural Equation Modeling (SEM) [11], Confirmatory Factor Analysis (CFA) [12], and the Path Analysis Model [13]. In the past few years, the Decision-making and Trial Evaluation Laboratory (DEMATEL) and Interpretive Structural Modeling (ISM) methods have been frequently applied to explore the influence of barrier factors. For example, Bali et al. [14] used this methodology to examine the purchase behavior of mobile phones, Koca et al. [15] used it to find the criteria and indicators for measuring the performance of smart cities in emerging countries, and Shieh et al. [16] found the key success factors for measuring the quality of services. The ISM method has been used to explore the factors for the successful implementation of sustainable supply chain management in the oil and gas energy sector [17]. Tan et al. [18] adapted ISM to investigate the factors which were barriers to the use of Building Information Modeling in conventional buildings. Rana et al. [19] applied ISM to explore the barrier factors to implementing e-business practices in small and medium-sized enterprises (SMEs). Kumar et al. [20] combined ISM and ANP to construct a research framework to explore the barrier factors to promoting Industry 4.0 and the circular economy. Singh and Rathi [21] used an integrated ISM and SEM methodology to investigate the barrier factors to the promotion of Lean Six Sigma certification for small and medium enterprises. The above studies show that DEMATEL and ISM have been widely used. DEMATEL has the following benefits: (1) it is effective in analyzing the direct and indirect effects of different factors, and helps to understand the complex causal relationships among factors in decision problems; (2) it can visually represent the interrelationships among factors and enable decision-makers to comprehend clearly which factors have greater influence on others; (3) it can also be used to rank alternatives, identify the key assessment criteria, and weigh differences among these criteria [22]. ISM, on the other hand, as proposed by Warfield in 1973 [23], has the advantageous features of: (1) helping to present complex systems in a simplified way; (2) providing an explanation of fixed objects; and (3) helping to identify structures within the system [17]. This study combines these methods to obtain these to develop a DEMATEL-ISM model, which can not only help understand the causal relationship among the factors but also explore the hierarchical structure they produce and provide more information to the decision-makers. The DEMATEL and ISM decision-making process is still reliant on expert judgements. However, experts often have differences in preferences depending on their industry experience and varied standpoints [24], which can lead to uncertainty and inconsistency in decision-making information [25,26]. To solve the above problems, two methods were used in this research. The Z-number technique, which has the advantage of being able to integrate the experts' opinions and judgments as well as determine the level of confidence of all experts in the assessment, is applied to resolve decision-making uncertainty [27]. In addition, Rough Dombi Weighted Geometric Averaging (RDWGA), which uses a mathematical formulation to obtain the weighted average is applied to fuse the uncertain and inconsistent expert assessment results during the group decision-making process, which can be expressed as interval numbers [28]. The combined Z-RDWGA method is effective at integrating the expert opinions. The proposed hybrid model has not been applied in the relative topics.

The highlights of this study are as follows:

1. Identification of the key barrier factors to the installation of energy storage systems in enterprises.
2. Develops a DEMATEL-ISM model to explore the degree of mutual influence and ranking of the key barrier factors.
3. Integration of the Z-RDWGA technique to overcome the disadvantages of uncertainty and inconsistency of the experts' information.
4. Proposes recommendations and strategies for enterprises, which can provide a reference for the enterprise decision-making about energy storage installation.

The rest of this paper is structured as follows. Section 2 contains a literature review related to the development of energy storage devices, discusses the criteria and framework for decision-making about its installation, and details the research methodology. Section 3 introduces the structure of the model and describes the computational process in detail. The empirical analysis is outlined in Section 4, the data sources are introduced and the results of the analysis, as well as the analysis of multi-attribute decision-making, are discussed. In Section 5, the validity of the methodology is explored and the management implications are discussed. Finally, Section 6 summarizes the research outcomes, contributions, and recommendations for future research.

2. Literature Review

2.1. Development of Energy Storage Equipment

The increased use of renewable energy has become an important goal for countries interested in energy transformation and reducing their dependence on fossil fuels. However, providing a continuous and stable energy supply is also important for sustainable economic development. How can companies strike a balance between the dependence on fossil fuels and the variability of renewable energy? Energy storage is a viable solution. At present, most of the literature on energy storage equipment focuses on the development of materials and technologies for the storage of electricity. For example, Faisal et al. [29] mentioned that the types of energy storage technologies that have been developed so far include batteries, compressed air energy storage, flywheel energy storage, superconducting magnetic energy storage, hydrogen storage, hybrid energy storage, and other projects. The application modes developed for energy storage systems have also been discussed for electricity supply applications, ancillary services, grid support applications, renewables integration applications, and end-user applications [30]. The power generated by wind power is intermittent and fluctuating, resulting in instability. Pontes et al. [9] used energy storage equipment to overcome the problem of the instability of wind-generated power. The use of an effective energy storage systems has the advantages of balancing demand and supply, improving power supply quality, smoothing the intermittency of renewable energy, and providing auxiliary services for regulating voltage and frequency on the grid [31]. Energy storage has become an important solution for government and businesses for energy transformation, but the rate of installation of energy storage equipment by enterprises is still very low. Therefore, the objective of this study is to explore those factors encountered during the decision-making process which act as barriers to businesses.

2.2. Barrier Factors to Installing Energy Storage Equipment

The possible barrier factors identified in this study after an in-depth literature review are presented in Table 1. In addition to the initial capital expenditure for the installation of energy storage facilities, the cost of installing fire safety facilities, air-conditioning, and cooling equipment, the cost of connecting to the internal power supply, the cost of installation site preparation, and the cost of professional technicians and governmental authorities must also be considered in the cost factor affecting the decision-making of the enterprise managers. Therefore, a "high initial setup cost" is one of the barrier factors for enterprises setting up energy storage facilities [29,32]. The steep costs for the setup energy storage equipment make the return on investment and the length of the payback period of the investment cost the focus of attention for financial executives, and if the enterprises are unable to confirm the management of the return on investment and the payback period for the equipment after purchase, this will affect the purchase decision [5,33]. Regular maintenance is indispensable to keep the equipment functioning properly, so the "maintenance cost" is of concern for business managers. If the known maintenance cost is high or there may be the danger of an unknown maintenance cost, it could discourage the business from purchasing energy storage equipment [34,35]. Currently, the technology for energy storage equipment is still under development and constant improvement so equipment currently on the market may not have the expected service life due to the immaturity of the technology. Although an energy storage system can improve the utilization rate of renewable energy and counter the problem of instability, the low technical and economic benefits may act as barriers that cause the CEOs of the enterprises to resist the installation of energy storage equipment [18,36].

Table 1. List of barrier factors.

Code	Barrier Factors	Main Cited References
B_1	High initial setup cost	[29,32]
B_2	Return on Investment (ROI) of operations	[5,33]
B_3	Maintenance cost	[34,35]
B_4	Low technical economic efficiency	[18,36]
B_5	The selection of installation location	[32]
B_6	Lack of certification and standardization system	[5,36]
B_7	Energy management system	[29,37]
B_8	Safety in the operation of energy storage equipment	[32,38]
B_9	Policy support on investment subsidies or tax incentives	[36,39]
B_{10}	Lack of knowledge about energy storage equipment	[33]
B_{11}	Difficulties in obtaining financing	[40,41]
B_{12}	Lack of clear regulatory guidelines	[34,42]
B_{13}	Environmental impact of battery recycling	[43,44]
B_{14}	Development of alternative technologies	[43]
B_{15}	Dynamic impact of energy storage equipment	[34,45]
B_{16}	Roles and functions of energy storage equipment	[39,46]
B_{17}	Lack of appropriate insurance planning	Expert interviews
B_{18}	Protests from surrounding residents	Expert interviews

If the government could provide a national certification and standardization system for products, it would help enterprises to make purchasing decisions, especially when it comes to power supply and safety considerations. The lack of national certification and safety standards for energy storage equipment is thus a barrier to enterprise decision-making [5,36]. A complete energy management system must be able to integrate the enterprise's internal power supply, both dispatch and management, and energy storage equipment should not operate independently of the energy management system. If the equipment cannot be integrated into the existing energy system for unified management, the enterprise will not be able to manage and schedule the use of its limited energy supplies [29,37]. The safety of energy storage equipment and the impact of its operation on human health are also concerns [32,38]. The inability to determine and assess hidden and unknown risks makes it difficult for businesses to make decisions and creates barrier factors to decision-making. Furthermore, management is still under the direction of government policies. Government could provide investment subsidies or tax incentives for equipment renewal and purchase in line with their policies, to prevent costs being a barrier for enterprise decision making [36,39].

