Supplementary material: Urban Distribution Mode Selection under Low Carbon Economy—A Case Study of Guangzhou City

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1. Detailed Calculation Process of the Specific Application of the Optimization Method of Low Carbon Urban Distribution Mode

1.1. Concrete Calculation Process of the Application of the Optimization Method in Enterprise A of Beverages

1.1.1. Constructing Fuzzy Judgment Matrix

In the communication and assistance of the project implementation unit and the industry association, one distribution management person of enterprise A provides support for the application research of this paper. The author describes the research purpose of this paper to the management personnel, and provides specific instructions. According to the actual situation of enterprise A, the distribution manager provided preference information about the influencing factors or the schemes. After arrangement, the value of each fuzzy judgment matrix is shown in Table S1 to Table S13.

Table S1. Fuzzy judgment matrix dominated by target *M*.

To Optimize the Urban Distribution Mode & to Reduce the Carbon Emissions Intensity *M*	Enterprise Scale Strength *Z*1	Distribution Service Capability *Z*2	Social Development Trend *Z*3
Enterprise scale strength *Z*1	0.5	0.5	0.6
Distribution service capability *Z*2	0.5	0.5	0.6
Social development trend *Z*3	0.4	0.4	0.5

Table S2. Fuzzy judgment matrix dominated by rule *Z*1.

Enterprise Scale Strength *Z*1	Investment Risk Bearing Capacity *G*1	Information Technology Level *G*2	Facilities and Equipment Level *G*3
Investment risk bearing capacity *G*1	0.5	0.7	0.8
Information technology level *G*2	0.3	0.5	0.6
Facilities and equipment level *G*3	0.2	0.4	0.5

Table S3. Fuzzy judgment matrix dominated by rule *Z*2.

Distribution Service Capability *Z*2	Timely Accuracy *G*4	Service Flexibility *G*5	Economical Efficiency *G*6
Timely accuracy *G*4	0.5	0.6	0.5
Service flexibility *G*5	0.4	0.5	0.4
Economical efficiency *G*6	0.5	0.6	0.5

Table S4. Fuzzy judgment matrix dominated by rule *Z*3.

Social Development Trend *Z*3	Distribution Policy and Regulation *G*7	Enterprise Cooperation Ability *G*8	Low Carbon Economy Development *G*9
Distribution policy and regulation *G*7	0.5	0.8	0.6
Enterprise cooperation ability *G*8	0.2	0.5	0.3
Low carbon economy development *G*9	0.4	0.7	0.5

Table S5. Fuzzy judgment matrix dominated by rule *G*1.

Investment Risk Bearing Capacity *G*1	Self Distribution Mode *F*1	Mutual Distribution Mode *F*2	Third Party Distribution Mode *F*3	Common Distribution Mode *F*4
Self distribution mode *F*1	0.5	0.8	0.9	0.7
Mutual distribution mode *F*2	0.2	0.5	0.4	0.3
Third party distribution mode *F*3	0.1	0.6	0.5	0.4
Common distribution mode *F*4	0.3	0.7	0.6	0.5

Table S6. Fuzzy judgment matrix dominated by rule *G*2.

Information Technology Level *g*2	Self Distribution Mode *f*1	Mutual Distribution Mode *f*2	Third Party Distribution Mode *f*3	Common Distribution Mode *f*4
Self distribution mode *F*1	0.5	0.6	0.8	0.7
Mutual distribution mode *F*2	0.4	0.5	0.7	0.4
Third party distribution mode *F*3	0.2	0.3	0.5	0.3
Common distribution mode *F*4	0.3	0.6	0.7	0.5

Table S7. Fuzzy judgment matrix dominated by rule *G*3.

Facilities and Equipment Level *G*3	Self Distribution Mode *F*1	Mutual Distribution Mode *F*2	Third Party Distribution Mode *F*3	Common Distribution Mode *F*4
Self distribution mode *F*1	0.5	0.8	0.6	0.7
Mutual distribution mode *F*2	0.2	0.5	0.4	0.4
Third party distribution mode *F*3	0.4	0.6	0.5	0.6
Common distribution mode *F*4	0.3	0.6	0.4	0.5

Table S8. Fuzzy judgment matrix dominated by rule *G*4.

Timely Accuracy *G*4	Self Distribution Mode *F*1	Mutual Distribution Mode *F*2	Third Party Distribution Mode *F*3	Common Distribution Mode *F*4
Self distribution mode *F*1	0.5	0.7	0.8	0.6
Mutual distribution mode *F*2	0.3	0.5	0.4	0.4
Third party distribution mode *F*3	0.2	0.6	0.5	0.4
Common distribution mode *F*4	0.4	0.6	0.6	0.5

Table S9. Fuzzy judgment matrix dominated by rule *G*5.

