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Original Research Article

Implementation of Knowledge-based Management System for Enterprises Key Carbon Neutral Measures by Grey Relational Analysis

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ABSTRACT

This study uses Grey Relational Analysis to investigate corporate resource allocation strategies for carbon reduction. Analysing 214 valid survey responses, it identifies five key measures prioritised by companies: "Resource recovery and reuse" as the most critical, followed by "Energy-saving lighting and equipment." "Enhancement of energy-saving behaviours" and "Optimisation of energy efficiency" are also important, with "Energy-saving policies and management" providing essential support. The research offers a novel perspective on resource allocation strategies and proposes a dynamic knowledge management system framework to evaluate and improve carbon reduction initiatives. Managerial implications include prioritising resource allocation, enhancing employee training, investing in advanced technologies, and reinforcing policy-making support. Recommendations for designing questionnaires tailored to information systems are provided, along with a system interface example to help businesses track carbon reduction progress.

KEYWORDS

Grey Relational Analysis, Carbon reduction strategies, Knowledge management.

INTRODUCTION

The intensification of global climate change has made reducing carbon emissions a critical issue that governments and businesses worldwide must urgently address. Many have committed to achieving net-zero carbon emissions by 2050. As environmental regulations tighten and public awareness of environmental protection grows, companies are under increasing pressure to reduce their carbon footprint. One of the key challenges for businesses in

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pursuing sustainable development is allocating resources effectively through various carbon reduction measures. Given these measures' cost, benefit, and feasibility differences, companies must formulate a strategic resource allocation plan to ensure successful carbon reduction efforts.

Current research predominantly focuses on the impact of policies, technological innovation, and market-driven factors, with relatively little attention paid to how businesses allocate resources when choosing carbon reduction measures. However, resource allocation strategies determine the selection of carbon reduction measures and significantly affect such initiatives' outcomes and economic performance. Therefore, understanding how companies allocate resources in this context is crucial for improving the effectiveness and efficiency of their carbon reduction efforts.

This study contributes to the existing literature by leveraging Grey Relational Analysis (GRA) to prioritise corporate carbon reduction measures. GRA is a method rarely applied in this context. Unlike prior studies focusing on policy or technological innovations, this research emphasises resource allocation strategies, providing empirical evidence to guide corporate decision-making. Furthermore, integrating knowledge management systems into carbon reduction strategies offers a novel, practical framework for businesses to assess and improve their environmental performance dynamically. These contributions advance theoretical understanding and provide actionable insights for practitioners.

This research will collect and analyse data from companies of different industries and sizes to explore their resource allocation strategies in selecting carbon reduction measures. Specifically, we will:

1. Identify and categorise standard carbon reduction measures.
2. Develop a GRA analysis model to assess the importance of each measure.
3. Analyse the results and provide targeted recommendations to help companies choose the most effective carbon reduction measures under limited resources.

Through this study, we aim to not only provide businesses with scientific support for carbon reduction decision-making but also offer valuable insights to policymakers, promoting optimised resource allocation and efficiency in the corporate carbon reduction process.

LITERATURE REVIEW

This study aims to establish a theoretical foundation for corporate carbon reduction measures by reviewing existing literature and analysing the effectiveness of various carbon reduction strategies. Through a comprehensive analysis of relevant studies, we can identify the key factors and resource allocation strategies that businesses adopt when implementing carbon reduction initiatives. The purpose of the literature review is to provide a broad knowledge base that supports the empirical part of the study, offering concrete references to help businesses develop effective carbon reduction strategies. This knowledge base ultimately contributes to achieving sustainability goals and enhancing competitiveness.

Regarding energy-saving measures, businesses should reduce their environmental impact by adopting more efficient office equipment and lighting systems, choosing eco-friendly travel options, and increasing the reuse and recycling of office supplies [1]. The study suggests methods for reducing office carbon emissions, such as using more efficient lighting and electronic devices, selecting more sustainable business travel methods, promoting office supply reuse and recycling, raising environmental awareness among employees, setting sustainable procurement and waste management policies, conducting environmental campaigns, utilising clean and renewable energy where possible, and upgrading office water, power, and heating systems. These measures are summarised in **Table 1** and **Table 2** which divide energy-saving measures into categories such as: 1. Energy-efficient lighting and equipment, 2. Green transportation and energy-saving mobility, 3. Resource recovery and

reuse, 4. Energy-saving behaviour and awareness enhancement, 5. Energy-efficient facility retrofits, and 8. Carbon footprint management and reduction.

Employee engagement in energy-saving efforts within commercial office buildings has been emphasised as a critical factor in sustainability strategies. One study demonstrated that combining behavioural changes with technical measures – such as promoting alternative commuting methods, implementing recycling programs, installing energy-saving equipment, organising energy-saving competitions, and ensuring top management support – can effectively reduce energy consumption [2]. Table 1 and Table 2 summarise these measures under the following categories: 2. Green transportation and energy-saving mobility, 3. Resource recovery and reuse, 4. Energy-saving behaviour and awareness enhancement, 5. Energy-efficient facility retrofits, and 8. Carbon footprint management and reduction.