There are still no set standards for financial institutions to assess the amount and period of financing for energy storage equipment, and there are still differences on whether energy storage equipment should be considered as facilities for which enterprises are unable to obtain financial support from financial institutions for their purchase. If equipment must be purchased with their own funds, enterprises may experience economic dispatch problems and this may become a barrier to the decision-making process [40,41]. The role and scope of energy storage equipment should be clearly defined to produce a clear regulatory framework which can be followed by enterprises when making decisions [34,42]. All equipment has a life cycle, and the environmental impact of the materials used for the fabrication of the equipment has to be considered after replacement or disposal. The company may be subject to penalties or claims from the authorities due to this impact or damage, which is a management risk that must be considered by the decision-makers, and if the risk is too high, it will be a barrier to decision-making [43,44].

The effect of the incorporation of energy storage equipment in an enterprise's power grid on the operation of other production equipment or the production yield is a concern of the enterprise's production managers. If the operation of the energy storage equipment could affect the quality of the product or the stability of the production line this will be a consideration for the managers considering the purchase of energy storage equipment [34,45]. The function and value of energy storage is not limited to the role of power backup, but also the ability to serve as energy arbitrage in energy dispatch management. It also helps to balance off-peak electricity consumption. This is another factor for enterprise decision-makers to consider in the purchase decision [39,46]. In addition, since energy storage equipment is a new product and new technology, property insurers lack past experience for risk assessment and actuarial calculations, affecting planning to avoid the occurrence of force majeure factors that lead to property loss or casualties. Therefore, the lack of proper risk management planning is also a barrier to the decision-making process. Communication and sharing information with residents around the location of the energy storage facility prior to the enterprise making the decision to install an energy storage system becomes an important task. Possible protests by surrounding residents could be a barrier to the installation of an energy storage system. If the residents' concerns and needs are not reasonably met, the enterprises' decision to install energy storage equipment may be affected. Therefore, "lack of appropriate insurance planning" and "protests from surrounding residents "are included in the assessment of barrier factors.

3. Research Methodology

Considering the uncertainty in expert decision-making, the research methodology is divided into three stages. First, we collected individual expert data through expert surveys and the Delphi method was used to identify key barrier factors. Second, the Z-RDWGA was utilized to integrate the inconsistent and uncertain decisions of the experts. Finally, the DEMATEL and ISM methodologies were applied to examine the interrelated causal influences among these factors. For making the research process clearer, the following research flow chart was created, as presented in Figure 1.

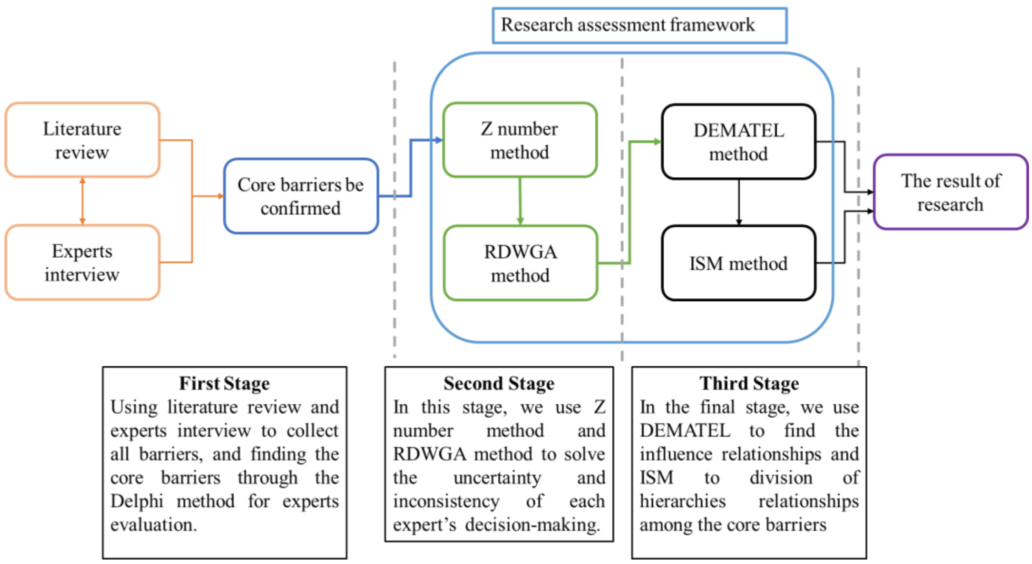

Figure 1. The research method flow chart.

3.1. Constructing the Framework for Assessing Barrier Factors

Exploring key barrier factors is an important objective of this study. The Delphi method is used to obtain a consensus of the experts' opinions and construct a framework of the key indicators. Industry experts were invited to assess the level of influence of each barrier factor on the following five level evaluation scale: "Very Low Significance (VLS), Low Significance (LS), Moderate Significance (S), High Significance (HS), and Very High Significance (VHS)" with corresponding scores of 1, 2, 3, 4, or 5, respectively. During this assessment stage, the experts engaged in multiple roundtable meetings to discuss the questionnaires and consolidate opinions. The key barrier indicators were identified for further assessment.

3.2. Integrating Expert Opinions

Zadeh's Z-number approach was utilized to determine the confidence level of the experts during the assessment process. For more details about the calculation process, please refer to Ahmandi et al. [47] and the following explanation.

Step 1. The confidence level $\widetilde{O}$ can be converted into a crisp value by applying the integral concept as shown in Equation (1), where the parameter "ϕ" denotes the confidence weight.

$$\phi = \frac{\int^{\eta} \mu_{\widetilde{O}} d\mathfrak{u}}{\int^{u_{\widetilde{O}}} d\mathfrak{u}}. \tag{1}$$

Step 2. The weighted Z-fuzzy membership function can be obtained with the confidence weight ϕ included in the assessment value Z^{ϕ}, as shown in Equation (2).

$$Z^{\phi} = \left\{ (\eta,\ u_{\widetilde{\mathrm{f}}^{\phi}}) \middle| u_{\widetilde{\mathrm{f}}^{\phi}}(\eta) = \varphi u_{\widetilde{\mathrm{f}}}(\eta),\ \eta \in [0,\ 1] \right\}. \tag{2}$$

Finally, the weighted Z-fuzzy membership function can be further converted into a regular triangular fuzzy number, as shown in Equation (3).

$$Z^{*} = (\sqrt{\phi} f^{L},\ \sqrt{\phi} f^{M},\ \sqrt{\phi} f^{U}). \tag{3}$$

In addition, the Z-number is modeled as a triangular fuzzy triplet, and can be explained by $Z = \left(\widetilde{\mathrm{f}},\ \mathrm{p}\right) = \left[\left(f^{L},\ f^{M},\ f^{U}\right),\ \mathrm{p}\right]$, where $\widetilde{\mathrm{f}}$ represents a triangle fuzzy membership function in the general assessment, i.e., $\widetilde{\mathrm{f}} = \left(f,\ u_{\widetilde{\mathrm{f}}}\right) | y \in [0,1]$, and p is the expert's confidence level in the assessment and can be shown as $\mathrm{p} = \left(\mathrm{p},\ u_{\mathrm{p}}\right) | y \in [0,1]$. Equation (3) can be de-fuzzified as a crisp number by the centroid method.

In group decision-making, achieving a more accurate consensus often involves incorporating the uncertain or inconsistent information provided by the experts, either through the assignment of explicit values or averaging calculations. The RDWGA method can be used to combine the rough preferences of the experts and identify the initial rough matrix for multi-criteria decision-making.

