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Evaluation of vegetable green logistics in Lanling County of China based on DEMATEL-ANP-FCE model

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Introduction: Due to the problems of greenhouse gas emissions, noise pollution, and vegetable waste pollution during the transportation of vegetables, it is not conducive to the sustainable development of the environment. To mitigate the pollution of the environment during transportation, vegetable green logistics plays a pivotal role in promoting both environmental sustainability and high-quality economic development. Therefore, it is crucial to evaluate the development of vegetable green logistics.

Methods: This research builds a DEMATEL-ANP-FCE model to scientifically assess the development of vegetable green logistics in Lanling County. In the first place, the model uses DEMATEL to verify the relationship and degree of influence between the primary indexes. In the second place, the ANP approach with Super Decisions software to determine the weights of the indexes at each level. Lastly, evaluating and scoring vegetable green logistics in Lanling County based on FCE.

Results and discussion: The results of the study show that there is an interaction relationship between the primary evaluation indexes, and its evaluation score is low, the vegetable logistics in Lanling County has not reached the degree of greening. Accordingly, the evaluation results obtained by the DEMATEL-ANP-FCE model in this work are in line with the actual situation of vegetable green logistics in Lanling County, which verifies that the model has good applicability. Moreover, managerial contributions for promoting the development of vegetable green logistics in Lanling County are put forward in response to the evaluation situation. Expecting to enhance the greening level of vegetable logistical development and advance agricultural sustainability. Finally, all four questions raised in this paper are well addressed. This study also provides a new perspective and evaluation model for future related research.

KEYWORDS

Lanling County, vegetables, green logistics, DEMATEL-ANP-FCE model, evaluation

1 Introduction

From 2010 to 2024, China's No. 1 central document consistently emphasized the imperative of "cultivating sustainable agriculture and fortifying ecological and environmental preservation (CPC and SC, 2024)." In addition, climate change is a formidable challenge confronting humanity in the 21st century. To achieve the objective set forth in the Paris Agreement of

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limiting global temperature rise to 2°C or even 1.5°C (UNFCCC, 2015), countries worldwide have successively presented carbon-neutral targets. As the world's largest emitter of carbon dioxide, China's national leaders first proposed in 2020 at the United Nations General Assembly's 75th session their commitment to strive for a "carbon peak" by 2030 and "carbon neutrality" by 2060, with corresponding reductions in China's carbon emissions by those respective years. This endeavor holds immense significance for advancing substantive implementation of the Paris Climate Agreement globally and injects strong impetus into the global response to climate change (Zheng et al., 2023). China is firmly taking the path of ecological priority and green development and is an important contributor to the construction of a global ecological civilization. To achieve common prosperity for farmers, China is actively practicing the concept of grass-roots development, encouraging the green development of agriculture and accelerating the process of agricultural modernization (Huang and Xiong, 2022; Yu and Lin, 2022). Green environmental protection is becoming more and more crucial in China, where it is gradually influencing every aspect of agriculture. The development of the logistics industry plays an important role in the high-quality development of the economy. However, logistics in the transportation process also cause greenhouse gas emissions, noise pollution, packaging waste, and other environmental pollution problems. Therefore, green logistics is receiving more and more attention due to the growing concern for the environment (Agyabeng-Mensah et al., 2020). "Green logistics" first surfaced around 1980 (Byrne and Deeb, 1993). Green logistics is regarded to be one component of a green supply chain (Al-Shboul, 2022; Li et al., 2022). To minimize the negative ecological effects associated with the distribution of products, green logistics refers to supply chain management tactics and procedures that involve the production and shipping of products sustainably and environmentally, with an emphasis on the handling of materials, recycling, packaging, and shipping (Sbihi and Eglese, 2007; Seroka-Stolka and Ociepa-Kubicka, 2019; Van Vo and Nguyen, 2023). Green logistics attempts to reduce the environmental effect of logistics operations by reducing the use of energy and waste, increasing brand value, improving the efficiency of operations, and saving money by using less energy, the goal is to create coordinated and sustainable worldwide development in terms of economy, society, and the environment (Sbihi and Eglese, 2007; Dekker et al., 2012; Rodrigue, 2013; Seroka-Stolka and Ociepa-Kubicka, 2019). Government regulations, as well as levels of social, environmental, technological, and economic development, all have an impact on the use of green logistics (Zhang M. et al., 2020; Zhang W. et al., 2020; Tian et al., 2023). Furthermore, scholars have determined the weights and evaluated green logistics from many angles using DEA (Gan et al., 2022; Qin and Qi, 2022), AHP (Agrawal et al., 2023; Jeevan et al., 2023), ANP (Hernandez et al., 2016), DEMATEL (Bouzon et al., 2020; de Campos et al., 2021), and TOPSIS (Naseem et al., 2021; Fahad et al., 2022).

The growth of China's green agriculture is vital to the field of vegetable logistics, which is a subset of agricultural logistics. However, global climate change, especially global warming, has aroused widespread concern in the international community. Increasing concentrations of greenhouse gases such as carbon dioxide, nitrous oxide, and methane from human activities are the main cause of global warming (Liu et al., 2019). Climate change due to global warming will bring worsening extreme weather and catastrophic sea level rise, directly jeopardizing the survival of human beings and the sustainable development of society (Hansen and Sato, 2016). Freight transportation, as one of the major sources of greenhouse gas emissions, makes a significant contribution to the greenhouse effect, which also includes vegetable transportation (Chocholac et al., 2021). At the same time, after picking vegetables, due to the influence of the external environment, it is easy to rot and deteriorate (Yang and Chen, 2022), impacting on sustainable development. In addition, there are other pollutions in the logistics of vegetables that cause serious damage to the environment (Figure 1). Considering China's current state of green agricultural production and distribution, building a closed supply chain is a practical strategy for the country's green agricultural development (Yan and Zhang, 2008). The theories of green supply chains for agricultural products, the mathematical framework, and the organizational structure of the development of a green supply chain for agricultural products are proposed (Tan, 2012). Scholars have developed matching strategies to address concerns related to carbon emissions, e-commerce channels, the relative dispersion of urban multi-regional commercial centers, and the creation of agricultural products' green logistics (Li et al., 2014; Fu et al., 2022; Yao et al., 2022). The increasing affluence of society has led to a growing need for fresh, safe, low-carbon agricultural products. Consumer behavior when it comes to buying green products is greatly influenced by their drive, intellectual capacity, and consciousness, which all have a substantial impact on consumer behavior (Yener et al., 2023). Marketing strategies are investigated and suggested as a way to overcome the challenge of developing green agricultural products (Yang, 2020). Given the current state of fruit and vegetable waste, a significant incentive structure to encourage the adoption of standard turnover baskets in agricultural product logistics was developed (Zhang et al., 2021). An important part of developing green agricultural products is setting up a practical method for evaluating green logistics for agricultural goods. A unique index approach for selecting sustainable fresh agricultural product suppliers was suggested with a focus on sustainability (Du et al., 2020). Green procurement, green transportation, green warehousing, ecological issues, and internal and external factors should all be included in the selection of evaluation indexes for agricultural green logistics (Verrier et al., 2014; Rostamzadeh et al., 2015; Ni et al., 2019; Han, 2021). The fuzzy analytic hierarchy process is suggested to conduct a comprehensive evaluation of agricultural green logistics (Ni et al., 2019). Many academics have used the green logistics of agricultural products using IFAHP-TODIM (Du et al., 2020), AHP (Cao, 2019), and fuzzy comprehensive evaluation.

In conclusion, studies evaluating vegetable green logistics as a whole are rather rare, but as more national policies are introduced and the notion of green development is developed, the body of research on this topic is growing. When doing green logistics evaluation research on vegetables or agricultural products, there is a dearth of scholarship on the evaluation of vegetable green logistics research, most researchers mostly employ IFAHP-TODIM (Du et al., 2020), AHP (Cao, 2019), and fuzzy comprehensive evaluation methods. However, the evaluation indexes of vegetable green logistics have a relationship of mutual influence and connection, which makes it difficult for AHP to cope with this situation. Therefore, by building the DEMATEL-ANP-FCE model, this study

Abbreviations: DEMATEL, decision-making trial and evaluation laboratory; ANP, analytic network process; FCE, fuzz comprehensive evaluation.