An investigation into energy-saving activities among industrial companies in Hyogo Prefecture, Japan, emphasised the importance of both independent internal initiatives and external organisational collaboration [3]. The study outlined several key approaches, including investing in new production equipment, enhancing routine equipment maintenance, participating in pilot projects with universities and government agencies, applying for government energy-saving subsidies, establishing internal energy management systems and regulations, collecting energy policy information, setting energy-saving targets, and encouraging daily office-based energy-saving practices These measures are organised in Table 1 and Table 2 under categories like 1. Energy-efficient lighting and equipment, 3. Resource recovery and reuse, 5. Energy-efficient facility retrofits, 6. Energy efficiency optimisation, 9. Energy-saving technology and innovation, and 10. Employee education and motivation.

A study examining the influence of feedback on energy consumption revealed its significant impact on shaping users' energy-saving behaviours [4]. The study categorised energy-saving actions into three types: daily habits (e.g., turning off lights, adjusting temperature), energy inventory (e.g., replacing energy-efficient light bulbs, fixing HVAC ducts), and consumer investments (e.g., purchasing more efficient appliances, improving home structures). Table 1 and Table 2 classify these measures under categories like 1. Energy-efficient lighting and equipment, and 9. Energy-saving technology and innovation.

To investigate factors influencing low-carbon workplace energy behaviour within large organisations, a study conducted interviews and focus groups with employees from a renewable energy company and a public university in Italy and Spain [5]. The study proposed four main energy-saving strategies: (1) structural and operational changes, such as replacing inefficient equipment or altering business processes; (2) behavioural changes, like reducing photocopying and turning off computers and lights; (3) infrastructure improvements, such as installing renewable energy sources or enhancing building energy efficiency; and (4) organisational communication and culture, including providing employees with information about environmental policies and energy-saving behaviours and creating an organisational atmosphere that supports and encourages energy-saving actions. These strategies are categorised in Table 1 and Table 2 as: 6. Energy efficiency optimisation, and 10. Employee education and motivation.

According to EU statistics, businesses accounted for about a quarter of energy consumption in the EU in 2021, highlighting their critical role in reducing energy consumption. Hungary has implemented several measures to encourage companies to improve energy efficiency, including the obligation for large consumer companies to conduct annual energy audits and disclose the results. The research by [6] focused on the energy efficiency measures adopted by these companies, including employee awareness-raising, lighting upgrades, heating and cooling system upgrades, ventilation system upgrades, window and door replacements, and vehicle upgrades. Table 1 and Table 2 organise these measures under categories such as: 1. Energy-efficient lighting and equipment, 3. Resource recovery and reuse, 6. Energy efficiency optimisation, and 9. Energy-saving technology and innovation.

An analysis of the food and beverage industry across six EU countries examined energy efficiency, carbon emissions, and potential improvement measures [7]. They conducted energy reviews of 204 small and medium-sized enterprises (SMEs). They recommended energy-saving and carbon reduction measures such as employee awareness programs, lighting upgrades, heating and cooling system upgrades, ventilation upgrades, production process modernisation, window and door replacements, pump upgrades, vehicle upgrades, propulsion system modernisation, and modernisation of water and wastewater systems. These measures are categorised in **Table 1** and **Table 2** under 1. Energy-efficient lighting and equipment, 4. Energy-saving behaviour and awareness enhancement, 7. Energy-saving policies and management, 9. Energy-saving technology and innovation, and 10. Employee education and motivation.

A literature review of 63 articles explored how university campuses located in diverse climatic regions implement low-carbon and energy-efficient measures [8]. They identified eight key factors influencing carbon reduction in universities: (1) spatial planning and landscaping, (2) renewable and clean energy, (3) energy systems, (4) building envelope thermal protection, (5) green transportation, (6) management and control, (7) human behaviour, and (8) smart systems. **Table 1** and **Table 2** organise these factors under 1. Energy-efficient lighting and equipment, 2. Green transportation and energy-saving mobility, 4. Energy-saving behaviour and awareness enhancement, 5. Energy-efficient facility retrofits, 6. Energy efficiency optimisation, and 9. Energy-saving technology and innovation.

A study investigated how employee commuting behaviour in an Indian company contributes to energy consumption and carbon emissions, highlighting the significant role of transportation in organisational carbon footprints [9]. The study found that combining multiple strategies yields the greatest energy-saving and carbon-reduction benefits, such as telecommuting, compressed workweeks, carpooling, and shuttle services. They suggested that the Indian government develop travel demand management policies to address urban congestion and air pollution. These strategies are categorised in **Table 1** under 2. Green transportation and energy-saving mobility.

An investigation into commercial buildings revealed that user behaviour – particularly during non-operational hours – is a major contributor to energy waste [10]. The authors conducted a detailed energy examination of six commercial buildings in Botswana and South Africa, breaking down energy consumption into three categories: heating/cooling, lighting, and office equipment. They found that 56% of energy was consumed during non-operational hours, significantly higher than the 44% used during operational hours, mainly due to occupants leaving lights and equipment on after hours and poor zoning and control. They estimated that improving user behaviour could save up to 40% of energy. Therefore, the authors suggested that in addition to turning off unused equipment, effective zoning control would also be an efficient energy-saving strategy. **Table 1** summarises these recommendations under the following energy-saving measure types: 5. Energy-efficient facility retrofits, 6. Energy efficiency optimisation.

Additionally, a set of energy-saving guidelines tailored for office environments was provided in a recent study [11], which are categorised in **Table 1** and **Table 2** as follows: 1. Energy-efficient lighting and equipment, 5. Energy-efficient facility retrofits, 6. Energy efficiency optimisation, 7. Energy-saving policies and management, 8. Carbon footprint management and reduction. The Greenhouse Gas Reduction Management Office, Ministry of Economy mentioned the practices and suggestions of internal carbon pricing within enterprises in the featured article "Preliminary Study on Internal Carbon Pricing Practices of International Enterprises" [12] as an effective tool for promoting low-carbon transformation in businesses, which is included in **Table 2** under the measure type: 12. Internal carbon pricing.