Suppose that $\mathrm{s}_{\mathrm{ij}}^{\mathrm{e}}$ is a full domain containing all objects (e.g., expert e evaluates the degree of influence of factor i on factor j). There are n factors in the full domain, and the lower approximate set of $\mathrm{s}_{\mathrm{ij}}^{\mathrm{e}}$ is comprised of all values equal to or less than $\mathrm{s}_{\mathrm{ij}}^{\mathrm{e}}$ in the full domain, as in Equation (4); the upper approximation set of $\mathrm{s}_{\mathrm{ij}}^{\mathrm{e}}$ is comprised of all values equal to or greater than $\mathrm{s}_{\mathrm{ij}}^{\mathrm{e}}$, as expressed in Equation (5).

$$LA(\mathrm{S}_{\mathrm{ij}}^{\mathrm{e}}) = \cup \left\{ \mathrm{s}_{\mathrm{ij}}' \in \mathrm{s}_{\mathrm{ij}} \middle| \mathrm{s}_{\mathrm{ij}}' \leq \mathrm{s}_{\mathrm{ij}}^{\mathrm{e}} \right\}; \tag{4}$$

$$UA(\mathrm{S}_{\mathrm{ij}}^{\mathrm{e}}) = \cup \left\{ \mathrm{s}_{\mathrm{ij}}'' \in \mathrm{s}_{\mathrm{ij}} \middle| \mathrm{s}_{\mathrm{ij}}'' \geq \mathrm{s}_{\mathrm{ij}}^{\mathrm{e}} \right\}. \tag{5}$$

Here, s_{ij}^{e} is a rough number (RN), represented by the lower approximation set $\underline{LIM}$ and the upper approximation set $\overline{LIM}$, as calculated by Equations (6) and (7), respectively.

$$\underline{LIM} = \left(\sum_{k}^{n_i} s_{ij}^{k} / n_L \middle| s_{ij}^{k} \in LA\left(S_{ij}^{e}\right) \right); \tag{6}$$

$$\overline{LIM} = \left(\sum_{k}^{n_j} s_{ij}^{k} / n_U \middle| s_{ij}^{k} \in UA\left(S_{ij}^{e}\right) \right). \tag{7}$$

After using the RN to represent the individual expert opinions, the Dombi method is applied [48] to integrate all expert opinions into a collection of Rough Numbers, as in Equations (8) and (9).

$$RDWGA\left\{RN_{(\Phi_1)}, RN_{(\Phi_2)} \ldots, RN_{(\Phi_n)}\right\} = \left[\frac{\sum_{j=1}^{n} \underline{LIM}_{(\Phi_j)}}{1 + \left\{ \sum_{j=1}^{n} w_j \left(\frac{1 - f\left(\underline{LIM}_{(\Phi_j)}\right)}{f\left(\underline{LIM}_{(\Phi_j)}\right)} \right)^{\rho} \right\}^{\frac{1}{\rho}}}, \frac{\sum_{j=1}^{n} \overline{LIM}_{(\Phi_j)}}{1 + \left\{ \sum_{j=1}^{n} w_j \left(\frac{1 - f\left(\overline{LIM}_{(\Phi_j)}\right)}{f\left(\overline{LIM}_{(\Phi_j)}\right)} \right)^{\rho} \right\}^{\frac{1}{\rho}}} \right] \tag{8}$$

$$f\left(RN_{(\Phi_i)}\right) = \begin{cases} f\left(\underline{LIM}_{(\Phi_i)}\right) = \frac{\underline{LIM}_{(\Phi_i)}}{\sum_{j=1}^{n} \underline{LIM}_{(\Phi_i)}} \\ f\left(\overline{LIM}_{(\Phi_i)}\right) = \frac{\overline{LIM}_{(\Phi_i)}}{\sum_{j=1}^{n} \overline{LIM}_{(\Phi_i)}} \end{cases} \tag{9}$$

where w_j is the expert weight, and ρ is 1, in this study.

3.3. Using DEMATEL-ISM for Relationship Assessment

The steps in the DEMATEL analysis are described below. Detailed computational descriptions can be found in Huang et al. [49].

Step 1. Acquiring a normalized matrix representing direct influence relationship

The direct influence matrix $\overline{\boldsymbol{A}}$ acquired from the survey responses is then normalized. The standardized direct influence matrix $\overline{\boldsymbol{N}}$ is presented in Equations (10) and (11), where $\boldsymbol{\psi}$ is the maximum of the calculated the sum of rows and columns, and $\overline{a}_{ij}$ is each element of the matrix $\overline{\boldsymbol{A}}$.

$$\overline{\boldsymbol{A}} = \left[\overline{a}_{ij}\right]_{\psi \times \psi} = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1\psi} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{i\psi} \\ \vdots & & \vdots & & \vdots \\ a_{\psi 1} & \cdots & a_{\psi j} & \cdots & a_{\psi\psi} \end{bmatrix}_{\psi \times \psi} \tag{10}$$

$$\overline{\boldsymbol{N}} = {}^{\overline{A}}\!\Big/_{\Omega} \quad \text{where } \Omega = \max\left\{ \max_i \sum_{j=1}^{n} a_{ij},\ \max_j \sum_{i=1}^{n} a_{ij} \right\} \tag{11}$$

Step 2. Generate the matrix that summarizes the total influence relation

Following Markov training convergence, the total influence relation matrix $\overline{\boldsymbol{T}}$ can be created, in which $\boldsymbol{I}$ denotes the identity matrix after an infinite number of interactions of influence relations, as in Equation (12).

$$\begin{aligned}\overline{\boldsymbol{T}} &= \overline{\boldsymbol{N}} + \overline{\boldsymbol{N}}^2 + \overline{\boldsymbol{N}}^3 + \cdots + \overline{\boldsymbol{N}}^k \\ &= \overline{\boldsymbol{N}}(\boldsymbol{I} + \overline{\boldsymbol{N}} + \overline{\boldsymbol{N}}^2 + \cdots + \overline{\boldsymbol{N}}^{k-1})[(\boldsymbol{I} - \overline{\boldsymbol{N}})(\boldsymbol{I} - \overline{\boldsymbol{N}})^{-1}] \\ &= \overline{\boldsymbol{N}}(\boldsymbol{I} - \overline{\boldsymbol{N}}^k)(\boldsymbol{I} - \overline{\boldsymbol{N}})^{-1} \\ &= \overline{\boldsymbol{N}}(\boldsymbol{I} - \overline{\boldsymbol{N}})^{-1}, \text{ when k} \to \infty, \ \overline{\boldsymbol{N}}^k = [0]_{m \times m}\end{aligned} \quad (12)$$

Step 3. Compute influence relationships

The degrees of the influence relationships among the indicators include the influence degree, the degree of being influenced, the total degree of influence, and the net degree of influence $(\overline{\boldsymbol{r}}, \overline{\boldsymbol{c}}, \overline{\boldsymbol{x}}, \overline{\boldsymbol{y}})$, which is summed to produce the "degree of influence", expressed as a vector $\overline{\boldsymbol{r}}$ in this study, as presented in Equation (13).

$$\overline{\boldsymbol{r}} = (\overline{r}_1, \overline{\mathrm{r}}_2, \cdots, \overline{r}_\psi) = (\overline{r}_i)_{\psi \times 1} = \left[\sum_{j=1}^{n} \overline{r}_{ij}\right]_{\psi \times 1} \text{ for } i, j = 1, 2, \cdots, \psi \quad (13)$$

The "degree of being influenced" quantifies how much an indicator is influenced by the other indicators. This is aggregated to form the "degree of being influenced," represented as a vector $\overline{\boldsymbol{c}}$ in this study, as illustrated in Equation (14).

$$\overline{\boldsymbol{c}} = (\overline{\boldsymbol{c}}_i)_{\psi \times 1} = (\overline{\boldsymbol{c}}_1, \overline{\boldsymbol{c}}_2, \cdots, \overline{\boldsymbol{c}}_\psi)' = (\overline{\boldsymbol{c}}_j)'_{1 \times \psi} = \left[\sum_{i=1}^{\psi} \overline{\boldsymbol{c}}_{ij}\right]'_{1 \times \psi} \text{ for } i, j = 1, 2, \cdots, \psi \quad (14)$$

The "degree of net effect" pertains to the level of influence exerted by an indicator, subtracted from the degree to which the indicator itself is influenced, resulting in the determination of the "degree of net effect.", which is denoted by the vector $\overline{\boldsymbol{y}}$, meaning the "relation" of the indicator. If y_i has a positive value, it signifies that the indicator is a cause and y_i has a negative value, as shown in Equation (15).

$$\overline{\boldsymbol{y}} = y_i = r_i - c_i, \text{ for } i = 1, 2, \ldots, \psi \quad (15)$$

The total degree of influence is the sum of the degree of influence of the indicator and the degree of being influenced. The "total degree of influence", which is represented by the vector $\overline{\boldsymbol{x}}$, means the "prominence" of the indicator, as shown in Equation (16).

$$\overline{\boldsymbol{x}} = x_i = r_i + c_i, \text{ for } i = 1, 2, \ldots, \psi \quad (16)$$

Step 4: Drawing influential network relationship map (INRM)

Following the calculation in Step 3, the influence relationships $\left(\overline{\boldsymbol{T}}, \overline{\boldsymbol{r}}, \overline{\boldsymbol{c}}, \overline{\boldsymbol{x}}, \overline{\boldsymbol{y}}\right)$ among the all the assessment indicators can be included, and the influential network relation map can be produced depending on the influence relationships.