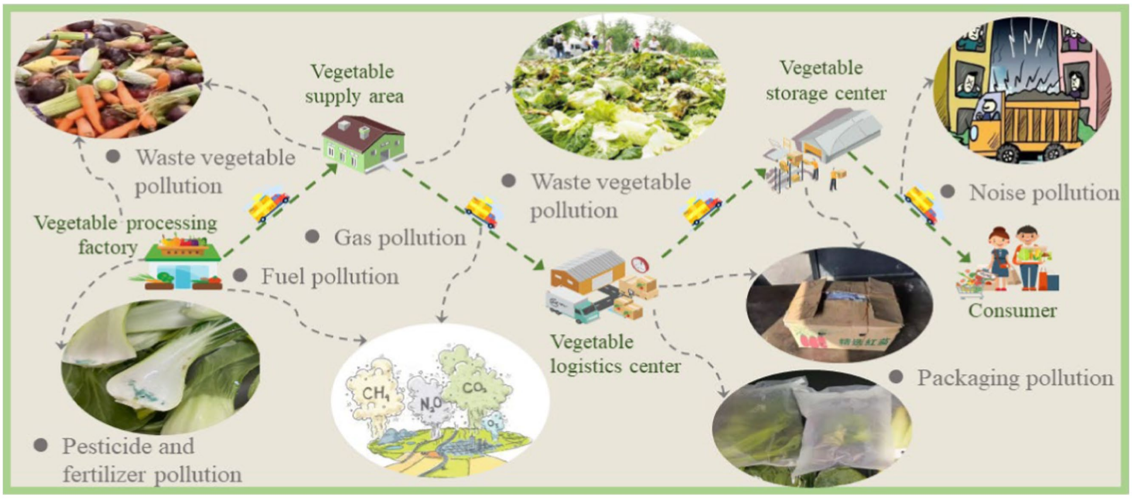

FIGURE 1
Pollution from vegetable logistics processes.

strives to address the aforementioned research gap. This study first uses DEMATEL to determine the relationship between the primary indexes, then the ANP approach with SD software to determine the weights of the indexes at each level, and finally a fuzzy comprehensive evaluation of vegetable green logistics in Lanling County based on FCE. Furthermore, managerial contributions are provided for the development of vegetable green logistics in Lanling County in light of the evaluation's findings. Based on this, this paper aims to address four key questions:

> Q1: How should the evaluation indexes be constructed?
>
> Q2: What is the relationship between the evaluation index?
>
> Q3: Is it feasible to utilize the DEMATEL-ANP-FCE model to evaluate Lanling County's vegetable green logistics?
>
> Q4: What managerial contributions are given to improve Lanling County's vegetable green logistics development?

The key contribution to this work is that it uses Lanling County as its study object and builds the DEMATEL-ANP-FCE model to address the issue of mutual dependency and mutual influence among the vegetable green logistics evaluation indexes. By collecting survey data from experts in logistics enterprises in Lanling County, utilizing the DEMATEL-ANP-FCE model to conduct an in-depth investigation and evaluation of vegetable green logistics in Lanling County, verifying the applicability of this evaluation model, and putting forward managerial contributions to advance the growth of vegetable green logistics in Lanling County, Figure 2 depicts the structure of this study (E_n indicates secondary index).

The following is how this paper is structured: In Section 2, the study area, evaluation indexes, and methods are introduced; in Section 3, the empirical results are presented and the evaluation scores are ranked and discussed; and in Section 4, the conclusions, managerial contributions, and prospects are provided.

2 Materials and methods

2.1 The study area

Lanling County, belonging to Linyi City, Shandong Province, China, is located on the east–west corridor of the southern Shandong Economic Belt, receiving the double radiation of the canal economic zone and harbor economic zone, and the transportation is convenient. Lanling belongs to the continental climate of the monsoon region in the warm zone, and its climate is characterized by mild and humid, with four distinct seasons, which is very suitable for vegetable growth. Vegetables, as the most beautiful name card of Lanling County, have a vegetable planting area of 1.12 million mu and a total output of 4.1 million tons, mainly planting garlic, burdock, chili, and other agricultural products, making it a major county in the production of agricultural products in the country (Sui, 2020). Lanling is known as "the hometown of Chinese vegetables," "the hometown of Chinese garlic," "the hometown of Chinese burdock" and "Shandong South Garden" (Figure 3). Lanling County is backed by China's "logistics capital" Linyi, relying on a strong vegetable industry foundation, is an important vegetable production, dredging, and distribution center in China. Lanling County is making every effort to lengthen the vegetable industry chain in planting, purchasing, processing, packaging, transportation, and other links to promote the high-quality development of the vegetable industry. Therefore, this paper chooses Lanling County as the empirical research area and adopts DEMATEL-ANP-FCE model to evaluate and study the development of vegetable green logistics in Lanling County.

2.2 The evaluation index system of Lanling County vegetable green logistics

To scientifically, reasonably, and accurately assess the degree of growth of Lanling County vegetable green logistics, when

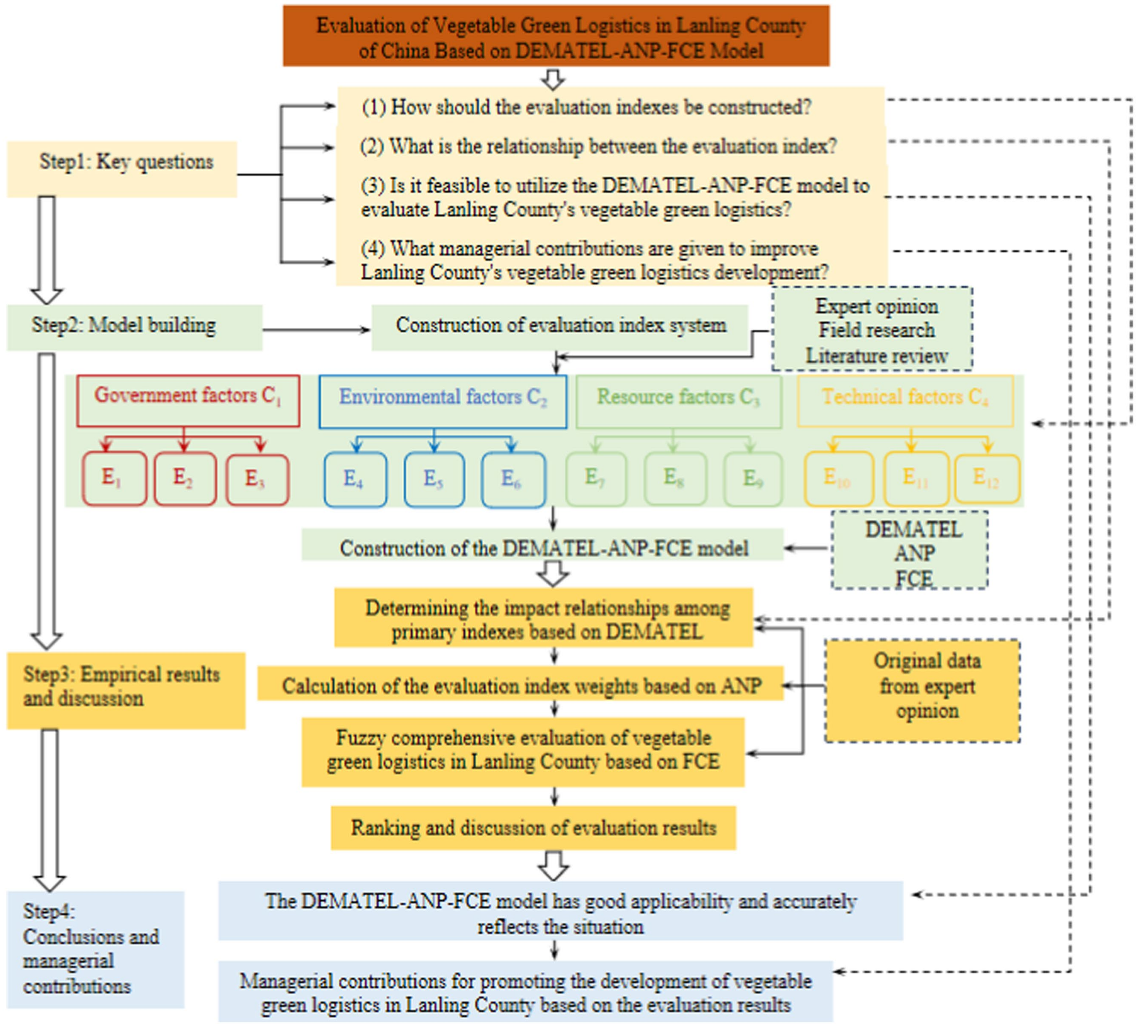

FIGURE 2
The structure of this study.