The shared office company in London [13] provided recommendations on how businesses can reduce their carbon footprint, focusing on four key areas: energy conservation, investment in renewable energy, waste reduction, and educating employees and clients. For energy

conservation, among others, installing smart thermostats, switching to LED bulbs, and unplugging unused devices. Renewable energy investments could involve using solar, wind, hydropower, or geothermal energy. Waste reduction can be achieved through waste management, using eco-friendly products, and recycling materials. Employee and client education can be promoted through environmental education programs. These measures are categorised in **Table 1** under the following energy-saving measure types: 1. Energy-efficient lighting and equipment, 2. Green transportation and energy-saving mobility, 3. Resource recovery and reuse, 6. Energy efficiency optimisation.

Since the construction industry is one of the most significant contributors to carbon emissions, a comprehensive review **[14]** examined carbon reduction strategies across both design and operational phases. The identified strategies include modifying cement production methods, recycling construction materials such as concrete aggregates and reclaimed asphalt, and adopting energy-efficient HVAC systems. These are categorised in **Table 1** under the measure type 5. Energy-efficient facility retrofits.

A study synthesising the literature on emission reduction strategies developed a classification framework and identified effective practices for reducing corporate greenhouse gas emissions **[15]**. They identified nine categories of measures companies can implement, including energy (e.g., using renewable, clean, or low-carbon energy sources), products (e.g., using recycled materials), processes (e.g., redesigning production processes), carbon capture, the 6R framework (reuse, recycle, reduce, restore, redesign, remanufacture), waste management, office and mobility (e.g., reducing paper usage and opting for low-carbon transportation), management (e.g., creating incentives for low-carbon behaviour and knowledge management), reporting and disclosure (e.g., self-regulation through sustainability organisations), and compensation (e.g., carbon emissions trading). **Table 1** and **Table 2** categorise these measures under the following types: 2. Green transportation and energy-saving mobility, 4. Energy-saving behaviour and awareness enhancement, 5. Energy-efficient facility retrofits, 8. Carbon footprint management and reduction, 10. Employee education and motivation.

Additionally, a study outlined five key approaches for reducing a company's carbon footprint, including the creation of a sustainability department, optimisation of freight transportation, improvements to factory and office heating, cooling, and lighting systems, and collaboration with environmentally conscious organisations **[16]**. These measures are classified as follows according to **Table 1**: 1. Energy-efficient lighting and equipment, 2. Green transportation and energy-saving mobility, 4. Energy-saving behaviour and awareness enhancement, 5. Energy-efficient facility retrofits.

In an article from Business.com on five ways to reduce a company's carbon footprint, **[17]** outlined several initial steps for corporate leaders to take: (1) implement zero-waste practices, (2) adopt renewable energy, (3) reduce carbon emissions from business travel, (4) educate and encourage employees to participate in carbon reduction and environmental activities, and (5) implement climate-appropriate temperature control. These measures are categorised in **Table 1** and **Table 2** under the following types: 3. Resource recovery and reuse, 4. Energy-saving behaviour and awareness enhancement, 5. Energy-efficient facility retrofits, 7. Energy-saving policies and management.

In a column article by recycle-truck systems enterprise **[18]**, five strategies to reduce corporate carbon emissions, the company recommended several actions: (1) reducing energy consumption, (2) eliminating single-use plastics, (3) offering flexible work options (e.g., remote work), (4) monitoring supply chain efficiency to lower environmental risks and reduce carbon emissions, and (5) educating employees. **Table 2** categorises these measures under three types 7. Energy-saving policies and management, 10. Employee education and motivation, and 11. Flexible work arrangements.

In a column article, “How to Reduce the Carbon Footprint of Your Business?”, Delubac **[19]** suggested various strategies, including avoiding air travel, reducing business

trips, switching to green energy suppliers, purchasing second-hand equipment, regularly maintaining equipment, and recycling or buying recycled products. These measures are shown in **Table 1** and **Table 2** under the following types: 3. Resource recovery and reuse, 5. Energy-efficient facility retrofits, 6. Energy efficiency optimisation, 11. Flexible work arrangements.

An article on the PlanetMark website **[20]** outlined seven ways for companies to reduce carbon emissions, including measuring the company's carbon footprint, using renewable energy, choosing sustainable virtual servers, applying the 3R principles (reduce, reuse, recycle), selecting sustainable suppliers, using online meetings, and investing in green office equipment. **Table 1** categorises these measures under type 5. Energy-efficient facility retrofits.

An article on the Business West website **[21]** suggested six methods for companies to reduce emissions, including recycling and reuse, investing in renewable energy, assessing and engaging with the supply chain, remote working, using electric vehicles, and educating employees through seminars. These measures are categorised in **Table 1** and **Table 2** under the following types: 2. Green transportation and energy-saving mobility, 3. Resource recycling and reuse, 9. Energy-saving technology and innovation.