Step 5: Overall influence matrix $\overline{\boldsymbol{H}}$

After obtaining the total influence matrix $\overline{\boldsymbol{T}}$ through Equation (12) and then adding the identity matrix $\overline{\boldsymbol{I}}$, the overall influence matrix $\overline{\boldsymbol{H}}$ is derived, as computed in Equation (17). Please refer to the work by Liang et al. [50] for a more detailed calculation.

$$\overline{\boldsymbol{H}} = \overline{\boldsymbol{T}} + \overline{\boldsymbol{I}} = [h_{ij}]_{\mathrm{n} \times \mathrm{n}}, (i = 1, 2, \cdots, \mathrm{n};\ j = 1, 2, \cdots, \mathrm{n}) \quad (17)$$

Step 6: The reachability matrix $\overline{\boldsymbol{M}}$

By utilizing the overall influence matrix $\overline{\boldsymbol{H}}$ and applying a threshold θ, the reachability matrix $\overline{\boldsymbol{M}}$ is generated, as well as the subsequent hierarchical structure, as shown in Equation (18). The threshold θ is used to exclude factors with lower influence, simplifying the composition of the hierarchical structure.

$$\overline{\boldsymbol{M}} = m_{ij} = \begin{cases} 1, \ h_{ij} \geq \theta \\ 0, \ h_{ij} \prec \theta \end{cases} \tag{18}$$

Step 7: Determine the reachable set

Depending on the reachability matrix $\overline{\boldsymbol{M}}$, the reachable set and precedent set for each element are calculated, as in Equations (19)–(21). These calculations determine the factors and levels and establish the ISM hierarchical structure.

$$R(C_i) = \left\{ C_i \middle| C_i \in Z, m_{ij} \neq 0 \right\}, i = 1, 2, \cdots, n \tag{19}$$

$$A(C_i) = \left\{ C_i \middle| C_i \in Z, m_{ij} \neq 0 \right\}, i = 1, 2, \cdots, n \tag{20}$$

$$C(C_i) = R(C_i) \cap A(C_i), i = 1, 2, \cdots, n \tag{21}$$

Step 8. Establishing the hierarchical structure of ISM

When the reachable set and the intersection set are equal, as shown in Equation (22), C_i should be removed from the reachability matrix $\overline{\boldsymbol{M}}$. Steps 3 and 4 are repeated until all the factors are deleted, and a multi-level hierarchical model is then established based on the order of deletion.

$$C(C_i) = R(C_i), i = 1, 2, \cdots, n \tag{22}$$

4. Case Study and Research Findings

The case study here highlights the key barrier factors in the decision-making process of installing energy storage equipment for Taiwanese businesses. This section explains the experience of the experts, the generation of the key barrier factors, the analysis process, and the results.

4.1. Key Assessment Framework

A total of ten experts were invited to join in this study and contribute to the assessment process of identifying key barrier factors. Of these, seven were male and three were female. In terms of positions held, one was the chairman of the board of directors, four were general managers, three were vice presidents, and two were chief financial officers of the businesses to which they belonged. In terms of industry experience, there were two experts with 20–25 years of experience, four with 30–35 years of experience, and four with 40 years of experience. The industry distribution of each expert was two in the manufacturing industry, one in the information service industry, one in the electronics industry, one in the chemical industry, one in the hotel industry, one in the retail industry, one in the trading industry, one in the transportation industry, and one in the construction industry. A representative sample was produced by inviting the experts with diversified backgrounds to participate in this study as mentioned above.

The experts responded to each barrier factor (see Table 1) according to their individual experience and knowledge. The significance level of each barrier factor was rated on a five-level scale: "Very Low Significance (VLS), Low Significance (LS), Moderate Significance (S), High Significance (HS), and Very High Significance (VHS)", corresponding to VLS: 1, LS: 2, S: 3, HS: 4, and VHS: 5, respectively. Thus, Expert 1 rated the significance of B_1 as very high, giving it a score of 5. The other barrier factors were assessed by the experts in the same way. The survey results for the 10 experts gave a minimum value (L) for B_1 of 3.00, a geometric mean (G) of 3.47, and a maximum value (M) of 5.00. The average of the first three values (I) was 3.82. The rest of the results are shown in Table 2. The Interquartile Range (IQR) method was used to establish the threshold value. The results are in the average value (I) column and indicate the nine barrier factors with significance coefficients exceeding 3.4, which were adopted as the core barrier factors.

Table 2. Results of the experts' assessment of the barrier factors.

Code	Criterion	L	G	M	I	Decision
B_1	High initial setup cost	3.00	3.47	5.00	3.82	KEEP
B_2	Return on Investment (ROI) of operations cannot be assessed	3.00	3.42	5.00	3.81	KEEP
B_3	Maintenance cost cannot be reliably assessed	4.00	3.36	5.00	4.12	KEEP
B_4	Low technical economic efficiency	2.00	3.30	5.00	3.43	KEEP
B_5	Selection of installation location	1.00	3.30	5.00	3.10	Delete
B_6	Lack of certification and standardization system	2.00	3.40	5.00	3.47	KEEP
B_7	Energy management system	1.00	3.38	5.00	3.13	Delete
B_8	Safety in the operation of energy storage equipment	3.00	3.41	5.00	3.80	KEEP
B_9	Lack of policy support for investment subsidies or tax incentives	2.00	3.30	5.00	3.43	KEEP
B_{10}	Lack of knowledge about energy storage equipment	1.00	3.21	4.00	2.74	Delete
B_{11}	Lack of appropriate insurance planning	2.00	3.34	5.00	3.45	KEEP
B_{12}	Protests from surrounding residents	1.00	3.34	5.00	3.11	Delete
B_{13}	Difficulties in obtaining financing	2.00	3.26	5.00	3.42	Delete
B_{14}	Lack of clear regulatory guidelines	3.00	3.12	5.00	3.71	KEEP
B_{15}	Environmental impact of battery recycling	1.00	2.86	5.00	2.95	Delete
B_{16}	Development of alternative technologies	2.00	2.69	5.00	3.23	Delete
B_{17}	Dynamic impact of energy storage equipment	1.00	2.56	5.00	2.85	Delete
B_{18}	Roles and functions of energy storage equipment	1.00	2.40	5.00	2.80	Delete

Note: Threshold value > 3.43.

For ease of reference and identification, the key barrier factors were renumbered as C_1–C_9, and the detailed definitions of each key barrier factor are summarized in Table 3.

Table 3. Key barrier factors.

Code	Assessment Criterion	Criterion Definition
C_1	High initial setup cost	If the amount of capital expenditure for energy storage equipment and peripheral coordination systems is too high for the management to accept, it will become a barrier during enterprise decision-making for the installation of energy storage equipment.
C_2	Return on Investment (ROI) of operations cannot be assessed	When the installation cost of energy storage equipment is high, whether the rate of return on investment and the length of the payback period meet the expectations of the enterprise will affect their investment willingness.
C_3	Maintenance costs cannot be reliably assessed	If the known maintenance costs are high or there may be unknown maintenance costs, it will become a concern for an enterprise making decisions about the purchase of an energy storage device.
C_4	Low technical economic efficiency	The technology of energy storage equipment continues to develop and improve, resulting in a short service life and short depreciation period for the equipment. Although equipment has the capacity to enhance the utilization rate of renewable energy, low economic efficiency will become a barrier to corporate decision-making.
C_5	Lack of certification and standardization system	The product certification and standardization system provided by the government is an important basis for enterprise decision-making. The lack of such mechanisms as reference may become a barrier for purchase decisions.
C_6	Safety in the operation of energy storage equipment	Energy storage systems are considered a solution to renewable energy dispatch, but for enterprises, there are still doubts about the safety of their use and whether their use will have a harmful effect on human health.
C_7	Lack of policy support for investment subsidies or tax incentives	The business direction taken by an enterprise is related to government policies, especially when equipment renewal and purchase are promoted in accordance with the policies. If the government does not provide investment subsidies or tax incentives, this may become a barrier to enterprise decision-making.
C_8	Lack of appropriate insurance planning	Given the newness of the products and technology, property insurers do not have experience in assessment and actuarial calculations. The lack of suitable insurance planning to avoid the possible risk of property loss is also a barrier to the installation of energy storage equipment.
C_9	Lack of clear regulatory guidelines	Relevant management laws and regulations should clearly define the role and applicable scope of energy storage equipment. Clear laws and regulations for enterprises to follow will allow them to make decisions and judgments more easily.

4.2. Integrating Experts' Opinions with Z-RDWGA

Once the essential barrier factors were established, the DEMATEL-ISM method was utilized to explore the influence relationships among them. The experts came from various fields with different industrial backgrounds and types of work experience. In this study, the Z-RDWGA method was employed to effectively integrate their opinions, to capture the uncertainty in expert assessments, and to integrate their inconsistent views. First, a linguistic variable correlation table was established, as shown in Table 4 [51], to facilitate the process.