Service Flexibility *G*5	**Self Distribution Mode *F*1**	**Mutual Distribution Mode *F*2**	**Third Party Distribution Mode *F*3**	**Common Distribution Mode *F*4**
Self distribution mode *F*1	0.5	0.6	0.8	0.6
Mutual distribution mode *F*2	0.4	0.5	0.6	0.4
Third party distribution mode *F*3	0.2	0.4	0.5	0.3
Common distribution mode *F*4	0.4	0.6	0.7	0.5

Table S10. Fuzzy judgment matrix dominated by rule *G*6.

Economical Efficiency *G*6	**Self Distribution Mode *F*1**	**Mutual Distribution Mode *F*2**	**Third Party Distribution Mode *F*3**	**Common Distribution Mode *F*4**
Self distribution mode *F*1	0.5	0.4	0.3	0.6
Mutual distribution mode *F*2	0.6	0.5	0.4	0.6
Third party distribution mode *F*3	0.7	0.6	0.5	0.7
Common distribution mode *F*4	0.4	0.4	0.3	0.5

Table S11. Fuzzy judgment matrix dominated by rule *G*7.

Distribution Policy and Regulation *G*7	**Self Distribution Mode *F*1**	**Mutual Distribution Mode *F*2**	**Third Party Distribution Mode *F*3**	**Common Distribution Mode *F*4**
Self distribution mode *F*1	0.5	0.3	0.4	0.2
Mutual distribution mode *F*2	0.7	0.5	0.5	0.3
Third party distribution mode *F*3	0.6	0.5	0.5	0.4
Common distribution mode *F*4	0.8	0.7	0.6	0.5

Table S12. Fuzzy judgment matrix dominated by rule *G*8.

Enterprise Cooperation Ability *G*8	**Self Distribution Mode *F*1**	**Mutual Distribution Mode *F*2**	**Third Party Distribution Mode *F*3**	**Common Distribution Mode *F*4**
Self distribution mode *F*1	0.5	0.6	0.7	0.9
Mutual distribution mode *F*2	0.4	0.5	0.6	0.7
Third party distribution mode *F*3	0.3	0.4	0.5	0.6
Common distribution mode *F*4	0.1	0.3	0.4	0.5

Table S13. Fuzzy judgment matrix dominated by rule *G*9.

Low Carbon Economy Development *G*9	**Self Distribution Mode *F*1**	**Mutual Distribution Mode *F*2**	**Third Party Distribution Mode *F*3**	**Common Distribution Mode *F*4**
Self distribution mode *F*1	0.5	0.4	0.5	0.4
Mutual distribution mode *F*2	0.6	0.5	0.5	0.6
Third party distribution mode *F*3	0.5	0.5	0.5	0.4
Common distribution mode *F*4	0.6	0.4	0.6	0.5

1.1.2. Checking and Improvement of Consistency of Judgment Matrix

Taking the fuzzy matrix of Table S5 as an example, according to the method proposed above, the process of matrix consistency checking and improvement is as following.

(1) Calculate the value of the four deviation: δ_{123}^{G1}, δ_{124}^{G1}, δ_{134}^{G1} and δ_{234}^{G1}, and values were: −0.2, −0.1, 0.3 and 0.2. Then according to the relational expression: $\delta_{ijp}^{G1} = -\delta_{ipj}^{G1} = \delta_{jpi}^{G1} (1 \le i < j < p \le 4)$, we can get other deviation values. Hence, $\rho^{G1} = 0.2 > 0.1$. The matrix does not meet the consistency requirements, and need to improve the judgment matrix.

(2) Count the positive and negative conditions of the deviation of the elements: c_{12}^{G1}, c_{13}^{G1}, c_{14}^{G1}, c_{23}^{G1}, c_{24}^{G1} and c_{34}^{G1}.

(3) Filter the elements that meet the conditions, and there are c_{12}^{G1}, c_{13}^{G1}, c_{24}^{G1} and c_{34}^{G1}.

(4) Calculate the value of each $c_{ip}^{G1} + c_{pj}^{G1} - 0.5$, and according to Equation (1) to adjust the elements, the values of the elements after adjustment respectively are: 0.9, 0.7, 0.4 and 0.4.

$$c_{i^*j^*}^{x_q^{m-1}} = \begin{cases} \max\left\{0.1, \max\left\{c_{ip}^{x_q^{m-1}} + c_{pj}^{x_q^{m-1}} - 0.5 \middle| \delta_{ijp}^{x_q^{m-1}} > 0, p \in N, p \ne i, j\right\}\right\}, S^+\left(c_{ij}^{x_q^{m-1}}\right) > 0 \\ \min\left\{0.9, \min\left\{c_{ip}^{x_q^{m-1}} + c_{pj}^{x_q^{m-1}} - 0.5 \middle| \delta_{ijp}^{x_q^{m-1}} < 0, p \in N, p \ne i, j\right\}\right\}, S^-\left(c_{ij}^{x_q^{m-1}}\right) > 0 \end{cases} \tag{1}$$

(5) Calculate $S\left(c_{ij}^{x_q^{m-1}}\right)\left|c_{i^*j^*}^{x_q^{m-1}} - c_{ij}^{x_q^{m-1}}\right|$, and improve the corresponding element whose value is biggest. After comparison and selection, improve c_{34}^{G1}, and the new value is 0.4. So $c_{43}^{G1} = 0.6$.

