

Green Supplier Selection for Small Enterprises without Impairing Earnings

-- AHP Hierarchical Analysis Based on ChatGPT Decision Empowerment

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Abstract: In recent years, more and more studies have shown that sustainable development and competitive profitability don't need to be mutually exclusive, and as a result, not only governments and non-profit organizations, but also more and more companies have started to look at green procurement as an important part of sustainable development. However, as a major contributor to carbon emissions and a key implementer of green procurement, MSMEs have long faced internal and external disadvantages in the form of a lack of expert support and external information. To prevent green procurement from becoming a strategy of information monopoly for large enterprises, and to reduce the cost of green procurement and encourage more SME to join, this paper focuses on the core link of green procurement - supplier selection, and uses AI model to enhance the traditional AHP hierarchical analysis method to provide a set of convenient and cost-effective green supplier selection solutions for SME. high performance green supplier selection program, and provides some observations and suggestions based on the model. In the information age, for individuals or organizations that lack information, large language models such as GPT provide a fast track. The nature of the decision-making capability of large language models, such as machine learning, is increasingly proving to be effective in addition to the traditional function of information retrieval. In this paper, we used ChatGPT to generate a group of virtual experts as an AHP expert panel, and established the method of developing AHP top guides and consistency tests to ensure that their scores are effective. Finally, we determined the 5 first-level indicators and 16 sub-indicators to be considered by micro and small enterprises to make a green supplier selection with guaranteed benefits and no cost increase, as well as the weights of these indicators. The method is highly feasible and scalable, and micro and small enterprises can easily reproduce the programme in practice and add to the learning materials or objectives according to the actual situation or to the specific needs of the enterprise.

Keywords: Supplier selection, Green Procurement, GPT-4, AHP, ChatGPT, LLM, Autonomous agents.

1. Introduction

1.1. Green Procurement

Green procurement is a strategy employed by enterprises and governments to promote green and low-carbon concepts in procurement activities. It entails giving full consideration to environmental protection, resource conservation, safety and health, recycling and the promotion of low-carbon and recycling. It also priorities the procurement and use of energy-saving, water-saving, material-saving and other raw materials, products and services that are conducive to environmental protection.

According to Wikipedia, green procurement is defined as a strategy that aims to establish a resource-saving and environmentally conscious society. Enterprises should consider environmental implications in procurement activities and prioritize the procurement of raw materials, products and services that are environmentally friendly, energy-saving and low-consumption, and easy to comprehensively utilize resources. This behavior is reflected in both enterprise and government procurement activities. There are a plethora of successful cases and well-established standards pertaining to government green procurement, including those issued by the United Nations Environment Programme (UNEP) and the International Organization for Standardization (ISO), the European Union's Environmental Procurement Directive, and the environmental protection policies of various countries. China's Green Procurement Guidelines for Enterprises (for Trial Implementation) provide

a series of specific recommendations and guidance on how to implement green procurement for large, complex enterprises with full staffing and technical support.

Taylor and Welford (1993) were the first to explore the application of green procurement in corporate environmental management through a case study of IBM UK. Azzone and Bertel (1994) then explored the opportunities and challenges of green strategies in their study, emphasizing the competitive advantages that can be brought to companies through green purchasing practices and providing practical examples to serve as examples. Hass (1996) proposed the first conceptual framework for the greening of supply chains. Finally, GEMI (2001) provided a new approach for firms to achieve commercial value from green strategies. Collectively, these literatures emphasize the importance of implementing green strategies and provide practical direction and theoretical support for enterprises.

1.2. Enterprise Green Supplier Management

1.2.1. Development Status

Amazon.com, the leading enterprise, has invested and established 310 renewable energy projects in 19 countries around the world. In 2021, Amazon.com will add 274 renewable energy projects around the world, becoming the world's largest corporate buyer of renewable energy for two consecutive years. In its 2023 Sustainability Report, Siemens has launched a programme called "20x25", which aims to source at least 20 agricultural products in a more sustainable way by 2025. In addition, Siemens proposes to strictly

discipline and select its suppliers in accordance with the Siemens Group Code of Conduct for Suppliers and Third Party Intermediaries, with the intention of improving the sustainability of its suppliers and providing them with extensive support for sustainable development.