Table 4. Linguistic variables for influence assessment and confidence level assessment.

Influence Significance	Code	Membership Function	Confidence Level Assessment	Code	Membership Function
Very weak	VW	(0, 0, 1)	Very low	VL	(0, 0, 0.3)
Weak	W	(0, 1, 2)	Low	L	(0.1, 0.3, 0.5)
Ordinary	MI	(1, 2, 3)	Ordinary	M	(0.3, 0.5, 0.7)
Strong	S	(2, 3, 4)	High	H	(0.5, 0.7, 0.9)
Very strong	VS	(3, 4, 4)	Very high	VH	(0.7, 1, 1)

Based on the linguistic variables in Table 4, pairwise comparisons were conducted by the experts for the key barrier factors. Each expert assessed the degree of influence and level of confidence for the barrier factors. Take Expert 1's assessment as an example (as shown in Table 5). This expert assessed the level of influence of C_1 on C_2 as "Moderate Influence (MI)" with a confidence level of "Moderate (M)".

Table 5. Expert 1′s assessment of the influence degrees between barriers.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	0	(MI, M)	(S, H)	(VS, M)	(MI, L)	(MI, L)	(S, M)	(MI, M)	(S, M)
C_2	(MI, M)	0	(S, M)	(S, M)	(MI, M)	(MI, M)	(MI, M)	(MI, M)	(S, M)
C_3	(MI, M)	(S, M)	0	(S, H)	(S, H)	(S, H)	(S, H)	(S, M)	(S, M)
C_4	(MI, M)	(MI, M)	(MI, H)	0	(MI, H)	(MI, M)	(S, M)	(S, M)	(MI, M)
C_5	(S, M)	(S, H)	(S, M)	(S, M)	0	(S, M)	(S, H)	(S, M)	(S, M)
C_6	(S, M)	(S, M)	(S, M)	(W, VL)	(MI, L)	0	(MI, L)	(MI, L)	(MI, L)
C_7	(S, M)	(MI, L)	(S, L)	(MI, L)	(MI, L)	(MI, M)	0	(MI, M)	(MI, M)
C_8	(MI, M)	(MI, L)	(MI, L)	(S, H)	(MI, M)	(MI, L)	(MI, L)	0	(MI, M)
C_9	(MI, H)	(S, H)	(S, M)	(MI, M)	(MI, M)	(MI, M)	(MI, M)	(MI, M)	0

The linguistic assessment results (Table 5) mentioned above were transformed into fuzzy numbers using Table 4. Then, by employing Equations (1)–(3) for Z-number calculation and defuzzification, the experts' assessments of the mutual influence among key barrier factors were converted into crisp values. Table 6 shows the results for the different degrees of influence and confidence levels after their conversion to crisp values through computation. First, we establish a semantic variable table with the associated Z-numbers [51]. Then, Equations (1)–(3) of Section 3 were used to de-fuzzify the Z-number. Subsequently, the de-fuzzified Z-numbers were indicated in Table 6 to show the various combination of membership numbers and confidence levels.

Based on Expert 1′s assessment results in Table 5, the linguistic variables can be defuzzified through Table 6 as crisp values. For example, Expert 1 considered C_1 to C_2 to be (MI, M). According to Table 6, MI (row) and M (column) yields 1.414, which is Expert 1′s influence matrix C_1 to C_2 in Table 7. Following the same process, the assessments of the remaining experts were processed resulting in 10 initial influence matrices. Some of the results are shown in Table 8. The inconsistency in the expert assessments which arises from their different background experience and subjective judgments is resolved by employing the RDWGA method for data integration.

Table 6. Linguistic variables and Z membership function.

	VL	**L**	**M**	**H**	**VH**
VW	0.105	0.183	0.236	0.279	0.316
W	0.316	0.548	0.707	0.837	0.949
MI	0.632	1.095	1.414	1.673	1.897
S	0.949	1.643	2.121	2.510	2.846
VS	1.160	2.008	2.593	3.068	3.479

Table 7. Initial impact matrix for Expert 1.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	0	1.414	2.510	2.593	1.095	1.095	2.121	1.414	2.121
C_2	1.414	0	2.121	2.121	1.414	1.414	1.414	1.414	2.121
C_3	1.414	2.121	0	2.510	2.510	2.510	2.510	2.121	2.121
C_4	1.414	1.414	1.673	0	1.673	1.414	2.121	2.121	1.414
C_5	2.121	2.510	2.121	2.121	0	2.121	2.510	2.121	2.121
C_6	2.121	2.121	2.121	0.316	1.095	0	1.095	1.095	1.095
C_7	2.121	1.095	1.643	1.095	1.095	1.414	0	1.414	1.414
C_8	1.414	1.095	1.095	2.510	1.414	1.095	1.095	0	1.414
C_9	1.673	2.510	2.121	1.414	1.414	1.414	1.414	1.414	0

Table 8. Results of influence degrees between barriers from 10 experts.

	EXP01	**EXP02**	**EXP03**	**EXP04**	**EXP05**	**EXP06**	**EXP07**	**EXP08**	**EXP09**	**EXP10**
C_1–C_2	1.414	3.068	2.121	3.068	0.316	1.095	2.846	2.510	1.414	2.510
C_1–C_3	2.510	2.510	0.837	1.095	0.316	1.414	1.897	2.510	1.414	0.949
…	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C_9–C_8	1.414	1.673	1.095	1.414	0.316	1.414	1.095	2.510	2.121	1.897

Taking the influence of C_1 on C_2 as shown in Table 8 as an illustrative example, the maximum value is 3.068 and the minimum value is 0.316. Equations (4)–(7) were used to obtain the upper and lower approximate values for each expert. For Expert 1, the upper bounds calculated for C_1 and C_2 were 2.578 and 0.997, respectively. The upper and lower approximate sets for the 10 sets of expert opinions can be obtained using Equations (8) and (9). Taking C_1–C_2 as an example, the calculation processes are illustrated below. The calculated upper and lower approximation results for the experts were collected and are shown in Table 9.

$$\underline{LIM_1} = (1.414+0.316+1.095+1.414)/\,4 = 1.060$$
$$\overline{LIM_1} = (1.414+3.068+2.121+3.068+2.846+2.510+1.414+2.510)/\,8 = 2.369\;;$$

$$RDWGA\left(\underline{I_1}\right) = \frac{1.060 + 2.036 + \cdots + 1.626}{(1 + (0.1 \times (((1-0.078)/0.078) + ((1-0.151)/0.151) + \cdots + ((1-0.120\,)/0.120))))} = 0.997;$$

$$RDWGA\left(\overline{I_1}\right) = \frac{2.369 + 3.068 + \cdots + 2.800}{(1 + (0.1 \times (((1-0.090)/0.090) + ((1-0.117)/0.117) + \cdots + ((1-0.107\,)/0.107))))} = 2.578.$$

The assessment results of pairwise comparisons by the experts were calculated through Equations (4)–(9). The upper and lower approximate values for the upper and lower approximate set matrix can be obtained after the integration of all expert opinions. The final calculation results are summarized in Table 10.

Table 9. Experts' upper and lower approximation matrix.