establishing the relevant index system, this study follows the principles of science, feasibility, systematicity, and practicability. This study developed an evaluation index system by examining the current state of vegetable green logistics development in Lanling County, and the findings of previous research by distinguished academics in this area (Verrier et al., 2014; Rostamzadeh et al., 2015; Cao, 2019; Ni et al., 2019; Han, 2021). In addition, this study designed a satisfaction questionnaire for the evaluation index system of vegetable green logistics in Lanling County, and invited 8 experts engaged in the research of green logistics of agricultural products, 5 staff members of the vegetable development center of Lanling County, 4 managers of vegetable logistic enterprises in Lanling County, and 3 heads of the vegetable trading market in Lanling County to score their satisfaction. A total of 20 valid questionnaires were recovered. In the recovered data, the degree of "satisfaction" with the evaluation index system is 95%, which further verifies the rationality of the evaluation index system of vegetable green logistics in Lanling County. Therefore, the question of how should the evaluation indexes be constructed for Q1 is well addressed. The evaluation indexes of Lanling County vegetable green logistics are separated into three layers, as shown in Table 1.

2.3 Model building

2.3.1 DEMATEL (decision-making trial and evaluation laboratory)

DEMATEL is mainly employed to analyze and address increasingly complex system issues by establishing a structural model with a causal relationship between indexes (Gabus and Fontela, 1972). The DEMATEL is used in this work to ascertain the nature and extent of interactions among the main evaluation indexes. The following are the precise calculation steps:

Step 1: determining the direct relationship matrix.

Establishing the direct impact relationship between the primary indexes, building the vegetable green logistics evaluation index system in Lanling County, and creating the direct relationship matrix A, where 0–4 denotes impact none, impact little, impact medium, impact high, and impact extremely high, respectively.

Step 2: calculating the direct impact matrix.

Normalizing A yields the direct impact matrix B:

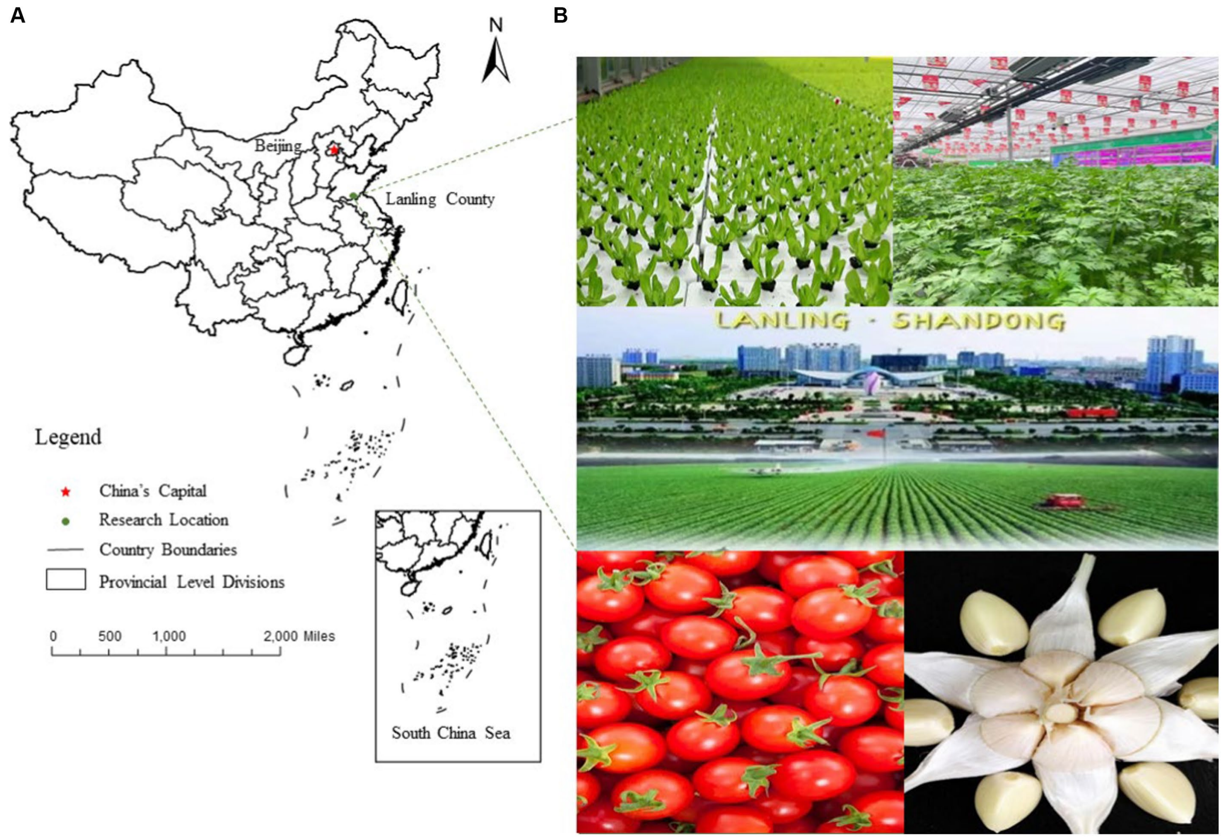

FIGURE 3
(A) The location and **(B)** the layout of Lanling County, Linyi City, Shandong Province, China.

TABLE 1 Lanling vegetable green logistics evaluation index system.

Goal layer	Primary evaluation indexes	Secondary evaluation indexes
		Number of green logistics policies E_1
	Government factors C_1	Green logistics publicity training E_2
		Green logistics financial expenditures E_3
Lanling County		Vegetable waste emissions E_4
vegetable green logistics	Environmental factors C_2	Vegetable waste recycling rate E_5
evaluation index system		Noise pollution E_6
U		Situation of transportation facilities E_7
	Resource factors C_3	Cargo loss and consumption rate E_8
		Number of logistics professionals E_9
		Level of logistics information technology E_{10}
	Technical factors C_4	Level of logistics equipment E_{11}
		Degree of logistics standardization E_{12}

$$B = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} A \qquad (1)$$

Step 3: calculating the comprehensive impact matrix T.

A comprehensive impact matrix T is calculated based on the matrix B:

$$T = \left[t_{ij}\right]_{n\times n} = \lim_{k \to +\infty}\left(B^1 + B^2 + B^3 + \cdots + B^k\right) = B\left(I - B\right)^{-1} \qquad (2)$$

Step 4: calculating the centrality D and the causality C:

$$D = \sum_{j=1}^{n} t_{ij} \qquad (3)$$

$$C = \sum_{i=1}^{n} t_{ij} \tag{4}$$

The causality degree is D-C, its value is greater than 0, it is the cause of the elements, the greater the impact on other factors, and vice versa, for the results of the elements. The centrality degree is D + C, the larger its value, the higher the correlation with other factors (Che et al., 2020).

2.3.2 ANP (analytic network process)

The ANP, which originated with the AHP, is a decision-making technique for non-independent recursive hierarchies. Complex internal reliance and external feedback connections can be resolved in decision-making situations by applying the ANP to determine each influencing factor's proportional value. A super matrix is created based on the relationships between the indexes. In line with this, the index weights are calculated (Saaty, 2004). The steps are as follows:

Step 1: constructing the judgment matrix.