However, for micro and small enterprises, despite the existence of relevant policies to support green procurement in many countries worldwide, the low procurement budget, high human cost and other internal disadvantages, as well as a lack of information support and other external disadvantages, make it difficult to obtain expert resources. Consequently, the actual procurement process involves a high degree of subjectivity, resulting in the Procurement Department having excessive rights and the occurrence of secret dealing.[1] The green procurement road of micro and small enterprises faces significant challenges, with the potential to contribute significantly to carbon emissions. It is therefore important to consider the empowerment of micro and small enterprises in green procurement.

1.2.2. Methodological Research

Green supplier management represents an essential component of green procurement and supply operations (Song Yuqing, 2000). Extensive attention has been paid to this topic by scholars, as evidenced by the work of Noci (1997), who designed the first green supplier rating system for assessing the environmental performance of suppliers in a study published in the *European Journal of Purchasing & Supply Management*. At the theoretical level, Humphreys et al. (2003) explored ways to integrate environmental criteria into the supplier selection process, while Li, Junying, and Dong, Li and Dong (2022) proposed a comprehensive theoretical indicator system for green suppliers. In practical research, Liu Bin and Zhu Qinghua (2009), Zhang Songbo and Song Hua (2012) and others have improved the review of enterprise green supplier management through the AHP hierarchical analysis method. This provides a certain reference method for supplier decision-making in green purchasing. However, due to the high requirements and difficulties of its data collection, it does not have a good ability to promote.

1.3. AHP Hierarchical Analysis

AHP (hierarchical analysis method) is a mathematical and psychological multi-criteria decision-making method based on hierarchizing complex problems and comparing them step by step to arrive at the optimal choice. It was developed by Thomas L. Saaty in the 1970s and has been widely applied and improved since then. [2] In the field of green procurement, the AHP method can be employed to select suppliers that meet environmental standards. By quantitatively evaluating the relative importance of different suppliers in terms of environmental protection, quality, price, etc., and comprehensively evaluating them based on weight allocation, the most suitable supplier can be identified. The method has the advantages of extensive scalability and robustness in enterprise supplier selection. However, it is more challenging for small and micro manufacturing enterprises with limited resources to access green industry services that require expert support [3]. There is a pressing need for the development of a new, cost-effective, and straightforward evaluation and analysis method. The development and prevalence of LLM large language modelling in recent years may provide new ideas and methods for efficient multi-scenario use of AHP methods.

1.4. Large Language Modelling for Decision Support

As early as 2018, a study by A. Radford et al. on improving language comprehension through generative pre-training confirmed the powerful comprehension and decision-making potential of large language models.

A study by M. Loya et al. explored the decision-making capabilities of language models and demonstrated the benefits of AI in terms of decision sensitivity. While M. Sallam and L. Tang et al. used Chat GPT to support decision making for healthcare programmes in their study, the findings of a more reliable comparison test also suggest that big language models have decision-making capabilities in healthcare.

S. S. Biswas subsequently discusses the capacity of Chat GPT to facilitate decision-making in the field of public health.

In the domain of supply chain management, C. Hendriksen initially investigated the utilization of Big Language Models in this context. Their findings indicate that these models can be effectively employed to optimize decision-making and management processes, thereby enhancing efficiency.

In 2023, Igor Svoboda and Dmytro Lande combined big language modelling with decision-making and AHP hierarchical analysis in their research on automated decision support based on GPT. This demonstrated the good applicability and superb cost-effectiveness of AI in basic decision-making frameworks, which provides a practical and efficient solution for AI-assisted decision making.