Details of the above calculation process are shown as Table S14, and the improvement result of the matrix of Table S5 is shown in the following. The consistency index is $\rho^{G1} = 0.1 \le \varepsilon$, and the matrix meets the consistency requirements. That is to say that the fuzzy judgment matrix of Table S5 has been improved to the fuzzy consistency matrix $G1$.

$$G1 = \begin{bmatrix} 0.5 & 0.8 & 0.9 & 0.7 \\ 0.2 & 0.5 & 0.4 & 0.3 \\ 0.1 & 0.6 & 0.5 & 0.4 \\ 0.3 & 0.7 & 0.6 & 0.5 \end{bmatrix}$$

Table S14. Consistency checking and improvement of fuzzy judgment matrix dominated by rule $G1$.

Element		Deviation		Positive and Negative of Deviation and Numbers	$c_{ip}^{G1} + c_{pj}^{G1} - 0.5$	$c_{i^*j^*}^{G1}$	$S\left(c_{ij}^{x_q^{m-1}}\right)\left\|c_{i^*j^*}^{x_q^{m-1}} - c_{ij}^{x_q^{m-1}}\right\|$
Symbol	**Value**	**Symbol**	**Value**				
c_{12}^{G1}	0.8	δ_{123}^{G1}	−0.2	Negative, 2	1	0.9	0.2
		δ_{124}^{G1}	−0.1		0.9		
c_{13}^{G1}	0.9	δ_{132}^{G1}	0.2	Positive, 2	0.7	0.7	0.4
		δ_{134}^{G1}	0.3		0.6		
c_{14}^{G1}	0.7	δ_{142}^{G1}	0.1	— —	0.6	— —	— —
		δ_{143}^{G1}	−0.3		1		
c_{23}^{G1}	0.4	δ_{231}^{G1}	−0.2	— —	0.6	— —	— —
		δ_{234}^{G1}	0.2		0.2		
c_{24}^{G1}	0.3	δ_{241}^{G1}	−0.1	Negative, 2	0.4	0.4	0.2
		δ_{243}^{G1}	−0.2		0.5		
c_{34}^{G1}	0.6	δ_{341}^{G1}	0.3	Positive, 2	0.3	0.4	0.4
		δ_{342}^{G1}	0.2		0.4		

The consistency checking and improvement process of the other twelve judgment matrixes are similar with the above. Finally, the results of the fuzzy consistent judgment matrixes (expressed by the symbol abbreviation of the dominant factor) improving from the thirteen judgment matrixes are as follows.

$$M=\begin{bmatrix}0.5&0.5&0.6\\0.5&0.5&0.6\\0.4&0.4&0.5\end{bmatrix},Z1=\begin{bmatrix}0.5&0.7&0.8\\0.3&0.5&0.6\\0.2&0.4&0.5\end{bmatrix},Z2=\begin{bmatrix}0.5&0.6&0.5\\0.4&0.5&0.4\\0.5&0.6&0.5\end{bmatrix},Z3=\begin{bmatrix}0.5&0.8&0.6\\0.2&0.5&0.3\\0.4&0.7&0.5\end{bmatrix},$$

$$G1=\begin{bmatrix}0.5&0.8&0.9&0.7\\0.2&0.5&0.4&0.3\\0.1&0.6&0.5&0.4\\0.3&0.7&0.6&0.5\end{bmatrix},\quad G2=\begin{bmatrix}0.5&0.6&0.8&0.7\\0.4&0.5&0.7&0.4\\0.2&0.3&0.5&0.3\\0.3&0.6&0.7&0.5\end{bmatrix},\quad G3=\begin{bmatrix}0.5&0.8&0.6&0.7\\0.2&0.5&0.4&0.4\\0.4&0.6&0.5&0.6\\0.3&0.6&0.4&0.5\end{bmatrix},$$

$$G4=\begin{bmatrix}0.5&0.7&0.8&0.6\\0.3&0.5&0.4&0.4\\0.2&0.6&0.5&0.4\\0.4&0.6&0.6&0.5\end{bmatrix},\quad G5=\begin{bmatrix}0.5&0.6&0.8&0.6\\0.4&0.5&0.6&0.4\\0.2&0.4&0.5&0.3\\0.4&0.6&0.7&0.5\end{bmatrix},\quad G6=\begin{bmatrix}0.5&0.4&0.3&0.6\\0.6&0.5&0.4&0.6\\0.7&0.6&0.5&0.7\\0.4&0.4&0.3&0.5\end{bmatrix},$$

$$G7=\begin{bmatrix}0.5&0.3&0.4&0.2\\0.7&0.5&0.5&0.3\\0.6&0.5&0.5&0.4\\0.8&0.7&0.6&0.5\end{bmatrix},\quad G8=\begin{bmatrix}0.5&0.6&0.7&0.9\\0.4&0.5&0.6&0.7\\0.3&0.4&0.5&0.6\\0.1&0.3&0.4&0.5\end{bmatrix},\quad G9=\begin{bmatrix}0.5&0.4&0.5&0.4\\0.6&0.5&0.5&0.6\\0.5&0.5&0.5&0.4\\0.6&0.4&0.6&0.5\end{bmatrix}.$$