Table 1. Summary table of energy-saving and carbon reduction strategies – implementation measures; the references are derived from the literature review

No.	Measure type	Specification	References
1	Energy-efficient lighting and equipment	Use more energy-efficient lighting and electronic devices, such as replacing bulbs with LEDs and using energy-saving computers. Upgrade factory equipment to energy-efficient models, such as energy-saving motors and LED lighting. Install automatic sensor lighting systems or smart lighting systems.	[1]–[4], [6]–[8], [11], [13], [16]
2	Green transportation and energy-saving mobility	Choose low-carbon transportation options for business trips and provide low-emission transport options like electric vehicles and bicycles. Use electric or hybrid police cars to reduce gasoline consumption, encourage walking or cycling for patrols, and organise online meetings to reduce the need for business travel.	[1], [2], [8], [9], [13], [15], [16], [21]
3	Resource recovery and reuse	Increase the reuse and recycling of office supplies (e.g., paper, plastic cups) and recycle waste and leftover materials from production processes. Implement recycling programs, purchase recycled or second-hand equipment, and source from companies committed to carbon neutrality or net-zero emissions, like Apple and Microsoft.	[1]–[3], [6], [13], [17], [19], [21]
4	Energy-saving behaviour and awareness enhancement	Raise employee environmental awareness by encouraging green commuting, supporting waste sorting and recycling, reducing paper use, and sending e-mails instead of printed communications. Promote environmental campaigns to increase awareness of resource conservation and green living. Cultivate energy-saving habits among staff and encourage adherence to energy-saving measures.	[1], [2], [7], [8], [15]–[17]
5	Energy-efficient facility retrofits	Retrofit and optimise office water, electricity, and heating systems for energy efficiency. Install smart thermostats, solar panels, weather stripping on windows and doors, and window films to better regulate office temperature. Utilise daylight harvesting and enable energy-saving modes on all computers and mobile devices.	[1]–[3], [8], [10], [11], [14]–[17], [19], [20]
6	Energy efficiency optimisation	Turn off unnecessary lights and appliances, including office lights, when leaving and turning off lights and air conditioning in unused meeting rooms. Choose energy-efficient appliances (e.g., LED lights, energy-saving computers), adjust indoor temperatures appropriately, and perform regular equipment maintenance to extend their life and reduce overall emissions. Consider switching energy suppliers for greater efficiency.	[3], [5], [6], [8], [10], [11], [13], [19]

The article titled "11 Ways Businesses Can Reduce Their Carbon Emissions" [22] discusses several methods that organisations can adopt to reduce their carbon footprint, including (1) recycling to reduce the need for raw materials, (2) using recycled resources, (3) partnering with sustainable suppliers, (4) switching to hybrid or electric vehicles, (5) conducting online meetings and events, (6) using public transportation or car-sharing for business travel, (7) investing in green energy and eco-friendly office equipment, (8) offsetting carbon emissions through certification programs such as carbon neutrality, (9) planting trees, (10) purchasing second-hand office furniture, and (11) engaging employees and clients in environmental discussions. These measures are categorised in Table 2 under the following types: 7. Energy-saving policies and management, 8. Carbon footprint management and reduction.

The reviewed studies and corporate examples collectively present a diverse range of strategies that businesses can adopt for energy conservation and carbon reduction, covering both implementation measures and strategic planning. Table 1 and Table 2 correspond to these two perspectives and show concrete measures compiled from literature and examples of enterprises. Therefore, these tables, which are consolidated in the present study, can provide concrete measures for enterprises that expect to increase carbon reduction efficiency but are not clear about ways to proceed and help enterprises make decisions on carbon reduction measures.

Table 2. Summary table of energy-saving and carbon reduction strategies – strategic planning; the references are derived from the literature review

No.	Measure type	Concrete measures	References
7	Energy-saving policies and management	Implement sound procurement policies and waste management practices to minimise waste generation and reduce environmental impact. Opt for reusable materials instead of single-use items. Establish company energy-saving policies, cultivate employee awareness, and ensure proper execution. Work with sustainable suppliers.	[7], [11], [17], [18], [22]
8	Carbon footprint management and reduction	Conduct carbon verification and pursue carbon neutrality by offsetting emissions. Use clean and renewable energy, track and change energy consumption behaviours using online tools, and secure senior management support for energy-saving initiatives. Engage in tree-planting efforts or create employee gardens to offset carbon.	[1], [2], [11], [15], [22]
9	Energy-saving technology and innovation	Adopt energy-saving technologies such as smart lighting and smart air conditioning. Invest in new production equipment to enhance energy efficiency, develop eco-friendly product designs, and invest in renewable energy.	[3], [4], [6]–[8], [21]
10	Employee education and motivation	Regularly provide employees with feedback on energy consumption, offer internal training to raise energy-saving awareness, organise energy-saving competitions among staff, and create incentives for low-carbon behaviours. Publicly commit to reducing carbon emissions, ensuring employees understand the reasons behind this commitment and how they can contribute.	[3], [5], [7], [15], [18]
11	Flexible work arrangements	Provide flexible working arrangements, such as encouraging remote work.	[18], [19]
12	Internal carbon pricing	Implement internal carbon pricing through three main methods: (1) internal carbon fees – charge business units based on their greenhouse gas emissions, (2) shadow price – calculate the cost of carbon and incorporate it into corporate investment, risk management, and long-term strategy, and (3) implicit pricing – reflect the costs companies have incurred in complying with climate-related policies and regulations.	[12]

METHODS

In this study, we will collect data through a questionnaire survey and use Grey Relational Analysis (GRA) to extract the most important carbon reduction measures according to businesses. Below, we first introduce the application of GRA, followed by an explanation of the research methodology.