1.5. Summary

Green procurement is of great significance in the sustainable development of enterprises, and has become increasingly popular. However, the green reform of its main force, small and micro enterprises, faces the problem of collecting data, and access to expert support services is more difficult. The utilization of an AI model for decision-making can not only reduce the cost of decision-making and provide feasibility, but also circumvent concerns regarding the excellent decision-making ability and low cost and high efficiency of the large language model. This paper will present a solution based on the AHP hierarchical analysis, which has been replicated and can be extended to the micro and small enterprises of the green supplier management programme.

2. GPT-assisted Decision-making for AHP Green Supplier Selection

2.1. Problem Analysis

This chapter focuses on the internal and external disadvantages of the lack of expert support and external information in green supplier selection for micro and small enterprises. In order to address these issues, we have chosen to use ChatGPT as a decision-making expert and process guidance expert. The AHP method is employed in conjunction with the virtual experts generated by ChatGPT, with the objective of comprehensively considering a number of factors. This is with a view to analyzing the elements of supplier selection in a hierarchical manner and providing knowledge assistance and decision-making advice based on the massive knowledge information base of the system.

2.2. AHP Hierarchical Analysis

The Analytic Hierarchy Process (AHP) is a decision-making model that combines quantitative and qualitative methods. It is capable of sorting and hierarchical processing of factors that affect the final goal. The AHP method is a systematic approach to decision-making that breaks down the factors affecting a decision into a hierarchical structure. It was developed by Professor Thomas L. Saaty in the 1970s and has since become a popular tool for governments, corporations, and other organizations. The AHP methodology comprises three main steps:

The initial step involves the collection of background information, the interpretation of the current state of the problem, the analysis of the organizational or individual objectives and levels of study, and the determination of the overall objectives of the analysis and the decision level. The overall structure of the AHP consists of three parts: the objective level, the criterion level, and the scenario level. The objective level is at the top, followed by the criterion level and the scenario level in descending order. The objective level represents the final goal that the decision is intended to evaluate. The criterion level encompasses the factors that affect the objective level. The programme level refers to the selected objects. Once these levels have been defined, the specific factors or programmes in each layer must be identified in order to complete the model construction.

Secondly, the importance of the factors is quantified through scoring, fuzzy scoring, or a two-by-two comparison of each element in each layer with reference to the classical nine-point method proposed by Thomas L. Saaty. The scoring scale is shown in Table 1. The relative importance, or weights, can be obtained by normalizing the element scores of each layer after obtaining the elements' comparative scoring scales.

Thirdly, the consistency index (CI) and the consistency ratio (CR) are calculated. A CR value of less than 0.1 indicates that the judges are more consistent about the ordering between different options, and the AHP analysis is considered meaningful. Otherwise, it has to be changed and re-done.

2.3. process

Firstly, we appointed an AHP guide to act as our process guidance expert, instructing us throughout the process to accurately interpret the AHP analysis method and provide us with the highest level of guidance. Their instructions are listed below:

Name of Intelligent Body (cannot be modified)

AHP Coach

Intelligence Body Description

Top-level coach and framework designer for AHP analysis of green procurement supplier selection issues

Role Description

be conducting AHP implementation guides for users to help micro and small enterprises deal with supplier evaluation issues when green procurement using Saaty's Hierarchical Analysis. You will guide the users on where they should consider this issue and will interact with them on an ongoing basis. The users will consult a group of external experts for their decision-making advice. It will be your role to guide the users in gathering input from these experts on various aspects of the AHP process, including criteria, structure selection, and two-by-two comparisons. Furthermore, you will be

responsible for guiding the user on how to ask for and interpret expert opinions in order to ensure that these inputs are accurately and effectively incorporated into the AHP framework. This approach is of critical importance to both the setup and execution of AHP methods, especially in complex decision-making scenarios that require external expertise. The guidance provided will be clear and easy to understand, accurately detailed and structured to facilitate a comprehensive and collaborative decision-making process.