1.1.3. Hierarchical single ranking

According to Equation (2), $A^{m-1}=(a_1^{m-1},a_2^{m-1},\cdots,a_k^{m-1})^T$, $b_q^m=(b_{1q}^m,b_{2q}^m,\cdots,b_{lq}^m)^T(q\le k,n\le l)$, $B^m=(b_1^m,b_2^m,\cdots,b_k^m)$, the ranking weight vector of each fuzzy consistency judgment matrix is as following.

$$A^m=B^mA^{m-1} \tag{2}$$

$$W_Z^M=\left(0.340944,0.340944,0.318112\right)^T,W^{Z1}=\left(0.372744,0.324493,0.302763\right)^T,$$

$$W^{Z2}=\left(0.340944,0.318112,0.340944\right)^T,W^{Z3}=\left(0.364261,0.295872,0.339867\right)^T,$$

$$W^{G1}=\left(0.290702,0.224162,0.232067,0.25307\right)^T,$$

$$W^{G2}=\left(0.276506,0.249202,0.220735,0.253557\right)^T,$$

$$W^{G3}=\left(0.276701,0.22868,0.253736,0.240883\right)^T,$$

$$W^{G4}=\left(0.27674,0.23271,0.236778,0.253772\right)^T,$$

$$W^{G5}=\left(0.271958,0.245102,0.224759,0.258181\right)^T,$$

$$W^{G6}=\left(0.241065,0.253928,0.272154,0.232853\right)^{T},$$

$$W^{G7}=\left(0.224705,0.249326,0.249326,0.276644\right)^{T},$$

$$W^{G8}=\left(0.281121,0.257789,0.240526,0.220563\right)^{T},$$

$$W^{G9}=\left(0.241393,0.258719,0.245613,0.254274\right)^{T}.$$

1.1.4. Hierarchical total ranking

Firstly, according to Equation (2), the weight vector of each factor of the sub criterion layer relative to the total target is calculated as follows.

$$W_G^M=(W_G^{Z1},W_G^{Z2},W_G^{Z3})W_Z^M$$

$$=\begin{bmatrix} 0.372744 & 0 & 0 \\ 0.324493 & 0 & 0 \\ 0.302763 & 0 & 0 \\ 0 & 0.340944 & 0 \\ 0 & 0.318112 & 0 \\ 0 & 0.340944 & 0 \\ 0 & 0 & 0.364261 \\ 0 & 0 & 0.295872 \\ 0 & 0 & 0.339867 \end{bmatrix}\left(0.340944,0.340944,0.318112\right)^{T}=\begin{bmatrix} 0.127085 \\ 0.110634 \\ 0.103225 \\ 0.116243 \\ 0.108458 \\ 0.116243 \\ 0.115876 \\ 0.09412 \\ 0.108116 \end{bmatrix}$$

As a result, the calculation results of the overall weight of each distribution scheme with respect to the total target are as follows.

$$W_F^M=(W_F^{G1},W_F^{G2},W_F^{G3},W_F^{G4},W_F^{G5},W_F^{G6},W_F^{G7},W_F^{G8},W_F^{G9})W_G^M$$

$$=\begin{bmatrix} 0.290702 & 0.276506 & 0.276701 & 0.27674 & 0.271958 & 0.241065 & 0.224705 & 0.281121 & 0.241393 \\ 0.224162 & 0.249202 & 0.22868 & 0.23271 & 0.245102 & 0.253928 & 0.249326 & 0.257789 & 0.258719 \\ 0.232067 & 0.220735 & 0.253736 & 0.236778 & 0.224759 & 0.272154 & 0.249326 & 0.240526 & 0.245613 \\ 0.25307 & 0.253557 & 0.240883 & 0.253772 & 0.258181 & 0.232853 & 0.276644 & 0.220563 & 0.254274 \end{bmatrix}$$

$$(0.127085,0.110634,0.103225,0.116243,0.108458,0.116243,0.115876,0.09412,0.108116)^{T}$$

$$=(0.26438,0.24394,0.241725,0.249954)^{T}$$

1.2. Concrete Calculation Process of the Application of the Optimization Method in Enterprise B and Enterprise C of Daily Necessities