	EXP01	EXP02	EXP03	EXP04	EXP05	EXP06	EXP07	EXP08	EXP09	EXP10
C_1–C_2	[0.997, 2.578]	[0.807, 1.204]	[0.891, 1.967]	[1.266, 1.882]	[1.289, 2.235]	[1.445, 2.225]	[0.834, 2.046]	[0.822, 1.984]	[0.143, 0.253]	[1.289, 2.328]
C_1–C_3	[1.114, 2.126]	[1.999, 2.104]	[1.299, 2.441]	[1.467, 2.11]	[0.692, 1.737]	[1.081, 1.895]	[1.186, 2.043]	[1.035, 1.853]	[1.509, 2.334]	[1.371, 2.635]
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C_9–C_8	[0.989, 2.461]	[1.07, 2.294]	[0.901, 2.392]	[1.619, 2.48]	[1.025, 2.473]	[1, 2.604]	[0.843, 2.178]	[0.99, 2.331]	[0.89, 2.239]	[0.912, 1.864]

Table 10. Aggregated initial decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	0	[0.997, 2.578]	[0.807, 1.204]	[0.891, 1.967]	[1.266, 1.882]	[1.289, 2.235]	[1.445, 2.225]	[0.834, 2.046]	[0.822, 1.984]
C_2	[0.143, 0.253]	0	[1.289, 2.328]	[1.114, 2.126]	[1.999, 2.104]	[1.299, 2.441]	[1.467, 2.110]	[0.692, 1.737]	[1.081, 1.895]
C_3	[1.186, 2.043]	[1.035, 1.853]	0	[1.509, 2.334]	[1.371, 2.635]	[1.620, 2.750]	[0.955, 1.603]	[0.866, 2.431]	[1.079, 1.652]
C_4	[1.230, 2.295]	[1.676, 2.592]	[2.751, 2.133]	0	[1.502, 2.561]	0	[0.949, 2.686]	[0.955, 2.702]	[0.986, 2.671]
C_5	[1.356, 2.321]	[1.521, 2.666]	[1.671, 2.691]	[1.121, 2.076]	0	[1.735, 2.737]	[1.466, 2.594]	[0.868, 2.405]	[0.899, 2.492]
C_6	[0.756, 2.517]	[0.816, 2.417]	[1.106, 2.727]	[1.112, 2.700]	[0.920, 2.275]	0	[0.973, 2.289]	[0.634, 2.074]	[0.940, 2.472]
C_7	[0.912, 2.465]	[1.540, 2.633]	[1.110, 2.607]	[1.148, 2.639]	[0.957, 2.541]	[1.559, 2.559]	0	[0.848, 2.294]	[0.674, 2.340]
C_8	[0.770, 1.660]	[0.794, 1.938]	[0.877, 1.935]	[1.318, 2.101]	[0.757, 1.632]	[0.985, 2.519]	[0.989, 2.461]	0	[1.070, 2.294]
C_9	[0.901, 2.392]	[1.619, 2.480]	[1.025, 2.473]	[1.000, 2.604]	[0.843, 2.178]	[0.990, 2.331]	[0.890, 2.239]	[0.912, 1.864]	0

4.3. Using DEMATEL-ISM to Explore the Causal Relationships among Barrier Factors

DEMATEL was used in this study to explore the causal relationships among the key barrier factors. Using the approximate matrix of expert upper and lower bounds from Table 9, we can derive the initial decision matrix for Table 10 by Equations (4)–(9). Through Equations (10)–(12), the initial influence matrix (Table 11) can be transformed into the rough total influence matrix $\overline{\boldsymbol{T}}$, as shown in Table 11.

After the total influence matrix $\overline{\boldsymbol{T}}$ is gained, the net influence degree ($r - c$) and centrality ($r + c$) of barrier factors can be computed as Equations (14)–(17). The various influence relationships in the overall assessment system can be expressed according to the fuzzy value of the total influence relationship matrix, as presented in Table 12. The crisp values are presented in Table 13. The results show that the top three barrier factors that influence the other barrier factors are C_4 (Low technical economic efficiency): 6.492 > C_5 (Lack of certification and standardization systems): 6.211 > C_7 (Lack of policy support for investment subsidies or tax incentives): 5.898; the top three barrier factors affected by other barrier factors are C_6 (Safety in the operation of energy storage equipment): 6.397 > C_2 (Operating return on investment cannot be assessed): 5.951 > C_3 (Maintenance cost cannot be assessed): 5.934. The total influence of the indicators from large to small is as follows: C_4 (Low technical economic efficiency) > C_6 (The safety in the operation of energy storage system) > C_5 (Lack of certification and standardization system) > C_7 (Lack of policy support for investment subsidies or tax incentives) > C_3 (Maintenance cost cannot be assessed accurately) > C_2 (Return on Investment (ROI) of Operations cannot be assessed) > C_9 (Lack of clear regulatory guidelines) > C_8 (Lack of appropriate insurance planning) > C_1 (High initial setup cost). It can be seen that C_4 (Low technical and economic benefits) exerts the greatest overall impact on the entire system, followed by C_6 (Safety in the operation of energy storage equipment), and C_7 (Lack of policy support for investment subsidies or tax incentives).

Table 11. Total influence matrix $\overline{\boldsymbol{T}}$.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	[0.204, 0.748] [0.419]	[0.35, 1.000] [0.618]	[0.356, 0.907] [0.576]	[0.324, 0.953] [0.579]	[0.362, 0.917] [0.582]	[0.410, 1.023] [0.655]	[0.360, 0.947] [0.591]	[0.250, 0.910] [0.518]	[0.275, 0.921] [0.537]
C_2	[0.243, 0.733] [0.439]	[0.304, 0.842] [0.519]	[0.425, 0.914] [0.622]	[0.367, 0.918] [0.591]	[0.442, 0.888] [0.609]	[0.446, 0.987] [0.663]	[0.387, 0.900] [0.588]	[0.259, 0.860] [0.508]	[0.316, 0.877] [0.543]
C_3	[0.326, 0.896] [0.553]	[0.394, 1.033] [0.650]	[0.341, 0.909] [0.567]	[0.405, 1.029] [0.652]	[0.411, 1.008] [0.652]	[0.481, 1.110] [0.731]	[0.363, 0.982] [0.609]	[0.280, 0.986] [0.572]	[0.326, 0.967] [0.58]
C_4	[0.380, 1.020] [0.636]	[0.504, 1.198] [0.779]	[0.610, 1.134] [0.794]	[0.360, 1.057] [0.636]	[0.490, 1.131] [0.744]	[0.583, 1.239] [0.833]	[0.426, 1.154] [0.725]	[0.333, 1.121] [0.660]	[0.375, 1.135] [0.686]
C_5	[0.356, 1.013] [0.616]	[0.452, 1.192] [0.748]	[0.489, 1.149] [0.751]	[0.404, 1.142] [0.699]	[0.336, 1.011] [0.604]	[0.519, 1.241] [0.804]	[0.424, 1.141] [0.709]	[0.298, 1.101] [0.626]	[0.334, 1.119] [0.654]
C_6	[0.242, 1.002] [0.550]	[0.308, 1.159] [0.655]	[0.348, 1.127] [0.669]	[0.312, 1.144] [0.647]	[0.310, 1.091] [0.628]	[0.280, 1.097] [0.606]	[0.298, 1.107] [0.622]	[0.216, 1.067] [0.553]	[0.261, 1.096] [0.593]
C_7	[0.282, 1.024] [0.582]	[0.399, 1.197] [0.716]	[0.394, 1.151] [0.704]	[0.355, 1.170] [0.683]	[0.357, 1.129] [0.672]	[0.444, 1.240] [0.761]	[0.264, 1.033] [0.566]	[0.259, 1.103] [0.596]	[0.276, 1.119] [0.617]
C_8	[0.249, 0.85] [0.487]	[0.315, 1.001] [0.591]	[0.341, 0.963] [0.592]	[0.334, 0.985] [0.589]	[0.305, 0.934] [0.557]	[0.364, 1.063] [0.649]	[0.306, 0.981] [0.579]	[0.171, 0.844] [0.432]	[0.277, 0.959] [0.547]
C_9	[0.268, 0.959] [0.547]	[0.389, 1.118] [0.675]	[0.368, 1.075] [0.658]	[0.328, 1.097] [0.640]	[0.332, 1.046] [0.622]	[0.384, 1.155] [0.697]	[0.317, 1.063] [0.617]	[0.253, 1.017] [0.553]	[0.209, 0.945] [0.495]

Table 12. Rough numbers of total and net influence.

Code	Assessment Criterion	$\boldsymbol{R}$	$\boldsymbol{c}$	$\boldsymbol{r+c}$	$\boldsymbol{r-c}$
C_1	High initial setup cost	[2.616, 8.326]	[2.281, 8.246]	[10.942, −5.710]	[10.527, −5.966]
C_2	Return on Investment (ROI) of operations cannot be assessed	[2.874, 7.919]	[3.026, 9.742]	[10.792, −5.045]	[12.767, −6.716]
C_3	Maintenance costs cannot be reliably assessed	[3.000, 8.921]	[3.304, 9.328]	[11.922, −5.921]	[12.632, −6.024]
C_4	Low technical economic efficiency	[3.686, 10.189]	[2.862, 9.496]	[13.875, −6.502]	[12.358, −6.634]
C_5	Lack of certification and standardization system	[3.278, 10.109]	[3.012, 9.154]	[13.387, −6.830]	[12.166, −6.142]
C_6	Safety in the operation of energy storage equipment	[2.314, 9.891]	[3.527, 10.156]	[12.205, −7.577]	[13.683, −6.628]
C_7	Lack of policy support for investment subsidies or tax incentives	[2.753, 10.167]	[2.829, 9.309]	[12.920, −7.414]	[12.138, −6.480]
C_8	Lack of appropriate insurance planning	[2.384, 8.581]	[2.066, 9.008]	[10.965, −6.196]	[11.074, −6.943]
C_9	Lack of clear regulatory guidelines	[2.848, 9.475]	[2.647, 9.138]	[12.323, −6.628]	[11.785, −6.491]

Note: The values in brackets show the de-fuzzified values.