According to the causality diagram derived from the DEMATEL, the network structure of the indexes was created in the SD software. In the ANP network structure diagram, take the goal as the criterion layer, the influence degree between the indexes in the network layer is compared, and the judgment matrix W_{ij} is constructed:

$$W_{ij} = \begin{bmatrix} w_{i1}^{(j1)} & w_{i1}^{(j2)} \cdots & w_{i1}^{(jn_j)} \\ w_{i2}^{(j1)} & w_{i2}^{(j2)} \cdots & w_{i2}^{(jn_j)} \\ \vdots & \vdots \quad \cdots & \vdots \\ w_{in_i}^{(j1)} & w_{in_i}^{(j2)} \cdots & w_{in_i}^{(jn_j)} \end{bmatrix} \tag{5}$$

Step 2: constructing the weighting matrix A whose elements a_{ij} are the weights.

Step 3: constructing the weighted super matrix $\bar{W}$.

The ranking vectors of the interactions between the indexes are combined to form the super matrix W. The columns of W are then normalized to get the weighted super matrix $\bar{W}$:

$$\bar{W} = a_{ij} W_{ij} \tag{6}$$

Step 4: constructing the limit super matrices $\lim_{k\to\infty} W^k$.

The limit super matrix W^∞ is obtained when $W^\infty = \lim_{k\to\infty} \bar{W}^k$ exists:

$$W^\infty = \lim_{k\to\infty} \left(\frac{1}{n}\right) \sum_{k=1}^{N} \bar{W}^k \tag{7}$$

2.3.3 FCE (fuzzy comprehensive evaluation)

FCE is to thoroughly evaluate qualitative indexes that are challenging to quantify by using fuzzy mathematical methods. When evaluating multi-objective issues with substantial uncertainty, the FCE provides computation results that are clearer, methodical, and scientific. The following illustrates the particular operating process.

Step 1: identifying index sets.

The evaluation metrics were stratified with the first level objective set: U= {C_1, C_2, C_3, C_4}, and the second level sub-objective set: C_1 = {E_1, E_2, E_3}, C_2 = {E_4, E_5, E_6,}, C_3 = {E_7, E_8, E_9}, C_4 = {E_{10}, E_{11}, E_{12}}.

Step 2: identifying the FCE set.

Determine the comprehensive evaluation target set {V_1, V_2, V_3, V_4, V_5}, containing 5 levels: V_1, V_2, V_3, V_4, V_5, with the evaluation criteria {Good, Better, General, Poor, Bad}, which can also be expressed numerically as V= {0.9, 0.7, 0.5, 0.3, 0.1}.

Step 3: first level of fuzzy integrated evaluation.

The affiliation matrix of the affiliation vector $r_i = (r_{i1}, r_{i2}, \cdots r_m)$ is R_n :

$$R_n = \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nm} \end{bmatrix} \tag{8}$$

$r_{ij} = \frac{l_{ij}}{l}$ where l is the number of experts, l_{ij} is the number of evaluators, and the sub-objective is Q_i:

$$Q_i = W_i \cdot R_n = [W_{i1}, W_{i2}, \cdots W_{im}] \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nm} \end{bmatrix} \tag{9}$$

Step 4: second level of fuzzy integrated evaluation.

Substituting the sub-objectives into the evaluation objective set yields Q:

$$Q = W \cdot R = [W_{i1}, W_{i2}, \cdots W_{im}] \begin{bmatrix} q_{11} & \cdots & q_{1m} \\ \vdots & \ddots & \vdots \\ q_{n1} & \cdots & q_{nm} \end{bmatrix} \tag{10}$$

Step 5: results of the analysis.

The final evaluation result is calculated as G:

$$G = Q \cdot V^T \tag{11}$$

The suggested methods are illustrated in Figure 4 (E_n indicates secondary index). As can be seen, these methods must be used at every point of the three-stage framework.

3 Empirical results and discussion

3.1 Data sources

The original data of this paper comes from the questionnaire. The questionnaire consists of three parts, one is the questionnaire on the influence relationship among the primary indexes, the second is the questionnaire on the importance of each index, and the third is the

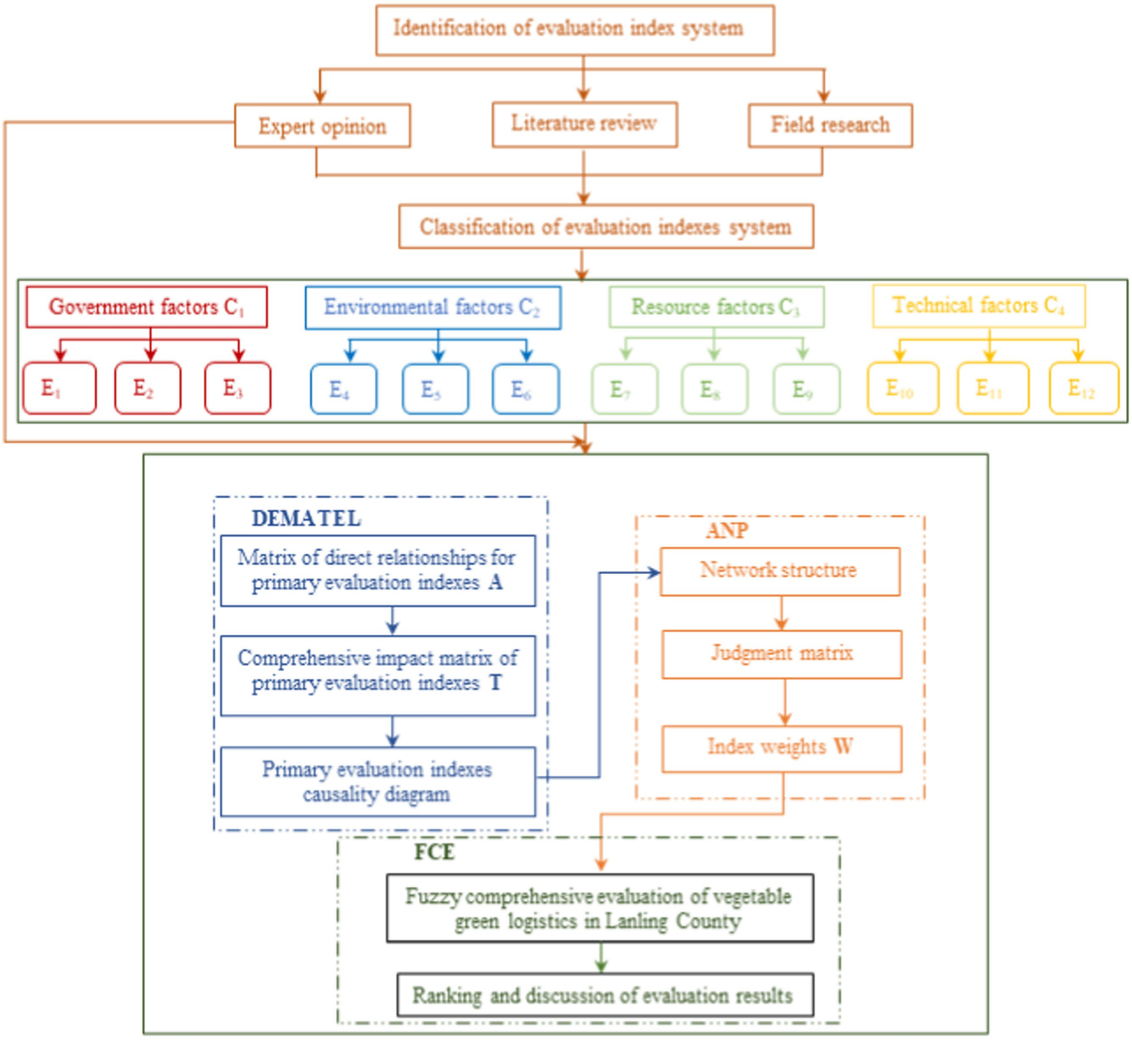

FIGURE 4
The model of DEMATEL-ANP-FCE.

comprehensive evaluation of each index. The survey is divided into three periods, inviting 8 experts engaged in the research of green logistics of agricultural products, 5 staff members of the vegetable development center of Lanling County, 4 managers of vegetable logistic enterprises in Lanling County, and 3 heads of the vegetable trading market to fill in the questionnaires, and 20 valid questionnaires were returned. Based on the recovered questionnaires and with strict reference to the scoring guidelines, this study adopts DEMATEL-ANP-FCE to comprehensively evaluate the green logistics of vegetables in Lanling County after processing the recovered data.