1.2.1. Constructing Fuzzy Judgment Matrix

Through the communication of the project implementation unit and the industry association, the author made contact with the distribution management of the two enterprises. On the basis of the detailed description of the research purpose, the present situation of the distribution of Guangzhou City and the research methods, and according to the actual situation of each enterprise, the two distribution managers make judgments about the relative importance of the paired influencing factors or schemes. After arrangement, the fuzzy complementary judgment matrixes of the two enterprises are as follows. Among them, matrix $M_B^{'}$ represents the fuzzy judgment matrix dominated by target M which is constructed by the distribution management personnel of enterprise B, and matrix $M_C^{'}$ represents the fuzzy judgment matrix dominated by target M which is constructed by the distribution management personnel of enterprise C. The definitions of other matrix symbols are similar.

$$M_B^{'}=\begin{bmatrix}0.5&0.5&0.7\\0.5&0.5&0.6\\0.3&0.4&0.5\end{bmatrix},Z1_B^{'}=\begin{bmatrix}0.5&0.4&0.7\\0.6&0.5&0.7\\0.3&0.3&0.5\end{bmatrix},Z2_B^{'}=\begin{bmatrix}0.5&0.8&0.4\\0.2&0.5&0.1\\0.6&0.9&0.5\end{bmatrix},Z3_B^{'}=\begin{bmatrix}0.5&0.5&0.7\\0.5&0.5&0.6\\0.3&0.4&0.5\end{bmatrix},$$

$$M_B^{'}=\begin{bmatrix}0.5&0.5&0.7\\0.5&0.5&0.6\\0.3&0.4&0.5\end{bmatrix},Z1_B^{'}=\begin{bmatrix}0.5&0.4&0.7\\0.6&0.5&0.7\\0.3&0.3&0.5\end{bmatrix},Z2_B^{'}=\begin{bmatrix}0.5&0.8&0.4\\0.2&0.5&0.1\\0.6&0.9&0.5\end{bmatrix},Z3_B^{'}=\begin{bmatrix}0.5&0.5&0.7\\0.5&0.5&0.6\\0.3&0.4&0.5\end{bmatrix},$$

$$G1_B^{'}=\begin{bmatrix}0.5&0.7&0.4&0.6\\0.3&0.5&0.2&0.3\\0.6&0.8&0.5&0.6\\0.4&0.7&0.4&0.5\end{bmatrix},\quad G2_B^{'}=\begin{bmatrix}0.5&0.4&0.6&0.7\\0.6&0.5&0.8&0.7\\0.4&0.2&0.5&0.5\\0.3&0.3&0.5&0.5\end{bmatrix},\quad G3_B^{'}=\begin{bmatrix}0.5&0.6&0.7&0.6\\0.4&0.5&0.7&0.6\\0.3&0.3&0.5&0.4\\0.4&0.4&0.6&0.5\end{bmatrix},$$

$$G4_B^{'}=\begin{bmatrix}0.5&0.4&0.3&0.4\\0.6&0.5&0.6&0.5\\0.7&0.4&0.5&0.4\\0.6&0.5&0.6&0.5\end{bmatrix},\quad G5_B^{'}=\begin{bmatrix}0.5&0.3&0.4&0.5\\0.7&0.5&0.5&0.6\\0.6&0.5&0.5&0.6\\0.5&0.4&0.4&0.5\end{bmatrix},\quad G6_B^{'}=\begin{bmatrix}0.5&0.4&0.5&0.4\\0.6&0.5&0.7&0.6\\0.5&0.3&0.5&0.4\\0.6&0.4&0.6&0.5\end{bmatrix},$$

$$G7_B^{'}=\begin{bmatrix}0.5&0.3&0.2&0.2\\0.7&0.5&0.2&0.4\\0.8&0.8&0.5&0.6\\0.8&0.6&0.4&0.5\end{bmatrix},\quad G8_B^{'}=\begin{bmatrix}0.5&0.5&0.6&0.6\\0.5&0.5&0.6&0.4\\0.4&0.4&0.5&0.3\\0.4&0.6&0.7&0.5\end{bmatrix},\quad G9_B^{'}=\begin{bmatrix}0.5&0.4&0.3&0.2\\0.6&0.5&0.2&0.3\\0.7&0.8&0.5&0.6\\0.8&0.7&0.4&0.5\end{bmatrix},$$

$$M_C^{'}=\begin{bmatrix}0.5&0.6&0.4\\0.4&0.5&0.4\\0.6&0.6&0.5\end{bmatrix},Z1_C^{'}=\begin{bmatrix}0.5&0.8&0.5\\0.2&0.5&0.3\\0.5&0.7&0.5\end{bmatrix},Z2_C^{'}=\begin{bmatrix}0.5&0.4&0.6\\0.4&0.5&0.6\\0.4&0.4&0.5\end{bmatrix},Z3_C^{'}=\begin{bmatrix}0.5&0.6&0.6\\0.4&0.5&0.4\\0.4&0.6&0.5\end{bmatrix},$$