Table 13. Core barriers impacting relationships.

Code	Assessment Criterion	*R*	*c*	*r* + *c*	Rank	*r* − *c*	Rank
C_1	High initial setup cost	5.077	4.831	9.908	8	0.246	5
C_2	Return on Investment (ROI) of operations cannot be assessed	5.080	5.951	11.031	7	−0.871	8
C_3	Maintenance costs cannot be reliably assessed	5.565	5.934	11.499	4	−0.368	7
C_4	Low technical economic efficiency	6.492	5.716	12.208	1	0.776	1
C_5	Lack of certification and standardization system	6.211	5.669	11.880	2	0.542	2
C_6	Safety in the operation of energy storage equipment	5.524	6.397	11.921	5	−0.873	9
C_7	Lack of policy support for investment subsidies or tax incentives	5.898	5.606	11.504	3	0.291	3
C_8	Lack of appropriate insurance planning	5.023	5.018	10.041	9	0.005	6
C_9	Lack of clear regulatory guidelines	5.504	5.252	10.756	6	0.252	4

The Influential Network Relation Map (INRM) of the entire system can be obtained by mapping the total influence ($r + c$) and net influence ($r - c$) of every assessment indicator onto the coordinate axis, as presented in Figure 2. The dotted squares at the top of the figure show the causal factors for the system, and the solid outline squares at the bottom of the figure show the effects. Higher total influence indicators are represented on the upper right side of the graph, and conversely, the lower left side indicates that the total influence is lower. To make the presentation of the INRM clearer and more explicit, the flow of influence is plotted according to the larger influence relationships. As depicted in the figure, "C_4 (Low technical economic efficiency)" serves as the primary "causal factor" within the entire assessment system because it has a larger total influence, suggesting that this is the pivotal element that affects the entire assessment system.

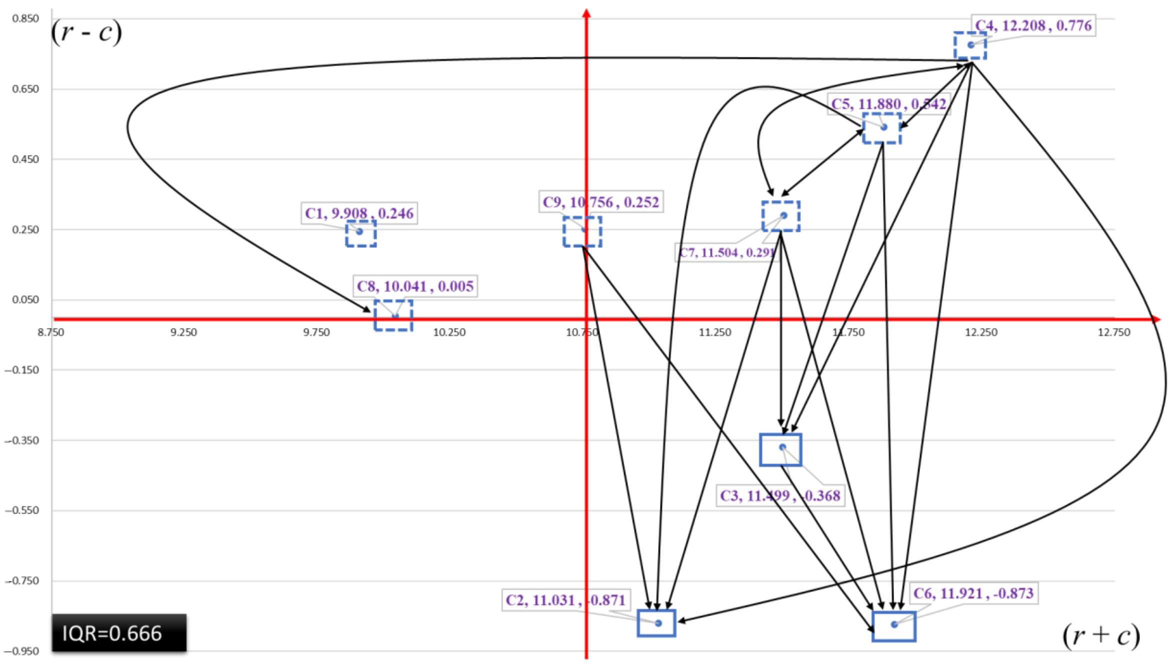

Figure 2. The Influential Network Relation Map.

The overall influence matrix $\overline{H}$, as presented in Table 14, is obtained by applying Equation (17). In accordance with the group decision-making process of the experts, the total mean and standard deviation for the total influence matrix $\overline{T}$ is set to 0.7040, as the threshold [52]. The threshold is obtained from Equation (18) and the reachability matrix $\overline{M}$ obtained after threshold filtering and aggregation appears in Table 15.

Table 14. Overall influence matrix $\overline{H}$.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1.419	0.618	0.576	0.579	0.582	0.655	0.591	0.518	0.537
C_2	0.439	1.519	0.622	0.591	0.609	0.663	0.588	0.508	0.543
C_3	0.553	0.650	1.567	0.652	0.652	0.731	0.609	0.572	0.580
C_4	0.636	0.779	0.794	1.636	0.744	0.833	0.725	0.660	0.686
C_5	0.616	0.748	0.751	0.699	1.604	0.804	0.709	0.626	0.654
C_6	0.550	0.655	0.669	0.647	0.628	1.606	0.622	0.553	0.593
C_7	0.582	0.716	0.704	0.683	0.672	0.761	1.566	0.596	0.617
C_8	0.487	0.591	0.592	0.589	0.557	0.649	0.579	1.432	0.547
C_9	0.547	0.675	0.658	0.640	0.622	0.697	0.617	0.553	1.495

Table 15. The reachability matrix $\overline{M}$.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	0	0	0	0	0	0	0	0
C_2	0	1	0	0	0	0	0	0	0
C_3	0	0	1	0	0	1	0	0	0
C_4	0	1	1	1	1	1	1	0	0
C_5	0	1	1	0	1	1	1	0	0
C_6	0	0	0	0	0	1	0	0	0
C_7	0	1	1	0	0	1	1	0	0
C_8	0	0	0	0	0	0	0	1	0
C_9	0	0	0	0	0	0	0	0	1

From the reachability matrix $\overline{M}$, Equations (19)–(22) are used to determine the first-level reachable set and the preceding set; the results are shown in Table 16. It can be seen from Table 16 that the first-level factors are C_1, C_2, C_6, C_8, and C_9. Following the removal of the rows and columns containing these factors and repeating the above steps, the hierarchical relationships among the factors can be drawn, as presented in Figure 3.

Table 16. The first-level reachable set and the prior set.

Factors	R(C_i)	A(C_i)	C(C_i)
C_1	C_1	C_1	C_1
C_2	C_2	C_2, C_4, C_5, C_7	C_2
C_3	C_3, C_6	C_3, C_4, C_5, C_7	C_3
C_4	C_2, C_3, C_4, C_5, C_6, C_7	C_4	C_4
C_5	C_2, C_3, C_5, C_6, C_7	C_4, C_5	C_5
C_6	C_6	C_3, C_4, C_5, C_6,C_7	C_6
C_7	C_2, C_3, C_6, C_7	C_4, C_5, C_7	C_7
C_8	C_8	C_8	C_8
C_9	C_9	C_9	C_9