Next, we consulted it for the proposed number of personnel for the virtual expert group, and the instructions are below:

In light of Saaty's 1990 paper on AHP, we now seek to conduct an AHP analysis of supplier evaluation metrics based on green purchasing objectives. To this end, we would be grateful if you could advise us on the number of experts we will require to complete this analysis comprehensively, objectively and accurately. In accordance with the tenets of AHP, it is recommended that at least three to five experts be invited to participate in the decision-making process in order to ensure a comprehensive, objective, and accurate AHP analysis of supplier evaluation metrics. This ensures access to the diverse perspectives and experiences of multiple experts, thereby reducing the impact of individual bias on the results. At the same time, the experts should possess knowledge and experience in the relevant field to be able to provide valuable opinions and assessments. When selecting experts, it is advisable to consider their background, professional qualifications and experience to ensure that they can make a useful contribution to the decision-making process.

In order to ensure rigour, we decided to form an AHP expert panel of five virtual experts. We then consulted the AHP coach for a description of each of these five virtual experts, examples of which are given below:

Zhao Min

Description: Young and dynamic environmental science and sustainability expert She is adept at supporting data and facts and is skilled at simplifying complex issues into actionable steps. She is organized and detail-oriented and enjoys setting clear plans and goals. She is open to innovation and new technologies and encourages her team to think of new solutions.

In addition, there are Yu Zhang, a supply chain management expert, Ming Wang, a passionate CSR expert, Na Li, a quality management expert specializing in quality management and supplier assessment, and Wei Zhang, an experienced marketing expert.

It can be observed that this expert team not only possesses professional backgrounds and experience, but also represents a diverse range of stakeholders, industries, academic backgrounds and experience levels. This helps to obtain a multitude of opinions and perspectives, reduces bias and blind spots, and constitutes a reasonably complete expert group.

Concurrently, as these five experts are autonomous in their decision-making, in order to synthesize the opinions in the future, the recommendations of the AHP guidance are integrated to assess the influence and applicability (weights) of these five experts based on the four dimensions of common expert evaluations (knowledge, skills, attitudes, and experience). The following steps are thus employed:

1. Definition of assessment dimensions and criteria

➤ Knowledge (K): refers to the expert's theoretical and practical knowledge of green procurement and sustainability.

➤ Skill (S): refers to the expert's ability to apply knowledge in a practical way to realize green procurement.

➤ Attitude (A): the expert's attitude towards recognizing and promoting the value and importance of green procurement.

➤ Experience(E): refers to the expert's practical experience in the field of green procurement.

2. Allocation of weights of the four indicators to the AHP guidance enquiry

➤ Knowledge (K): 20 per cent

➤ Skills (S): 30 per cent

➤ Attitude (A): 20 per cent

➤ Experience (E): 30 per cent

3. guide the scoring.

A score from 1 to 10 should be set and the experts should be rated according to their profile and background.

◇ Zhao Min: K=8, S=7, A=9, E=7

◇ Zhang Yu: K=7, S=9, A=8, E=8

◇ Wang Ming: K=7, S=8, A=8, E=7

◇ Li Na: K=9, S=8, A=7, E=9

◇ Zhang Wei: K=8, S=7, A=6, E=8

4. Calculation of The weights of the experts

◇ Zhang Yu: 0.199

◇ Zhao Min: 0.207

◇ Wang Ming: 0.199

◇ Li Na: 0.209

◇ Zhang Wei: 0.186

5. Calculate the weighted scores.

The score of the other nth expert's ith indicator is calculated according to the AHP guide, with each expert developing the weight of the indicators and the scoring of each indicator. The nth expert's weight is calculated as follows: The general objective of the AHP analysis was thus defined as aiding micro and small enterprises in completing the supplier evaluation in response to the call for green procurement. In order to achieve this, it was necessary to consult with The five virtual experts of the expert panel were asked to determine the top criteria independently. Each expert proposed five to six criteria, and duplicates were removed, as were items that were similar to each other. This process resulted in a total of six top criteria, which are described in detail below.