GRA is a method used to handle uncertainty, multivariate data, and small data samples. It is widely applied in various fields, including environmental management (to analyse the effectiveness of different environmental measures, identify the best strategies, and assess the effectiveness of corporate emission reduction measures, providing suggestions for improvement [23]); manufacturing (to optimise production processes, identify key factors affecting product quality, and select the best production techniques and equipment [24]); and education and training (to evaluate the effectiveness of different teaching methods, improve teaching quality, and analyse student learning behaviour to identify factors influencing learning outcomes [25]). Based on GRA's characteristics, this study will use GRA to identify the most important carbon reduction measures for companies. The questionnaire survey for this study targets business managers involved in carbon reduction decision-making. The questionnaire will be distributed through actual interviews and e-mail invitations to respondents. Samples will be selected based on industry category, company size, and geographical location to ensure diversity and representativeness, resulting in 214 valid responses from participants with relevant experience. The survey will be conducted over four weeks, with regular follow-ups to enhance the response rate. These details will help clarify the representativeness of the sample and the generalisability of the findings, thereby improving the reliability of the research.

The research methodology includes the following steps:

1. Research Design
   This study adopts a quantitative research approach, using a questionnaire to gather business opinions and evaluations of carbon reduction measures. GRA will then be used to process the data and extract the top 3–6 key measures. GRA's adaptability and accuracy in analysing the relationships among factors in multivariate systems make it a valuable tool in decision-making across various fields [26], [27].
2. Questionnaire Design
   The questionnaire consists of two parts:
   I. Background Information
   This section collects basic data about the companies surveyed, such as industry type and company size (e.g., number of employees and capital). According to [28], these background variables help understand a company's environmental strategy and competitiveness, allowing it to discover differences in carbon reduction measures among various companies.
   II. Evaluation of Carbon Reduction Measures
   A list of 12 carbon reduction measures is provided, and respondents are asked to rate them based on their importance and relevance to their company's practices. A Likert five-point scale is used, ranging from 1 (very unimportant) to 5 (very important). The Likert scale is commonly used in social science research to reflect respondents' attitudes and views [29].
3. Operating Procedures of GRA
   This part draws on the works of [23]–[25], [30] and [31] as a basis for applying GRA in this study. The steps are as follows:
   (1) Determine the Reference and Comparative Sequences
   The reference sequence represents the ideal carbon reduction effect, e.g., [5, 5, 5, 5, 5], indicating the highest scores for all measures on the Likert scale.
   The comparative sequence reflects the actual performance of the company's carbon

reduction measures. For example, Measure 1 might have a sequence of [4, 3, 5, 4, 3]

(2) Data Standardisation

To eliminate the effects of different measurement units, the raw data are normalised, often using the min-max normalisation method according to the formula:

$$X' = \frac{X - min(X)}{max(X) - min(X)} \tag{1}$$

which is applied to each comparative sequence. For example, the Standardised sequence for Measure 1 could be [0.75, 0.5, 1.0, 0.75, 0.5].

(3) Calculate the Relational Degrees

Using the grey relational formula, the relational degrees between the reference sequence and each comparative sequence are calculated.

The relational degrees formula is:

$$\varepsilon_i(k) = \frac{min\ min|X_0(k) - X_i(k)| + \rho\ max\ max|X_0(k) - X_i(k)|}{|X_0(k) - X_i(k)| + \rho\ max\ max|X_0(k) - X_i(k)|} \tag{2}$$

where X_0 is the reference sequence, X_i is the comparative sequence, and ρ is the distinguishing coefficient, typically set to 0.5. The result (relational degree) might look like this for Measure 1: [0.6667, 0.5, 1.0, 0.6667, 0.5]

(4) Rank the Relational Degrees

The average relational degree of each comparative sequence is calculated to rank the measures. For example, the relational degree for Measure 1 might be calculated as:

$$\frac{0.6667+0.5+1.0+0.6667+0.5}{5} = 0.6667$$

(5) Extract Key Factors

Based on the average relational degrees, the carbon reduction measures are ranked, and the top 3–6 most important measures are extracted.

However, despite the advantages of GRA in dealing with multivariate and small sample data, its method has certain limitations. First, the results of GRA are highly dependent on the quality and completeness of the data source. Collecting too small a number of samples may reduce the stability and representativeness of the analysis results. Secondly, the respondents' evaluations of the importance of various carbon reduction measures may be influenced by factors such as subjective perception, industry background or company size, which can introduce potential biases. In addition, although the processes of data normalisation and relational degree calculation in GRA are technically feasible, it is still necessary to interpret the analysis results carefully in practical application to avoid over-interpreting the ranking results of minor differences. Therefore, while using GRA to extract key factors, it is essential to combine expert opinions and practical background to explain and corroborate in multiple aspects so as to improve the reliability and practical value of the findings.

The 12 carbon reduction measures analysed in this study were derived from an extensive literature review and validated through consultations with industry experts. These experts, representing diverse sectors such as manufacturing, retail, and finance, were selected based on their professional experience in environmental management and sustainability practices. Their input ensured the practical relevance and comprehensiveness of the measures.

To ensure the sample's representativeness, the study targeted companies across various industries and sizes, including manufacturing, wholesale and retail trade, and professional services. This diverse sampling approach enables the findings to reflect a broad spectrum of corporate carbon reduction strategies. The sample of 214 valid responses from 34 companies aligns with similar studies in the field, providing a robust basis for analysis.