$$G1_C^{'}=\begin{bmatrix}0.5&0.4&0.5&0.4\\0.6&0.5&0.6&0.5\\0.5&0.4&0.5&0.3\\0.6&0.5&0.7&0.5\end{bmatrix},\quad G2_C^{'}=\begin{bmatrix}0.5&0.5&0.6&0.4\\0.5&0.5&0.7&0.5\\0.4&0.3&0.5&0.3\\0.6&0.5&0.7&0.5\end{bmatrix},\quad G3_C^{'}=\begin{bmatrix}0.5&0.4&0.6&0.5\\0.6&0.5&0.7&0.5\\0.4&0.3&0.5&0.3\\0.5&0.5&0.7&0.5\end{bmatrix},$$

$$G4_C^{'}=\begin{bmatrix}0.5&0.4&0.5&0.3\\0.6&0.5&0.7&0.6\\0.5&0.3&0.5&0.4\\0.7&0.4&0.6&0.5\end{bmatrix},\quad G5_C^{'}=\begin{bmatrix}0.5&0.2&0.3&0.4\\0.8&0.5&0.6&0.5\\0.7&0.4&0.5&0.4\\0.6&0.5&0.6&0.5\end{bmatrix},\quad G6_C^{'}=\begin{bmatrix}0.5&0.3&0.5&0.4\\0.7&0.5&0.6&0.7\\0.5&0.4&0.5&0.5\\0.6&0.3&0.5&0.5\end{bmatrix},$$

$$G7_C^{'}=\begin{bmatrix}0.5&0.4&0.3&0.3\\0.6&0.5&0.6&0.4\\0.7&0.4&0.5&0.4\\0.7&0.6&0.6&0.5\end{bmatrix},\quad G8_C^{'}=\begin{bmatrix}0.5&0.4&0.5&0.4\\0.6&0.5&0.5&0.6\\0.5&0.5&0.5&0.4\\0.6&0.4&0.6&0.5\end{bmatrix},\quad G9_C^{'}=\begin{bmatrix}0.5&0.4&0.4&0.2\\0.6&0.5&0.6&0.4\\0.6&0.4&0.5&0.4\\0.8&0.6&0.6&0.5\end{bmatrix}.$$

1.2.2. Checking and improvement of consistency of judgment matrix

Then adopt the algorithm optimized in this paper to check and improve the consistency of the fuzzy judgment matrixes constructed in the above, and it is found that only matrix $Z2_B^{'}$ does not meet the consistency requirement. The result of the improved fuzzy consistency matrix $Z2_B$ is shown as follows. The other fuzzy judgment matrixes are all fuzzy consistent matrixes.

$$Z2_B = \begin{bmatrix} 0.5 & 0.8 & 0.4 \\ 0.2 & 0.5 & 0.1 \\ 0.6 & 0.9 & 0.5 \end{bmatrix}$$

1.2.3. Hierarchical single ranking

According to Equation (3), the ranking weight vector of each fuzzy consistency judgment matrix of enterprise B is as following.

$w_i^{x_q^{m-1}}$ represents the weight of the factor x_i^m dominated by the factor x_q^{m-1} in the upper layer.

$$w_i^{x_q^{m-1}} = \beta^{\frac{1}{n}\sum_{j=1}^{n} c_{ij}^{x_q^{m-1}}} \Bigg/ \sum_{s=1}^{n} \beta^{\frac{1}{n}\sum_{j=1}^{n} c_{sj}^{x_q^{m-1}}} \quad (i \in N, \beta = 2) \tag{3}$$

$$\left(W_Z^M\right)_B = \left(0.348668, 0.340704, 0.310628\right)^T, \left(W^{Z1}\right)_B = \left(0.340345, 0.356442, 0.303213\right)^T,$$

$$\left(W^{Z2}\right)_B = \left(0.346738, 0.281638, 0.371624\right)^T, \left(W^{Z3}\right)_B = \left(0.348668, 0.340704, 0.310628\right)^T,$$

$$\left(W^{G1}\right)_B = \left(0.258072, 0.220805, 0.271843, 0.249281\right)^T,$$

$$\left(W^{G2}\right)_B = \left(0.258113, 0.276639, 0.232624, 0.232624\right)^T,$$

$$\left(W^{G3}\right)_B = \left(0.267484, 0.258373, 0.228858, 0.245284\right)^T,$$

$$\left(W^{G4}\right)_B = \left(0.233051, 0.258586, 0.249778, 0.258586\right)^T,$$

$$\left(W^{G5}\right)_B = \left(0.237104, 0.263083, 0.258564, 0.241249\right)^T,$$

$$\left(W^{G6}\right)_B = \left(0.241211, 0.26764, 0.237067, 0.254082\right)^T,$$

$$\left(W^{G7}\right)_B = \left(0.216619, 0.240354, 0.28092, 0.262108\right)^T,$$

$$\left(W^{G8}\right)_B = \left(0.258586, 0.249778, 0.233051, 0.258586\right)^T,$$

$$\left(W^{G9}\right)_B = \left(0.224436, 0.232351, 0.276313, 0.266901\right)^T.$$