The availability and cost-effectiveness of green products and services must be evaluated. This entails assessing the substitutability and cost-effectiveness of green products and services offered by suppliers, as well as determining whether green procurement can be achieved at no additional cost.

The environmental impact reduction and resource efficiency of the supplier must be assessed. This entails determining whether the supplier is able to significantly reduce its environmental impacts in the production process, including the efficient use of energy and resources, and the effectiveness of waste management and disposal measures. It is necessary to assess the supplier's ability to cooperate and coordinate in the supply chain, as well as the transparency and traceability of information about the supply chain, in order to ensure sustainability and compliance.

In addition, it is important to assess the supplier's innovation and technological capabilities, including continued investment in research and development and improvements, as well as the ability to adopt new technologies to improve the benefits of green procurement. The assessment determines whether suppliers provide products that meet environmental requirements and ensure

product quality and sustainability.

Social responsibility performance is evaluated to assess the supplier's performance in social responsibility, including employee welfare, labor rights and community support. (As decision-makers are willing to act as individual entities, it is possible for each decision-maker to collaborate on the scoring matrix after making a two-by-two comparison on their own.)

Subsequently, the general objective of the AHP analysis was established: to assist micro and small enterprises in completing the supplier evaluation in response to the call for green procurement. In order to achieve this, we consulted with The five virtual experts of the expert panel were asked to determine the top criteria independently. Each expert proposed five to six criteria, and duplicates were removed, as were items that were similar to each other. This process yielded a total of six top criteria, which are described in detail below.

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Each entry of the comparison matrix was then aggregated into a final group judgement using the geometric mean method (WGMM) (Saaty 1989; Forman and Peniwati 1998). After obtaining the aggregated matrix, it was tested for consistency. The resulting consistency ratio (CR) was 0.099, which is less than 0.1 and has a tendency to be close to 0. It can be assumed that the matrix is relatively consistent. The development and comparison of the primary criteria is reasonable. The weights of the six primary factors are calculated according to the final comparison scoring matrix using the following formula:

$$W_i = \frac{\sqrt[6]{\prod_{k=1}^6 a_{ik}}}{\sum_{i=1}^6 \sqrt[6]{\prod_{k=1}^6 a_{ik}}} \quad (1)$$

[0.253, 0.132, 0.176, 0.292, 0.097, 0.049] for each of the six top criteria.

Subsequently, the sub-criteria were subjected to questioning in the form of interviews with five experts, resulting in the identification of 16 sub-criteria. These were categorized, de-weighted and aggregated, as detailed below.

Availability and cost-effectiveness of green products and services:

Substitutability assessment: This sub-criterion assesses whether the green products and services provided by the supplier are substitutable.

Cost-effectiveness assessment: This criterion assesses the

cost-effectiveness of green products and services, i.e. whether green procurement can be achieved without additional costs.

Additional cost assessment: To assess whether the green products and services provided by suppliers will add additional costs, such as packaging, transport, etc.

Environmental impact reduction and resource utilization efficiency:

Energy utilization assessment: To assess whether the supplier is able to use energy efficiently in the production process and take energy saving measures to reduce environmental impact.

Resource utilization assessment: To assess whether the supplier can effectively utilize resources, such as water and raw materials, in the production process and reduce waste.

Waste Management Assessment: To assess the effectiveness of suppliers' waste management and disposal measures, including recycling, recovery and safe disposal of waste.

Supply chain co-operation and transparency:

Co-operation and co-ordination capability: assesses the supplier's ability to co-operate and co-ordinate in the supply chain, including with other suppliers and partners.

Information Transparency: Assesses suppliers' transparency and traceability of supply chain information to ensure supply chain sustainability and compliance.

Supply chain management system certification: Assess the supplier's supply chain management system certification, such as ISO 9001 quality management system certification and ISO 14001 environmental management system certification.