RESULTS AND DISCUSSION

The GRA results are presented below, along with an interpretation of the findings. **Table 3** displays the GRA scores and rankings for each factor, showing the Grey relational values and the importance ranking of each factor as a carbon reduction measure for businesses.

According to **[32]**, 3 to 6 key factors typically influence an enterprise's success. If an enterprise lacks these critical factors, it will likely face failure. The number of key factors should not exceed half of the total number of factors; otherwise, the representativeness of these factors would be compromised. Based on this theoretical foundation, this study adopts the Grey Relational Analysis (GRA) method to extract 3 to 6 representative key factors from a set of candidate factors.

The results of the GRA analysis revealed that the Grey Relational values of the sixth to eighth factors were very close, indicating similar levels of importance among these factors. However, if these three factors were also extracted as key ones, this would result in 8 out of the 12 candidate factors being classified as key factors. Such an outcome would fail to effectively distinguish the criticality of the factors, contradicting Daniel's concept **[32]**, which emphasises maintaining a reasonable number of key factors to ensure their representativeness and decisiveness.

Table 3. Scores and rankings of GRA results by factor

Factor	Code	Grey relation value	Rank
Resource recovery and reuse	F3	0.752	1
Energy-efficient lighting and equipment	F1	0.730	2
Energy-saving behaviour and awareness enhancement	F4	0.710	3
Energy efficiency optimisation	F6	0.698	4
Energy-saving policies and management	F7	0.683	5
Energy-efficient facility retrofits	F5	0.668	6
Carbon footprint management and reduction	F8	0.667	7
Energy-saving technology and innovation	F9	0.665	8
Employee education and motivation	F10	0.634	9
Flexible work arrangements	F11	0.627	10
Green transportation and energy-saving mobility	F2	0.623	11
Internal carbon pricing	F12	0.597	12

Taking these considerations into account, this study ultimately selected 5 key factors for its findings. This decision aligns with the recommendation regarding the appropriate number of key factors and provides a more precise representation of the relative importance of each factor to enterprise success **[32]**. This approach ensures the scientific rigour and rationality of the results and avoids diluting the representativeness of key factors by including an excessive number of them. Moreover, this decision-making process reflects the study's commitment to respecting its theoretical foundation and carefully interpreting the data analysis results.

The findings could facilitate the prioritisation of carbon-neutral measures by cooperating managers. Companies with limited resources could conduct formal or informal carbon footprint verification to identify obvious or unexpected factors among all factors. By

identifying these 5 key factors, this study offers targeted recommendations for resource allocation, enabling enterprises with limited resources to prioritise the most influential areas to enhance their operational efficiency and competitiveness. For instance, companies can focus on "Resource recovery and reuse" and "Energy-efficient lighting and equipment" as primary strategies, as these factors hold the highest Grey relational values.

Additionally, industry-specific considerations should be taken into account when implementing these recommendations. Each sector has its characteristics; manufacturing, tech, logistics, financial and service sectors all have vastly verified patterns of carbon emission. Different industries may face unique challenges and opportunities regarding carbon reduction measures. For example, manufacturing firms may prioritise energy-efficient equipment, while service-oriented businesses might focus more on employee education and behaviour enhancement. The survey was conducted among managerial positions of enterprises from various sectors. However, the results from this study are especially suitable for office operations in the service, financial and educational sectors.

Furthermore, it is valuable to discuss how these findings align with or differ from previous studies in the field, particularly regarding resource allocation strategies for carbon reduction. This study's emphasis on a limited number of key factors resonates with existing literature that advocates for focused strategies in resource-limited environments. By doing so, companies can avoid spreading their efforts too thin and instead concentrate on the most impactful measures.

According to the GRA analysis results illustrated in **Figure 1**, the study identified five key carbon reduction measures out of 12, even though the initial assumption was to select 3 to 6. Ranked from highest to lowest in importance, the selected measures are: F3 "Resource recovery and reuse", F1 "Energy-efficient lighting and equipment", F4 "Energy-saving behaviour and awareness enhancement", F6 "Energy efficiency optimisation," and F7 "Energy-saving policies and management." The reason for selecting only five key measures, rather than six, is that the Grey relational values for F5 "Energy-efficient facility retrofits" (ranked 6th), F8 "Carbon footprint management and reduction" (ranked 7th), and F9 "Energy-saving technology and innovation" (ranked 8th) were too close, making it difficult to separate this group.

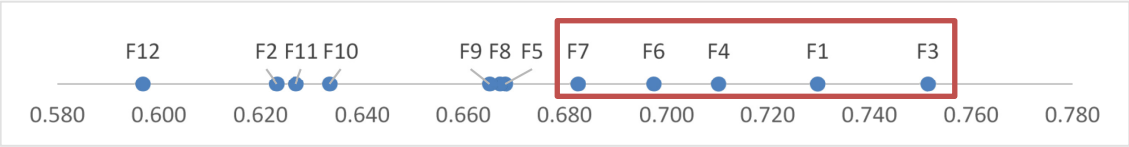

Figure 1. Ranking of Grey relation value of each factor

Figure 2 shows the group classification of the five key factors extracted from the previous study based on the similarity of the Grey relation value of F3 "Resource recovery and reuse" and F1 "Energy-efficient lighting and equipment". In this case, these two key factors were grouped into cluster A. F3 "Resource recovery and reuse" was re-coded as A1, and F1 "Energy-efficient lighting and equipment" was re-coded as A2 according to the degree of importance, followed by F4 "Energy-saving behaviour and awareness enhancement", F6 "Energy efficiency optimisation", and F7 "Energy-saving policies and management", for which the difference in the Grey relation value was no more than 0.015. Therefore, the previous study classified these three key factors into cluster B, re-coding F4 "Energy-saving behaviour and awareness enhancement" as B1, F6 "Energy efficiency optimisation" as B2, and F7 "Energy-saving policies and management" as B3 according to the degree of importance. Following the above criteria, **Figure 2** finally presents the status of the five key factors after classification.