Similarly, according to Equation (3), the ranking weight vector of each fuzzy consistency judgment matrix of enterprise C is as following.

$$\left(W_Z^M\right)_C = \left(0.333096, 0.318054, 0.34885\right)^T, \left(W^{Z1}\right)_C = \left(0.356075, 0.295983, 0.347942\right)^T,$$

$$\left(W^{Z2}\right)_C = \left(0.338428, 0.338428, 0.323145\right)^T, \left(W^{Z3}\right)_C = \left(0.34885, 0.318054, 0.333096\right)^T,$$

$$\left(W^{G1}\right)_C = \left(0.241249, 0.258564, 0.237104, 0.263083\right)^T,$$

$$\left(W^{G2}\right)_C = \left(0.249649, 0.258452, 0.228929, 0.26297\right)^T,$$

$$\left(W^{G3}\right)_C = \left(0.249649, 0.26297, 0.2289290.258452,\right)^T,$$

$$\left(W^{G4}\right)_C = \left(0.236996, 0.267561, 0.236996, 0.258446\right)^T,$$

$$\left(W^{G5}\right)_C = \left(0.224847, 0.267389, 0.249483, 0.258281\right)^T,$$

$$\left(W^{G6}\right)_C = \left(0.23701, 0.272253, 0.245368, 0.245368\right)^T,$$

$$\left(W^{G7}\right)_C = \left(0.228893, 0.253973, 0.24961, 0.267525\right)^T,$$

$$\left(W^{G8}\right)_C = \left(0.241393, 0.258719, 0.245613, 0.254274\right)^T,$$

$$\left(W^{G9}\right)_C = \left(0.228804, 0.253874, 0.245226, 0.272096\right)^T.$$

1.2.4. Hierarchical total ranking

For enterprise B, firstly, according to Equation (2), the weight vector of each factor of the sub criterion layer relative to the total target is calculated as follows.

$$(W_G^M)_B = \left[(W_G^{Z1})_B, (W_G^{Z2})_B, (W_G^{Z3})_B\right](W_Z^M)_B$$
$$= \begin{bmatrix} 0.340345 & 0 & 0 \\ 0.356442 & 0 & 0 \\ 0.303213 & 0 & 0 \\ 0 & 0.346738 & 0 \\ 0 & 0.281638 & 0 \\ 0 & 0.371624 & 0 \\ 0 & 0 & 0.348668 \\ 0 & 0 & 0.340704 \\ 0 & 0 & 0.310628 \end{bmatrix} \left(0.348668, 0.340704, 0.310628\right)^T = \begin{bmatrix} 0.118667 \\ 0.12428 \\ 0.105721 \\ 0.118135 \\ 0.095955 \\ 0.126614 \\ 0.108306 \\ 0.105832 \\ 0.09649 \end{bmatrix}$$

As a result, for enterprise B, the calculation results of the overall weight of each distribution scheme with respect to the total target are as follows.

$$(W_F^M)_B = \left[(W_F^{G1})_B, (W_F^{G2})_B, (W_F^{G3})_B, (W_F^{G4})_B, (W_F^{G5})_B, (W_F^{G6})_B, (W_F^{G7})_B, (W_F^{G8})_B, (W_F^{G9})_B\right](W_G^M)_B$$
$$= (0.244289, 0.252463, 0.251449, 0.251799)^T$$

Similarly, for enterprise C, firstly, according to Equation (2), the weight vector of each factor of the sub criterion layer relative to the total target is calculated as follows.

$$(W_G^M)_C = \left[(W_G^{Z1})_C, (W_G^{Z2})_C, (W_G^{Z3})_C\right](W_Z^M)_C$$

$$= \begin{bmatrix} 0.356075 & 0 & 0 \\ 0.295983 & 0 & 0 \\ 0.347942 & 0 & 0 \\ 0 & 0.338428 & 0 \\ 0 & 0.338428 & 0 \\ 0 & 0.323145 & 0 \\ 0 & 0 & 0.34885 \\ 0 & 0 & 0.318054 \\ 0 & 0 & 0.333096 \end{bmatrix} \left(0.333096, 0.318054, 0.34885\right)^T = \begin{bmatrix} 0.118607 \\ 0.098591 \\ 0.115898 \\ 0.107638 \\ 0.107638 \\ 0.102778 \\ 0.121696 \\ 0.110953 \\ 0.116201 \end{bmatrix}$$

As a result, for enterprise C, the calculation results of the overall weight of each distribution scheme with respect to the total target are as follows.

$$(W_F^M)_C = \left[(W_F^{G1})_C, (W_F^{G2})_C, (W_F^{G3})_C, (W_F^{G4})_C, (W_F^{G5})_C, (W_F^{G6})_C, (W_F^{G7})_C, (W_F^{G8})_C, (W_F^{G9})_C\right](W_G^M)_C$$
$$= (0.237458, 0.261302, 0.240931, 0.260309)^T$$