Innovation and Technology Capabilities:

R&D Investment Assessment: This assesses the supplier's ability to continuously invest in R&D and improvements to

drive innovation and technological advancement in green procurement. It is necessary to assess whether the products provided by suppliers meet environmental requirements, such as compliance with relevant environmental standards and certifications.

New technology application: Assessing suppliers' ability to adopt new technologies to improve the benefits of green procurement, such as intelligent production and renewable energy application.

Quality of environmentally friendly products and services:

Environmental requirements compliance assessment: Assess whether the products provided by suppliers meet environmental requirements, such as compliance with relevant environmental standards and certifications.

Product quality assessment: Assess the quality and sustainability of products offered by suppliers, including aspects such as performance, durability and renewability.

Social Responsibility Performance:

Employee Welfare Assessment: To assess the supplier's performance on employee welfare, such as remuneration packages, training and development, and working environment.

Labor rights and interests assessment: to assess the supplier's concern and protection of labor rights and interests, such as reasonable working hours, working conditions and welfare benefits.

Community Support Evaluation: Evaluating suppliers' performance in community support, such as social donations, public welfare activities and environmental protection.

At this point the AHP tree has been established, its structure is shown in **Figure 1**.

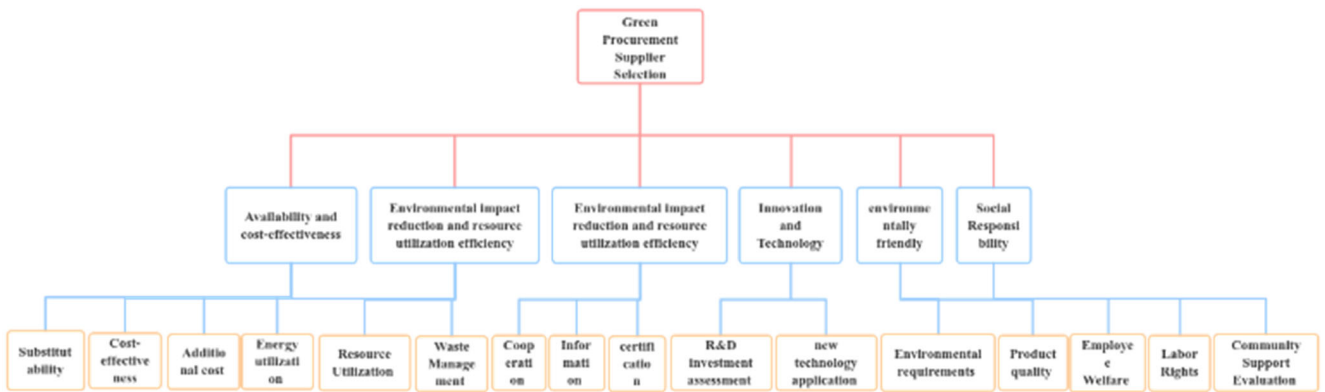


Figure 1. AHP Tree

Then I asked five virtual experts to compare the sub-level criteria two by two to construct the sub-criteria comparison matrix under the five top-level criteria. A total of 30 comparison matrices were received. Then, using the arithmetic average method to aggregate the comparison matrices of the five virtual experts under each top-level criterion, which is set to be the corresponding element in the evaluation matrix given by the n th expert under the i th top-level criterion, the formula for calculating the element in the evaluation matrix given under the i th top-level criterion in the final comparison matrix is as follows:

$$a_{ij} = \sqrt[5]{\sum_{n=1}^5 a_{ijn}} \quad (2)$$

The sub-criteria comparison matrices under the six top criteria are finally obtained. Next, they are checked for consistency and the eigenvalues and eigenvectors of the matrices are calculated using the `np.linalg.eig` function in python. Finally, we multiply each sub-factor weight by its top criterion weight to get the global sub-criteria weight. Let there are m sub-criteria under the i th main factor ($m=2,3$). Then the global weight of the j th sub-criterion under the i th main factor

is calculated as in equation below.

$$W_{ij} = W_i \frac{\sqrt[m]{\prod_{k=1}^m a_{ik}}}{\sum_{j=1}^m \sqrt[m]{\prod_{k=1}^m a_{ik}}} \quad (3)$$

The weights of the sixteen sub-factors shown in Table 1.