3.2 Determining the impact relationships among primary indexes based on DEMATEL

The first period of data collection in this study was 20 experts using a five-level scale {0, 1, 2, 3, 4} to score the degree of influence of the primary indexes of vegetables green logistics in Lanling County, and the recovered data were processed to derive the direct relationship matrix A (Eq. 12):

TABLE 2 Comprehensive impact matrix of primary evaluation indexes T.

Indexes	C_1	C_2	C_3	C_4
C_1	0.339	0.364	0.719	0.861
C_2	0.691	0.354	0.942	0.965
C_3	0.497	0.420	0.470	0.766
C_4	0.302	0.256	0.460	0.336

$$A = \begin{bmatrix} 0 & 1 & 3 & 4 \\ 3 & 0 & 4 & 3 \\ 2 & 2 & 0 & 3 \\ 1 & 1 & 2 & 0 \end{bmatrix} \tag{12}$$

The matrix A was normalized by DEMATEL to obtain the direct impact matrix B (Eq. 1), this study obtained the comprehensive impact matrix T (Eq. 2) of the primary evaluation indexes, which is shown in Table 2, the centrality degree (Eq. 3) and causality degree (Eq. 4) as shown in Table 3, and the primary evaluation indexes causality diagram as shown in Figure 5. As can be seen from Figure 5, the D-C value of

TABLE 3 Centrality degree and causality degree of primary evaluation indexes.

Indexes	Centrality (D + C)	Causality (D-C)
C_1	4.112	0.454
C_2	4.347	1.558
C_3	4.745	−0.439
C_4	4.282	−1.573

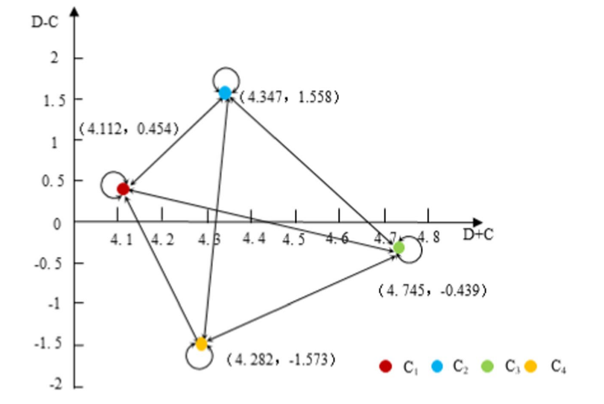

FIGURE 5
Primary evaluation indexes causality diagram.

the C_1 and C_2 indexes is greater than 0, which is the causality index, and the D-C value of the C_3 and C_4 indexes is less than 0, which is the result index. This shows that the index capacity of C_1 and C_2 will affect the capacity of C_3 and C_4 indexes, C_1 and C_2 indexes are the most fundamental capacity indexes of Lanling County vegetable green logistics, and C_3 and C_4 are the most direct capacity indexes of vegetable green logistics in Lanling County. The size of the value of the centrality degree D + C shows the size of its role in the green logistics of vegetables in Lanling County, according to which, the status and role of the four primary evaluation indexes in the green logistics of vegetables in Lanling County in this paper are ordered from big to small as C_3, C_2, C_4, C_1. Thus, it is evident from Figure 5 that the four primary evaluation indexes in this paper have an interaction relationship with each other, which is a good answer to Q2's question about the relationship between the evaluation indexes, and provides a prerequisite for the next step of constructing the ANP network structure model in SD software.

3.3 Calculating evaluation index weights based on ANP

Based on the causality diagram of the primary evaluation indexes of vegetable logistics in Lanling County by DEMATEL, with the use of SD software, the ANP is utilized to calculate the weight values of each index of vegetable green logistics in Lanling County. First of all, the ANP network structure should be constructed, and from Table 3 combined with Figure 5, the ANP network structure and ANP model of the evaluation index system of vegetable green logistics in Lanling County are drawn in SD software, as shown in Figure 6 (E_n indicates secondary index) and Figure 7.

The second period of data collection in this research was to design the questionnaire of the importance of each index based on the establishment of the primary evaluation indexes' relationship and invited 20 experts to score each index on a scale of 1 to 9. After organizing the scoring of experts, the judgment matrix W_{ij} (Eq. 5) was constructed. Pairwise comparisons were conducted to generate distinct comparison matrices. The judgment matrix of primary evaluation indexes is shown in Table 4, and the weights from largest to smallest, are as follows: environmental factors C_2 > governmental factors C_1 > resource factors C_3 > technical factors C_4. Among them, the development of vegetable green logistics in Lanling County is mostly influenced by environmental and governmental variables, which rank highest in importance. This consistency test yielded a score of 0.0713 < 0.1, meeting the requirements. Additionally, all of the secondary indexes' judgment matrix consistency tests that were entered into the SD software passed. The weighted super matrix $\overline{W}$ (Eq. 6) and limit matrix W^{∞} (Eq. 7) that were produced are displayed in Tables 5, 6, respectively, the results of the weights of each secondary evaluation index were obtained as shown in Table 7. The index items account for a larger weight, but at the same time, it should not ignore the index items with a smaller weight, and it is necessary to make the coordinated development of all the indexes to make the logistics of vegetables in Lanling County move steadily in the direction of greening.

3.4 Fuzzy comprehensive evaluation of vegetable green logistics in Lanling County based on FCE

The third period of data collection was to set the quantitative evaluation on the green logistics evaluation model for vegetables in Lanling County as V = {good, better, fair, poor, bad} = {0.9, 0.7, 0.5, 0.3, 0.1}, and invite 20 experts to score it. The raw data scored by experts were calculated and processed to obtain the evaluation results of the membership degree of vegetable green logistics evaluation index in Lanling County as shown in Table 8. The affiliation matrix of vegetable green logistics evaluation indexes in Lanling County is as follows (Eq. 8):

$$R_1 = \begin{bmatrix} 0.05 & 0.05 & 0.35 & 0.4 & 0.15 \\ 0.05 & 0.05 & 0.4 & 0.3 & 0.2 \\ 0.1 & 0.15 & 0.35 & 0.25 & 0.15 \end{bmatrix} \quad (13)$$

According to Eqs. 9, 13 the vector of the first level of fuzzy integrated evaluation is calculated as follows:

$$Q_1 = W_1 \cdot R_1 = (0.0205\ 0.0258\ 0.1139\ 0.0917\ 0.0529)$$

Similarly, the other matrices can be obtained as:

$$Q_2 = W_2 \cdot R_2 = (0.0378\ 0.0550\ 0.1463\ 0.1245\ 0.0812)$$

$$Q_3 = W_3 \cdot R_3 = (0.0162\ 0.0230\ 0.0491\ 0.0664\ 0.0432)$$

$$Q_4 = W_4 \cdot R_4 = (0.0017\ 0.0085\ 0.0113\ 0.0143\ 0.0137)$$

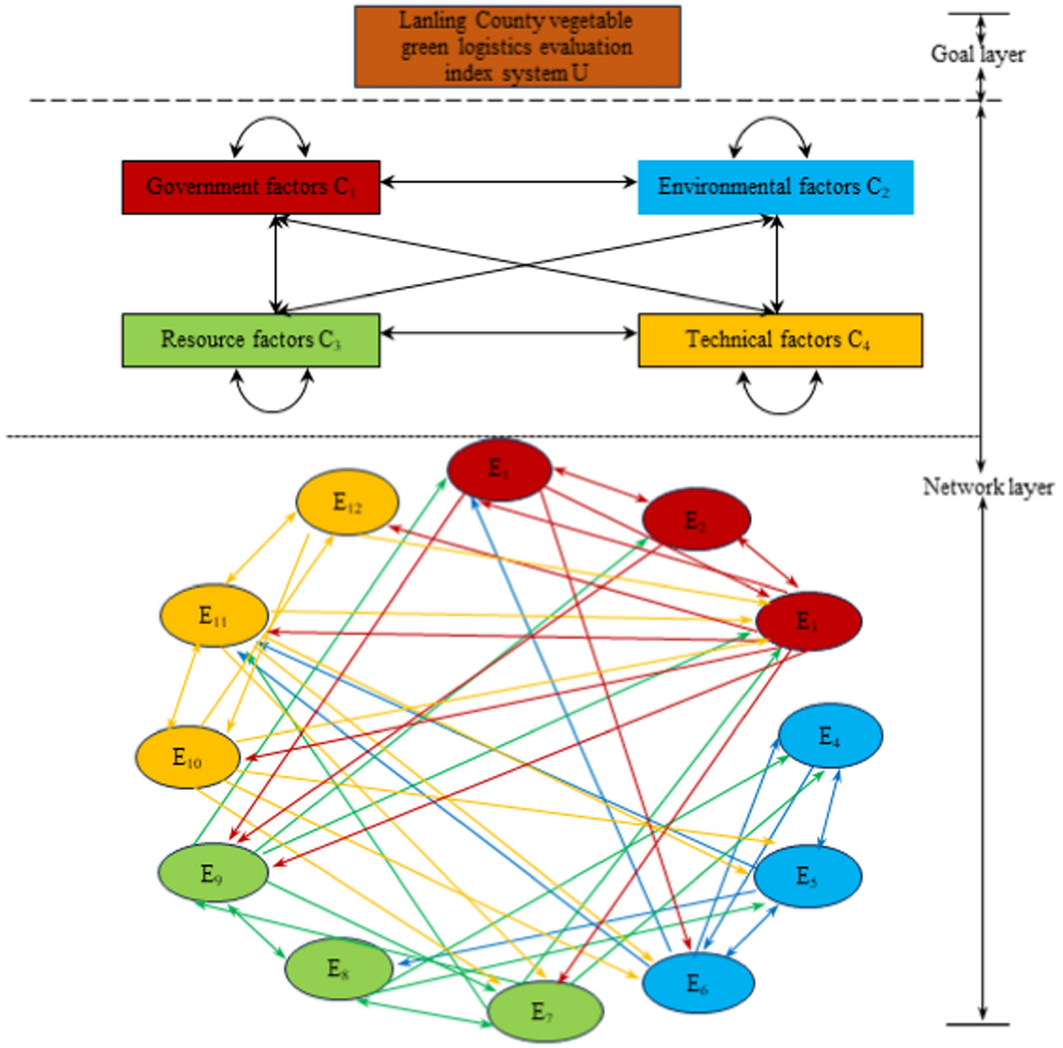

FIGURE 6
ANP network structure diagram.

From the calculated primary evaluation indexes vector matrix, the second level evaluation vector of vegetable green logistics in Lanling County can be calculated according to Eq. 10:

$$Q = \left(0.0270\ 0.0385\ 0.1140\ 0.0989\ 0.0627\right)$$

According to Eq. 11, the evaluation results are converted into scores, and the final evaluation composite score is:

$$G_1 = Q_1 \cdot V^T = 0.1262$$

$$G_2 = Q_2 \cdot V^T = 0.1912$$

$$G_3 = Q_3 \cdot V^T = 0.0794$$

$$G_4 = Q_4 \cdot V^T = 0.0188$$

$$G = Q \cdot V^T = 0.1442$$

Summarizing the above calculation results, the evaluation results are shown in Tables 9, 10.

3.5 Discussion

First of all, discussing the evaluation score of green logistics of vegetables in Lanling County as a whole, based on the principle of maximum affiliation, Table 9 shows that the maximum affiliation values of government and environmental factors are 0.1139 and 0.1463 respectively, and the evaluation values are "General," and the maximum affiliation values of resource and

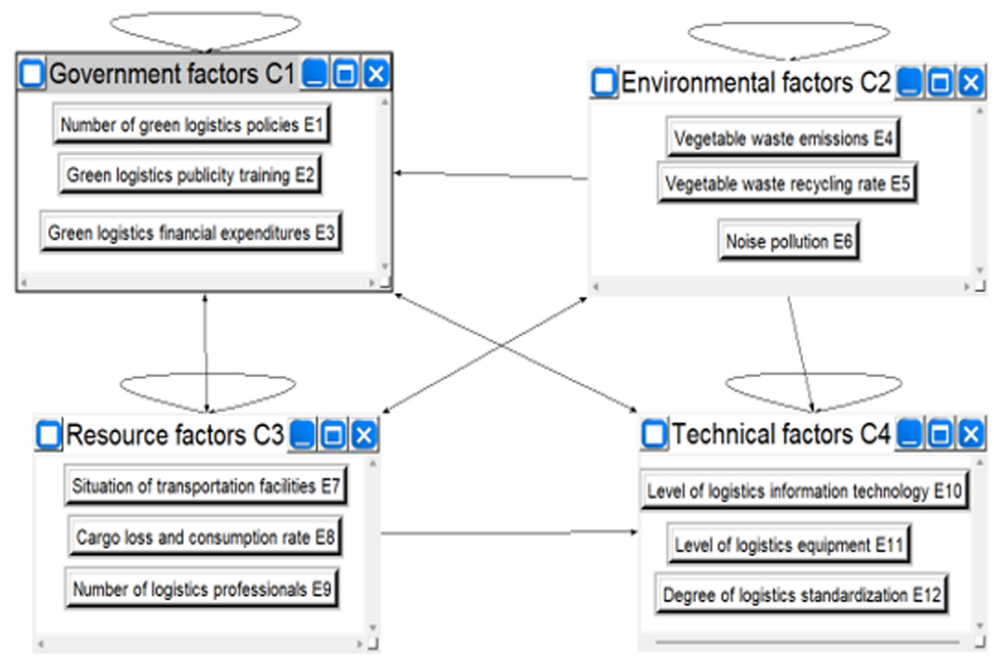

FIGURE 7
ANP model.

TABLE 4 Judgment matrix of primary evaluation indexes.

Indexes	C_1	C_2	C_3	C_4	Weights
C_1	1	1/2	3	5	0.3106
C_2	2	1	5	4	0.4880
C_3	1/3	1/5	1	3	0.1301
C_4	1/5	1/4	1/3	1	0.0713
		CR = 0.0713			

technical factors are 0.0664 and 0.0143, and the evaluation set is "Poor". Table 10 indicates that the overall evaluation of vegetable green logistics in Lanling County has a maximum affiliation value of 0.1140, and the comment value is "General". Table 9 indicates that the government factors, environmental factors, resource factors, and technical factors ratings are 0.1262, 0.1912, 0.0794, and 0.0188, respectively, of which the environment factors have the highest score, followed by the governmental factors, and the resource factors and technical factors are the lowest in turn. Table 10 illustrates that Lanling County's overall evaluation score for vegetable green logistics is 0.1442 points, indicating a low overall score for Lanling County.

Furthermore, the specific discussion is shown below:

The environmental factor has the highest composite score (0.1912 points). Compared to the other three factors, the environmental factor received a considerably higher score. It can be seen from this that Lanling County's vegetable retailers, wholesalers, logistics and transportation companies, and farmers have all recognized the need to protect the environment when it comes to minimizing waste production, increasing recycling of vegetable waste, and lowering noise pollution during the vegetable logistics and transportation process. However, the environmental protection effect of vegetable logistics in Lanling has not yet reached the best, and more steps should be taken to protect the environment to encourage the growth of vegetable green logistics in Lanling County.

The government factor has the second-highest overall score (0.1262 points). Although the government of Lanling County is steadily increasing its support for vegetable green logistics, there are some issues with this process. In Lanling County, the government is a major factor in promoting the growth of vegetable green logistics. Firstly, while Lanling County actively supports the vegetable logistics and transportation sector, there aren't enough rules and legislation about vegetable green logistics. In addition, there are still issues that need to be resolved about Lanling County government policy orientation about law enforcement initiatives, policy publicity, and funding investments for vegetable green logistics. To effectively develop vegetable green logistics in Lanling County, government departments must increase their focus on vegetable green logistics, create laws and regulations about vegetable green logistics, and enhance their public relations and training efforts regarding green logistics policy.