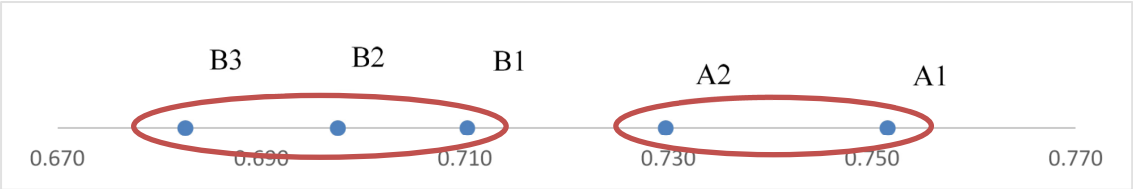

Figure 2. Group classification of key factors in the previous study

CONCLUSIONS

This study investigates how companies allocate resources when selecting carbon reduction measures and utilises Grey Relational Analysis (GRA) to identify and rank the five most critical carbon reduction actions based on data from 214 valid questionnaires. The resulting ranking is as follows.

1. Resource recovery and reuse (F3): Companies prioritise waste recovery and reuse as the most important measure, as it effectively reduces resource waste and carbon emissions.
2. Energy-efficient lighting and equipment (F1): Adopting high-efficiency lighting systems and energy-saving equipment is identified as a key strategy for improving energy efficiency, ranking second.
3. Energy-saving behaviour and awareness enhancement (F4): Companies emphasise cultivating energy-saving behaviours and raising awareness among employees, making this the third most important measure.
4. Energy efficiency optimisation (F6): Improving production processes and operational efficiency of equipment is a significant approach to reduce energy consumption further, ranking fourth.
5. Energy-saving policies and management (F7): Developing and implementing effective energy-saving policies and management mechanisms provide critical support for overall carbon reduction strategies, ranking fifth.

The findings of this study not only identify critical carbon reduction measures for businesses but also emphasise the importance of integrating knowledge management systems to optimise resource allocation. Specifically, the results suggest that companies should prioritise resource recovery and reuse as their primary focus, followed by technological advancements in energy-efficient equipment and behavioural changes to promote energy-saving awareness. Energy efficiency optimisation and policy management are highlighted as complementary measures supporting strengthening carbon reduction initiatives.

To further enhance the applicability and robustness of these findings, future research could broaden the scope by incorporating energy-saving and carbon-reduction strategies to track long-term impacts and exploring the proposed strategies' effectiveness across different industries. Such efforts would provide deeper insights into the adaptability and scalability of these measures, enabling businesses to develop more tailored and sustainable carbon reduction frameworks.

MANAGEMENT IMPLICATIONS

1. Prioritising resource allocation: Based on the research findings, companies should prioritise allocating resources to resource recovery and reuse as well as energy-saving lighting and equipment. These areas effectively reduce carbon emissions and result in long-term energy cost savings, enhancing the company's environmental image.
2. Staff training and awareness-raising: Energy-saving behaviours and awareness enhancement are recognised as key measures, and companies should strengthen environmental education and training for employees to encourage them to adopt energy-saving habits in their daily work. Specifically, companies can develop professional training programs tailored to different positions and departments and

regularly hold workshops inviting experts to share the latest environmental technologies and successful case studies. Additionally, establishing incentive mechanisms, such as reward systems, can motivate employees or teams that perform well in energy-saving efforts while also encouraging participation in carbon reduction activities. Promoting a culture of environmental awareness is also crucial; companies can utilise internal promotional materials and meetings to emphasise the value of environmental protection and share success stories in energy saving, allowing employees to feel the significance of their participation. At the same time, setting quantifiable goals encourages departments to report their energy-saving achievements monthly, and data analysis can be used to evaluate the effectiveness of training and incentive measures. Through these comprehensive strategies, companies can not only enhance employees' environmental awareness but also integrate environmental values into their corporate culture, ultimately achieving the goals of reducing carbon emissions and improving operational efficiency, thereby shaping a more sustainable work environment and promoting long-term corporate development.

3. Investment in technology and equipment: Investing in energy-efficient technologies and equipment is crucial to improving energy efficiency. Companies should continuously monitor and adopt advanced energy-saving technologies and equipment to minimise energy waste during production processes.
4. Policy development and management assistance: Developing clear energy-saving policies and reinforcing management support can help companies implement carbon reduction initiatives systematically. Leadership should actively promote the execution of these policies and regularly monitor and evaluate their effectiveness to ensure the smooth implementation of various carbon reduction measures.
5. Synergy: Combining different carbon reduction measures can create synergies. For instance, resource recycling and reuse can be paired with employee energy-saving behaviours to enhance overall carbon reduction outcomes. Companies should consider the interactions between various measures and optimise resource allocation accordingly.