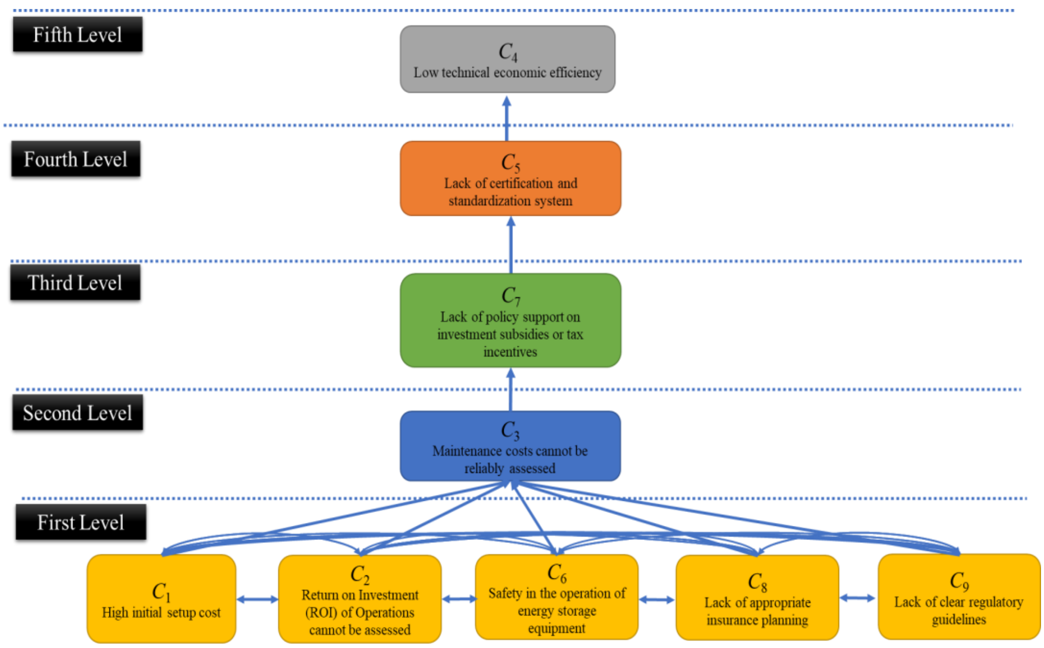

Figure 3. Multi-level step-up structural model on factors influencing.

5. Discussion

Some theoretical and management implications are proposed and the analytical results presented in Section 4 are explained.

5.1. Implications for Management

This study explores the barrier factors for enterprise decision-making in the installation of energy storage equipment. The Delphi method was first used to extract 9 key factors from 18 possible barrier factors, and then Z-RDWGA combined with DEMATEL-ISM was applied to further explore the mutual influence relationships and influence hierarchy map among the key barrier factors. The findings, which are presented in Tables 12 and 13 and Figure 1, indicate that "C_4 (Low technical economic efficiency)" is ranked first overall, and therefore can be regarded as the most influential barrier to the installation of energy storage systems. The continuous advancement of the technology and the materials used for energy storage equipment mean that the early products may not be as useful as expected. Their service life and performance may be adversely affected due to the immature technology, with expectations that later products might be better. This key barrier factor conforms with the results of Yu et al. [36] and Tan et al. [18]. As can be seen in the INRM, "C_4 (Low technical economic efficiency)" has a significant influence on the other key barrier factors. The results of an ISM analysis of the hierarchical structure model show C_4 as top-level, being the most important factor for businesses to decide whether to install energy storage equipment or not. This result suggests that although advancements of technology are helpful in terms of innovation, they influence decision-makers to anticipate the availability of better products in the future, thus forming the main barrier to the promotion of energy storage equipment. It is recommended that the main considerations for enterprises considering the purchase of energy storage equipment be that it meets their specifications, that the technology is relatively mature, and that is satisfies the needs of the enterprise. From INRM, the second most important barrier factor in the total influence relationship is "C_6 (Safety in the operation of energy storage equipment)". The same conclusion was also reached in previous studies by Remillard [32], Tan et al. [18], Ali et al. [38], etc. Threats to human health and the environment during the manufacturing of the materials and the operation of the equipment have led decision-makers to be concerned about whether future usage risks can be managed. The INRM results show that the two key barrier factors of "C_4 (Low technical and economic benefits)" and "C_6 (Safety of energy storage system)" have a mutual influence relationship, and the ISM results from analysis of the multi-level structure model also show that C_6 affects the other five key barrier factors at the same level. These results indicate that the safety of energy storage systems is crucial to business leader decision-making. It is recommended that the energy storage equipment selected be produced by reputable manufacturers, have passed safety certification by the government and international certification agencies, or be obtained from companies with a certain market share. The third-ranked barrier in the total influence relationship is "C_5 (Lack of certification and standardization system)". The product certification and standardization system provided by the government comprise important guidelines for enterprise decision-making. Certification and standards provide an important reference for enterprises looking to purchase energy storage equipment, and if they are lacking, it will become a barrier to decision-making. The results of the ISM analysis also show that C_5 is the key barrier factor on the second-top level of the multi-level structure, and one of the main factors affecting the enterprises' decision whether to install energy storage equipment. It is recommended that relevant standards and certification systems be jointly developed by industry associations and the academic community through seminars and consultative communication meetings. The fruits of these meetings should then be provided to government regulatory authorities for reference to help expedite the modification and establishment of relevant regulations.

5.2. Implications for Theory

The Delphi method was used in this study to identify barrier factors from a literature review and expert interviews, and the Z-number method was used to investigate the incomplete and uncertain decision-making information given by the experts. This method is different from the traditional fuzzy number technique, and it is more effective for converting linguistic variables into fuzzy scales and confidence levels. In addition, in real decision-making, although there might be a consensus between experts, they still hold different opinions on the details of the discussion. In the past, the fusion of decision-making information among experts was mostly done by average aggregation [53]. However, this method ignores the differences in the opinions of each expert. In this study, the fusion of information using RDWGA allowed for a fuller consideration of the inconsistency of each expert's decision-making opinion. Displaying more useful information makes the decision-making process more flexible. The academic contribution of this research is related to the methodology, that is the use of the Delphi method to extract the key factors from many barrier factors. This was then combined with Z-RDWGA to integrate the inconsistency of the information, to minimize the uncertainty and ambiguity in group decision-making, and integrate subjective opinions from experts with different work experience. Finally, DEMATEL analysis was used to draw an INRM diagram illustrating the causal relationships and mutual degrees of influence between each key barrier factor. The DEMATEL method was used in combination with ISM to stratify the relationships among the factors, which can simplify the complex influence relationships between them [54]. The combined model allows the application of the DEMATEL results to obtain the ISM reachability matrix, thereby avoiding a time-consuming ISM survey. Based on the INRM and hierarchical map of factors, decision-makers can better understand the relationships between and the influence of the barrier factors which affect decision-making about the installation of energy storage equipment, and allow them to obtain information that is helpful for judgment from complex influence systems. This hybrid model can help enterprises explore the complex relationship among factors from different perspectives, and it can also be used to analyze key factors in other industries.

6. Conclusions

The increased use of renewable energy is an important policy goal for various industries to promote energy transformation. In this process, the utilization of energy storage equipment is the main solution to improve the intermittency and instability of renewable energy. However, the adoption of energy storage systems has not been as smooth as expected. In this study, 18 barrier factors that affect an enterprise's decision to install energy storage equipment were first collected through a literature review and expert interviews, from which the nine most important were identified. Finally, the Z-RDWGA research method was used to measure the inconsistent and uncertain information of individual expert opinions, and DEMATEL and ISM were combined to generate an INRM diagram to show the causality, interaction, and the top-level structure of the influence degree ranking of the key barrier factors. The results show that "C_4 (Low technical economic efficiency)" ranks first of all in both the total influence relationship and the net influence relationship and appears at the root level in the hierarchical structure model of the ISM. The results show that "C_5 (Lack of certification and standardization system)" ranks second in the total influence relationship. The research results show that certification mechanisms and national and international certification standards are needed for enterprises to follow when purchasing. The results of the ISM multi-level structure model also show that "C_5 (Lack of certification and standardization system)" is at the second-top level of key barrier factors having a direct or indirect effect on other key barrier factors. The third factor in the total influence relationship is "C_7 (Lack of policy support for investment subsidies or tax incentives)", which is at the third-top level in the ISM hierarchical structure model. If the government can offer businesses favorable financing rates or tax incentives, it will accelerate the decision-making process for businesses to acquire energy storage equipment. The recommended priorities to evaluate energy storage equipment for enterprises are as follows: (1) assess the technical needs and economic efficiency; (2) evaluate if the suppliers have good reputations and if their products have been certified; and (3) consider a suitable installation environment for safety.

The recommendations provided by this study in terms of management implications should help improve key impediments to expedite the decision-making process for businesses to acquire energy storage equipment. The limitations of this study lie in the fact that the energy storage technology is not mature and is still under continuous development, and there may be other influencing factors in the existing literature that have not been considered. The use of the DEMATEL-ISM methodology mainly relies on the subjective judgments and empirical knowledge of experts. Although the acquisition of a threshold value was discussed with the experts, it may still have a certain degree of influence and bias on the final conclusions. It is suggested that future research methods employ Type-2 Fuzzy Sets with higher modeling flexibility and adaptability. Consistency checks can be conducted for each expert's opinions to enhance the representativeness of the research outcomes. Moreover, the energy storage system technology continues to improve in response to user demands and legal regulations. Therefore, new barriers should be considered in the future work.

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