The resource factor ranks third (0.0794 points). The score of resource factors is relatively low. When it comes to transportation infrastructure, the routes taken for Lanling vegetables' logistics have not been optimized, and their circulation time during transit has been extended. In addition, the majority of Lanling County's vegetable transportation is done through railroads and highways, meaning that fewer vehicles are refrigerated, increasing the rate of vegetable loss and wasting resources. Promoting the growth of vegetable green logistics in Lanling County involves lowering the loss rate of produce. Furthermore, the cultural background of the vegetable logistics workforce in Lanling County is generally low, manual labor still makes

TABLE 5 Weighted super matrix $\overline{W}$.

Indexes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
E_1	0.0392	0.0826	0.0711	0.0000	0.0000	0.3570	0.0000	0.0000	0.0826	0.0000	0.0000	0.0000
E_2	0.2055	0.4330	0.3727	0.0000	0.0000	0.0000	0.0000	0.0000	0.4330	0.0000	0.0000	0.0000
E_3	0.0898	0.1891	0.1628	0.0000	0.0000	0.0000	0.3106	0.0000	0.1891	0.8133	0.3106	0.8133
E_4	0.2627	0.0000	0.0000	0.2753	0.2469	0.1956	0.4880	0.0000	0.0000	0.0000	0.0000	0.0000
E_5	0.0000	0.0000	0.0000	0.3818	0.3423	0.2713	0.0000	0.7895	0.0000	0.0000	0.2440	0.0000
E_6	0.2627	0.0000	0.0000	0.1324	0.1187	0.0941	0.0000	0.0000	0.0000	0.0000	0.2440	0.0000
E_7	0.0000	0.0000	0.1271	0.2105	0.0000	0.0000	0.0354	0.0572	0.0984	0.0000	0.1301	0.0000
E_8	0.0000	0.0000	0.0000	0.0000	0.1887	0.0000	0.0860	0.1392	0.0984	0.0000	0.0000	0.0000
E_9	0.1401	0.2952	0.1271	0.0000	0.0000	0.0000	0.0087	0.0141	0.0984	0.0000	0.0000	0.0000
E_{10}	0.0000	0.0000	0.0464	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0505	0.0193	0.0505
E_{11}	0.0000	0.0000	0.0464	0.0000	0.1034	0.0820	0.0713	0.0000	0.0000	0.1203	0.0459	0.1203
E_{12}	0.0000	0.0000	0.0464	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0159	0.0061	0.0159

TABLE 6 Limit matrix W^{∞}.

Indexes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
E_1	0.0552	0.0552	0.0552	0.0552	0.0552	0.0552	0.0552	0.0552	0.0552	0.0552	0.0552	0.0552
E_2	0.1444	0.1444	0.1444	0.1444	0.1444	0.1444	0.1444	0.1444	0.1444	0.1444	0.1444	0.1444
E_3	0.1052	0.1052	0.1052	0.1052	0.1052	0.1052	0.1052	0.1052	0.1052	0.1052	0.1052	0.1052
E_4	0.1563	0.1563	0.1563	0.1563	0.1563	0.1563	0.1563	0.1563	0.1563	0.1563	0.1563	0.1563
E_5	0.2111	0.2111	0.2111	0.2111	0.2111	0.2111	0.2111	0.2111	0.2111	0.2111	0.2111	0.2111
E_6	0.0775	0.0775	0.0775	0.0775	0.0775	0.0775	0.0775	0.0775	0.0775	0.0775	0.0775	0.0775
E_7	0.0645	0.0645	0.0645	0.0645	0.0645	0.0645	0.0645	0.0645	0.0645	0.0645	0.0645	0.0645
E_8	0.0610	0.0610	0.0610	0.0610	0.0610	0.0610	0.0610	0.0610	0.0610	0.0610	0.0610	0.0610
E_9	0.0723	0.0723	0.0723	0.0723	0.0723	0.0723	0.0723	0.0723	0.0723	0.0723	0.0723	0.0723
E_{10}	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063	0.0063
E_{11}	0.0409	0.0409	0.0409	0.0409	0.0409	0.0409	0.0409	0.0409	0.0409	0.0409	0.0409	0.0409
E_{12}	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053

up the majority of jobs in the vegetable logistics sector, and there aren't many highly skilled individuals working in green logistics.

The technical factor is the lowest (0.0188 points). The thorough evaluation score makes clear that there are discrepancies between the green objectives and the technical features of vegetable green logistics in Lanling County. First and foremost, Lanling County's vegetable logistics equipment is facing a major issue that requires immediate attention: excessive aging or delayed updating. Furthermore, given the current state of the Internet, which has taken on a dominant role, many vegetable companies have adopted the online trading strategy. This network trading method has significantly optimized the vegetable trading process. However, there are still several obstacles that face vegetable farmers in Lanling County when using bar code technology for vegetable trading, and information technology is still not fully integrated into the entire industrial chain of vegetable logistics in Lanling.

As can be seen from the use of the DEMATEL-ANP-FCE model to obtain the evaluation score, Lanling County's vegetable green logistics evaluation score is on the low side. Indicating that Lanling County has not been able to meet the greening standards in its growth of green vegetable logistics, which is highly detrimental to the county's development as a transportation and vegetable logistics hub. Consequently, the evaluation score of the DEMATEL-ANP-FCE model is consistent with the actual situation of vegetable green logistics in Lanling County. The DEMATEL-ANP-FCE model is well applied, which solves the Q3 proposed in this paper.

In summary, although scholars have already evaluated the green logistics of agricultural products using IFAHP-TODIM, AHP, and fuzzy comprehensive evaluation (Cao, 2019; Du et al., 2020), few scholars have focused on the evaluation of the green logistics of vegetables in a certain region, in addition to the fact that the evaluation indexes of the vegetables green logistics have complex relationships with each other, making it difficult for the AHP to solve this complex challenge. Therefore, this research adopts a new perspective to fill this gap. To begin with, this research selects Lanling County, the "hometown of vegetables" in China, as the research object, which is extremely representative. Moreover, to solve the complex relationship between the evaluation indexes of vegetable green logistics, this study adopts the new DEMATEL-ANP-FCE model, which has not been used by existing studies in evaluating the green logistics of agricultural products. Finally, this study provides a comprehensive and targeted discussion of the evaluation scores of vegetable green logistics in Lanling County, which further confirms that the DEMATEL-ANP-FCE model has a good application in evaluating vegetable green logistics.

TABLE 7 Secondary weight results of evaluation index system.

Secondary indexes	Dependency feedback relationships between indexes	Weights W_i
E_1	E_2, E_3, E_4, E_6, E_9	0.0552
E_2	E_1, E_3, E_9	0.1444
E_3	E_1, E_2, E_7, E_9, E_{10}, E_{11}, E_{12}	0.1052
E_4	E_1, E_5, E_6, E_7	0.1563
E_5	E_4, E_6, E_8, E_{11}	0.2111
E_6	E_1, E_4, E_5, E_{11}	0.0775
E_7	E_3, E_4, E_8, E_9, E_{11}	0.0645
E_8	E_5, E_7, E_9	0.0610
E_9	E_1, E_2, E_3, E_7, E_8	0.0723
E_{10}	E_3, E_{11}, E_{12}	0.0063
E_{11}	E_3, E_5, E_6, E_7, E_{10}, E_{12}	0.0409
E_{12}	E_3, E_{10}, E_{11}	0.0053

4 Conclusions, managerial contributions, and prospects

4.1 Conclusion

According to the results of the study, this article has shown to be a good answer to the four questions mentioned in this paper. The specific solutions are shown below:

First and foremost, this research builds a more sensible and comprehensive vegetable green logistics evaluation index system from four perspectives: government, environmental, resources, and technical through field investigation, special interviews, distribution of questionnaires, and drawing on the research results of outstanding scholars. Thus, future researchers can refer to this evaluation index system when choosing evaluation indexes for vegetable green logistics.