From a management perspective, companies should emphasise creating and applying new knowledge, particularly in environmental management and carbon reduction. Developing or utilising a knowledge management system to input information and provide real-time evaluation of carbon reduction measures is crucial for improving decision-making efficiency. Such a system not only offers a detailed analysis of current carbon reduction initiatives but also provides specific recommendations for improvement, helping businesses stand out in a competitive market. Additionally, it aligns with modern corporate social responsibility expectations, further enhancing the company's public image and market competitiveness. It is recommended that companies develop or adopt a knowledge management system that allows employees to report on the implementation status of current carbon reduction measures. This study established three predefined status types for carbon reduction measures: completed, in progress, and not implemented. The "completed" status indicates that the company has already developed and fully executed the strategy for that particular measure. The "in progress" status means the strategy has been developed or is currently being implemented. The "not implemented" status signifies that the company has not yet formulated any plans for that measure.

In using the knowledge management system, companies must first fill in the execution status of the 12 Carbon Reduction Strategies listed in **Table 1** and **Table 2**. This action serves as the basis for the knowledge management system to provide recommendations. The system will then identify which of the 12 Strategies the company lacks compared to the majority of companies in the database. Further, the system will determine which of these lacking measures overlap with the five key factors extracted from this study's GRA analysis. These overlapping carbon reduction measures will be prioritised as recommendations for companies to implement

first. Once these key carbon reduction measures have been completed, companies can proceed with other measures.

After completing the assessment of the company's carbon reduction measure implementation, the knowledge management system will recommend that businesses focus on executing critical carbon reduction actions. The system will compare the company's current status with the large dataset of other companies' implementation statuses for the same measures and provide suggestions based on these comparisons. These recommendations are pre-programmed into the system and will be adjusted according to the information entered by the company. When offering recommendations, the system should compare the company's implementation status (categorised as not implemented, in progress, or completed) with the status of all companies in the database, resulting in nine possible combinations. For example, if both the company and the dataset show that the measure is not implemented, the system will advise delaying the execution of that measure. **Table 4** shows a detailed comparison of these nine combinations. Additionally, the system can offer specific advice on carbon reduction measures by referring to the contents of **Table 1** and **Table 2** in this study, allowing companies to identify additional steps they can take to improve or begin implementing, thereby enhancing their carbon reduction efficiency.

Table 4. Suggestions on the knowledge management system for corporate carbon-reduction measures panel

Resource recovery and reuse	**Completed**	**Completed**	**None**
Energy-efficient lighting and equipment	In progress	Completed	It is necessary to monitor the progress of energy-efficient lighting and equipment replacements within the company and set a deadline for their completion.
Energy-saving behaviour and awareness enhancement	Not performed	In progress	Employee awareness and behaviour regarding energy conservation should be enhanced as soon as possible through training sessions or awareness programs.
Energy efficiency optimisation	Completed	Not performed	None
Energy-saving policies and management	Not performed	Completed	An energy conservation policy should be developed and managed by the company without delay. It could start by establishing a dedicated committee or department to formulate and implement the policies.
Energy-efficient facility retrofits	Not performed	Not performed	Implementing the company's facility upgrades is recommended only after completing the more critical carbon reduction strategies.
Carbon footprint management and reduction	Completed	In progress	None
Energy-saving technology and innovation	In progress	Not performed	None
Employee education and motivation	In progress	In progress	The company should continuously monitor the progress of employee education and incentive programs.

Table 4 is the recommendation screen displayed after companies enter the implementation status of their carbon reduction measures into the knowledge management system. The system will prioritise the carbon reduction measures based on their importance, as identified by this study, and then compare the company's implementation status with the most common status found in the system's large dataset from other companies. This action allows the company to

understand its progress in implementing carbon reduction measures and make improvements based on the system's recommendations.

Based on the comparison results of the case study's carbon reduction strategy implementation status, the carbon reduction strategies that overlap with the five key carbon reduction strategies extracted by GRA are Energy-efficient lighting and equipment (F1), Energy-saving behaviour and awareness enhancement (F4), and Energy-saving policies and management (F7). Therefore, these three carbon reduction strategies should be prioritised for implementation in this case. The knowledge management system will apply the above-described method to provide users with a recommended implementation sequence and specific execution suggestions.

In order to implement this knowledge management system, companies must first have a basic digital infrastructure and internal process recording mechanism to ensure that data on the implementation of carbon reduction measures are accurately entered into the system. However, potential challenges may include staff resistance to the new system, difficulties in integrating data across departments, and the additional staffing and resources required to maintain and update the database. To overcome these challenges, companies can improve the usability and willingness of the system by providing education and training, establishing cross-departmental collaboration mechanisms, and introducing automated reporting tools. Moreover, through continuous monitoring and employee feedback mechanisms, companies can ensure the system operates effectively and continuously improves.

In addition, the system is highly resilient and scalable, adapting to the company's industry branch, size, and carbon emission profile. For example, the manufacturing industry can focus on equipment upgrades and energy management. In the service sector, employee behaviours and policy guidance can be prioritised by study participants in areas such as manufacturing, retail, and professional services. Furthermore, in the future, it can also simplify or expand functions according to the scale of enterprises (e.g., small and medium-sized enterprises and large enterprises) through modular design so that it can better meet the operational needs and resource conditions of different organisations.

The findings of this study provide clear guidance for companies in selecting and implementing carbon reduction measures under limited resources, helping them maximise carbon reduction benefits and achieve sustainability goals. With proper resource allocation and effective management strategies, companies can make significant progress in reducing carbon emissions and enhancing their competitive advantage.

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