Table 1. sub-factors and their value

Category	Normalized Value
Alternatives	0.0688
Cost-effectiveness	0.0597
Additional costs	0.0584
Energy utilization	0.0621
Resource utilization	0.0663
Waste management	0.0646
Cooperation & coordination	0.0636
Information transparency	0.0636
Supply chain management	0.0623
Research & development investment	0.0629
Application of new technologies	0.0639
Environmental requirements	0.0636
Product quality	0.0645
Employee benefits	0.0631
Labor rights	0.0627
Community support	0.0615

A multi-objective planning model can be constructed based on the above indicators as parameters and weights as coefficients when making supplier selection, or you can choose indicators with larger weights for consideration.

3. Conclusion and Recommendations

At this juncture, we have procured a comprehensive set of sixteen green supplier selection indicators, which can be employed as a reference for MSMEs when selecting green suppliers. The bubble diagram is depicted in Figure 2.

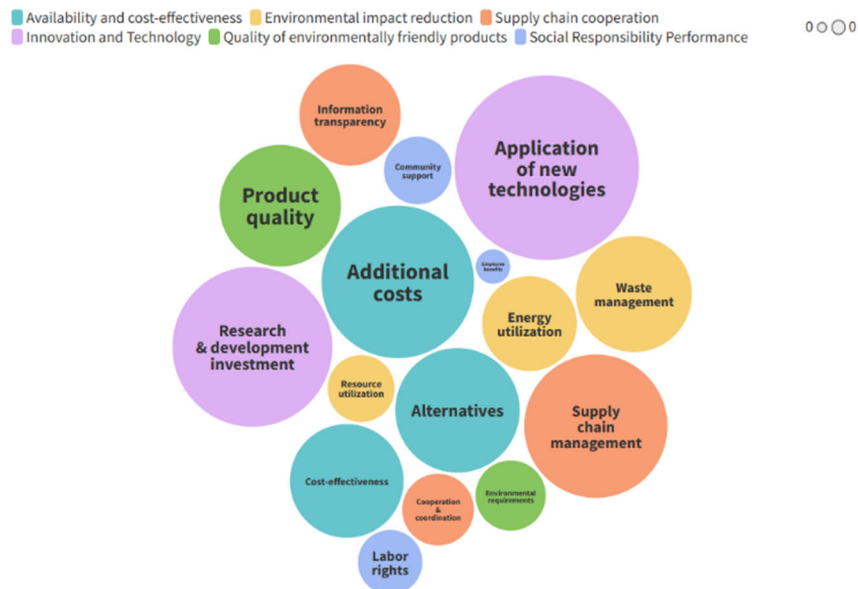


Figure 2. Sub-factors bubble chart

It can be observed that the assessment of the enterprise's scientific and technological innovation capacity and cost-effectiveness are considered to be of paramount importance. The cost-effectiveness reflects the profitability and investment efficiency, thereby ensuring that the green supplier assessment remains aligned with the primary objective of supplier assessment is to ascertain the supplier's

capacity for innovation and technological advancement. This core competence enables and empowers green production, thereby guaranteeing that the supplier can bring about the dual benefits of the enterprise in terms of both the environment and the economy. The second most important factor in conventional procurement is the ability of the supplier to produce green products. Secondly, it is the

economic aspects such as product or service availability and cost-effectiveness that are most concerned in conventional procurement, which also reflects the sustainable and technological innovation orientation of green procurement.

Concurrently, this paper presents a convenient and feasible solution for micro and small enterprises to select suppliers. All the steps in this paper are easy to reproduce and have the double guarantee of AHP guidance and consistency check. When implementing this paper, enterprises only need to supplement the objectives or current situation as needed, or feed more learning materials to the experts to obtain a more customized model of enterprise supplier selection strategy.

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