Furthermore, to ascertain whether each primary evaluation index is related to the others, this paper adopts the DEMATEL method to determine that the four primary indexes are interconnected and influenced by each other. This fully compensates for the lack of correlation between the evaluation indicators of green logistics of agricultural products in the previous studies.

Besides, Using the DEMATEL-ANP-FCE model to evaluate the vegetable green logistics in Lanling County based on the interconnections of the primary evaluation indexes. The results indicate that Lanling County's vegetable green logistics evaluation

TABLE 8 Membership degree of vegetable green logistics evaluation index in Lanling County.

Primary indexes	Secondary indexes	Good	Better	General	Poor	Bad
Government factors C_1	Number of green logistics policies E_1	0.05	0.05	0.35	0.4	0.15
	Green logistics publicity training E_2	0.05	0.05	0.4	0.3	0.2
	Green logistics financial expenditures E_3	0.1	0.15	0. 35	0.25	0.15
Environmental factors C_2	Vegetable waste emissions E_4	0.1	0.1	0.4	0.2	0.2
	Vegetable waste recycling rate E_5	0.05	0.15	0.25	0.35	0.2
	Noise pollution E_6	0.15	0.1	0.4	0.25	0.1
Resource factors C_3	Situation of transportation facilities E_7	0.1	0.15	0.3	0.25	0.2
	Cargo loss and consumption rate E_8	0.1	0.1	0.25	0.35	0.2
	Number of logistics professionals E_9	0.05	0.1	0.2	0.4	0.25
Technical factors C_4	Level of logistics information technology E_{10}	0.05	0.2	0.25	0.35	0.15
	Level of logistics equipment E_{11}	0.1	0.15	0.2	0.25	0.3
	Degree of logistics standardization E_{12}	0.05	0.2	0.3	0.35	0.1

TABLE 9 First level membership and evaluation scores.

Indexes	Good	Better	General	Poor	Bad	Overall rating
Government factors C_1	0.0205	0.0258	0.1139	0.0917	0.0529	0.1262
Environmental factors C_2	0.0387	0.0550	0.1463	0.1245	0.0812	0.1912
Resource factors C_3	0.0162	0.0230	0.0491	0.0664	0.0432	0.0794
Technical factors C_4	0.0017	0.0085	0.0113	0.0143	0.0137	0.0188

TABLE 10 Second level membership degree and evaluation scores.

Index	Good	Better	General	Poor	Bad	Overall rating
Overall evaluation	0.0270	0.0385	0.1140	0.0989	0.0627	0.1442

score is low and that it has not yet achieved the point of greening. Consequently, the evaluation results obtained by using the DEMATEL-ANP-FCE model are consistent with the actual development of vegetable green logistics in Lanling County, which confirms that this evaluation model has good applicability and accurately reflects the situation. It is worth emphasizing that this study provides a new and applicable research methodology for the future evaluation of vegetable green logistics.

Lastly, according to evaluation scores, this article makes managerial contributions to advancing the long-term growth of vegetable green logistics in Lanling County. Therefore, the study's findings can serve as a reference for the vegetable green logistics evaluation study to realize the long-term growth strategy. To sum up, this research offers a useful evaluation framework for vegetable green logistics.

4.2 Managerial contributions

Based on the evaluation scores derived from the DEMATEL-ANP-FCE model, this study targeted the following four management contributions. This helps to promote the degree of greening of vegetable logistics in Lanling County and provides a new perspective for future research the vegetable green logistics. As a result, the Q4 proposed in this paper is also well addressed.

The logistics equipment structure requires reinforcement. Accelerating the development of Lanling's vegetable logistics infrastructure and cold chain technologies. Vegetables in Lanling County are currently mostly transported at ambient temperature, with little to no usage of cold chain equipment. In the meantime, a large-scale cold storage facility for vegetables should be established, appropriate refrigerated vehicles for vegetables should be bought, and the number of refrigerated transportation options should be expanded. To jointly encourage the application of vegetable cold chain technology, the innovation of vegetable cold chain technology, and logistics enterprises in the county can engage in negotiations and cooperative efforts with vegetable enterprises.

Taking notice of how logistics technologies are being developed and applied. Vegetable waste will be generated in enormous quantities during the transportation process, and improper handling of this trash will have detrimental effects on the environment. Firstly, to enhance the standardization of logistics, Lanling County should implement automated sorting equipment for vegetable logistics in addition to real-time updating of transport road planning system equipment. Moreover, to minimize resource waste, it should also actively develop and implement a system for recycling vegetable waste logistics, achieve uniform recovery and systematic waste categorization, and process leftover renewable materials for secondary processing. Lastly, resource restrictions can be eased and environmental contamination can be solved with the construction of an effective network for the exploitation of agricultural waste resources (Wang et al., 2023). An information technology platform for vegetable logistics transactions should be built to address the unbalanced competition within the logistics industry and enhance economic efficiency. Information on vegetable logistics might be shared by customers, logistics companies, wholesalers, retailers, and manufacturers using this platform.

Promoting the sustainable development of vegetables and fully improving Lanling's vegetable processing, packing, and transporting. In the first place, to minimize the loss of vegetable products, vegetable processing businesses must first understand processing technology and equipment, choose and employ excellent machinery and equipment, and employ scientific processing techniques. When handling pollutants found in vegetables, they must adhere to the applicable rules and regulations. Additionally, using materials that are healthy for the environment and human health is referred to as "green packaging." When selecting packaging materials for the vegetable logistics sector, every important body in Lanling uses vacuum packing or biodegradable materials to raise the level of environmental friendliness in the transportation of vegetables. Vegetable packaging materials can be buried in the ground and soon degrade, without polluting the land or the air, provided they are burned safely. Thirdly, since the primary modes of vegetable logistics and transportation in Lanling County are the railroad and the highway, the fuel used for these modes of transportation is primarily gasoline and diesel, which results in a significant amount of harmful substance-containing vehicle exhaust as well as a significant amount of greenhouse gas emissions from burning freight fuel, which worsens air pollution and contributes to climate change. To lessen environmental pollution, logistics and transportation companies in Lanling should use modern energy fuels like electricity and hydrogen.

The Lanling government ought to create and enhance the legal framework governing agricultural items, as well as utilize legal tools to oversee industrial organizations. Firstly, specific legislative measures might offer precise direction and limitations for the several facets of vegetable transportation. What's more, the Lanling County government needs to do a better job of publicizing and training about green logistics. The Lanling administration should organize training sessions regularly basis and encourage practitioners of all stripes to acquire an understanding of vegetable green logistics. Additionally, government subsidies help the logistics industry become more environmentally friendly and are a useful tool for lowering the adverse impacts of the industry (Ren et al., 2020). The Lanling County government ought to encourage or provide preference to certain taxes, funds, and regulations. Enough financial assistance can also help to foster the improved growth of vegetable green logistics in Lanling County. Lastly, a shortage of qualified personnel is impeding the advancement of green logistics (Kay et al., 2018). The Lanling County administration and the education sector can work together to strengthen the training of logistics-related professions, implement pertinent incentives, and raise the amount of money allocated to logistics education.

4.3 Prospects

The research and discussion on the following topics in this study are not sufficiently comprehensive and should be followed up on to do more thorough research. On the one hand, the questionnaire data used in this study's evaluation of Lanling vegetable logistics is more subjective and requires more research to be supported by a more thorough and scientific system to conduct a more reasonable review. On the other hand, the current Lanling vegetable logistics system is not as sound as it could be, which limits the scope of this study. Further in-depth research on the particulars of Lanling's vegetable logistics system is needed to enable more insightful analysis. Scholars should conduct more comprehensive and effective research on vegetable logistics evaluation in the future.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

HW: Formal analysis, Writing – original draft, Funding acquisition, Investigation, Supervision, Writing – review & editing. ZL: Formal analysis, Writing – original draft, Methodology, Software. LL: Formal analysis, Methodology, Writing – original draft. HC: Formal analysis, Funding acquisition, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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