1.2.5. Piloting distribution mode optimization scheme and comparison of carbon emission intensity

Due to the focus of this paper is the change of urban distribution carbon emission intensity after enterprises adopt the optimized urban distribution mode, so we need to pilot the distribution mode optimization scheme in the research enterprises to measure low carbon benefits of the optimized distribution mode. In the communication and organization of the industry association, enterprise B and enterprise C reached an agreement in the form of contract. They decided to implement mutual distribution mode in the pilot period of half a natural year, and mutually used each other's distribution system, and the ownership and management rights of the distribution system remain unchanged. Meanwhile, in order to achieve one of the purpose of this paper: comparing the changes of urban distribution carbon emission intensity before and after the optimization of enterprises urban distribution mode, this paper requires in the end of the pilot period the two enterprises to collect and provide energy consumption data in each distribution link and activity in the pilot period and the same period of last year, as well as the revenue of the two periods. This paper provides detailed description of the energy data collection method to enterprise B and enterprise C.

Table S15. Specific energy consumption of enterprise B and enterprise C before and after the pilot of distribution mode optimization scheme.

Distribution Links or Activities	Energy Consumption Equipment	Energy Consumption Type	Unit of Activity Data	Value of Activity Data	
				The Same Period of Last Year	The Pilot Period
Stocking	Barcode scanners	Electricity	MWh	0.19	0.23
Storage	Dehumidification, ventilation, insulation, monitoring and other devices	Electricity	MWh	0.61	0.59
Loading	Computers	Electricity	MWh	4.69	5.35
Transport	Van trucks with internal combustion	Diesel fuel	t	31.31	33.15
Transport	Van trucks with internal combustion	Liquefied natural gas	t	6.85	8.45
Handling	Forklifts with internal combustion	Diesel fuel	t	6.79	8.59
Handling	Electric forklifts and guided vehicles	Electricity	MWh	34.76	40.15
Lighting	Lighting equipments	Electricity	MWh	1.83	1.83

Table S16. Tabulate data on energy consumption and revenue of enterprise B and enterprise C before and after the pilot.

Energy Consumption Type	Activity Data of the Same Period of Last Year	Activity Data of the Pilot Period
Diesel fuel	38.1 t	41.74 t
Liquefied natural gas	6.85 t	8.45 t
Electricity	42.08 MWh	48.15 MWh
The revenue of the same period of last year: 923,500 CNY; The revenue of the pilot period: 1164,200 CNY.		

Although the ownership and management rights of the distribution system remain unchanged after adopting mutual distribution mode, due to the sharing and integration of distribution resources, therefore, taking urban distribution system carbon footprint of enterprise B and enterprise C as a whole is more reasonable, and the collection of energy consumption activity data does not distinguish between enterprises. The pilot of mutual distribution mode in enterprise B and enterprise C ends in September 2014. Specific energy consumption data is shown as Table S15, and the tabulate results of activity data and revenue according to the energy category are shown as Table S16.

Based on the completion of the collection of the activity data in the above, according to Equation (4) and Equation (5) constructed in the part of carbon accounting methods as well as the relevant reference data (Shown as Table S4, Table S5 and Table S6), the carbon emission intensity before and after enterprise B and enterprise C pilot mutual distribution mode can be calculated. The specific calculation process is as follows.

$$m = CE_d + CE_{in} = \sum_l \sum_f (AD_f \times Q_f \times EF_{f,l} \times 10^{-6} \times GWP_l) + AD_e \times EF_e \tag{4}$$

$$UDCEI = m/R \tag{5}$$

$$\begin{aligned} UDCEI' = m'/R' &= \left[\sum_l \sum_f (AD_f' \times Q_f \times EF_{f,l} \times 10^{-6} \times GWP_l) + AD_e' \times EF_e \right] \Big/ R' \\ &= [38.1 \times 42652 \times (72.6 \times 1 + 0.0039 \times 25 + 0.0039 \times 298) \times 10^{-6} + 6.85 \times 46900 \times \\ &\quad (62.9 \times 1 + 0.092 \times 25 + 0.003 \times 298) \times 10^{-6} + 42.08 \times 0.9223] \div 92.35 \\ &= 180.07 \div 92.35 \\ &\approx 1.95 tCO_2 / 10^4 CNY \end{aligned}$$

$$\begin{aligned} UDCEI = m/R &= \left[\sum_l \sum_f (AD_f \times Q_f \times EF_{f,l} \times 10^{-6} \times GWP_l) + AD_e \times EF_e \right] \Big/ R \\ &= [41.74 \times 42652 \times (72.6 \times 1 + 0.0039 \times 25 + 0.0039 \times 298) \times 10^{-6} + 8.45 \times 46900 \times \\ &\quad (62.9 \times 1 + 0.092 \times 25 + 0.003 \times 298) \times 10^{-6} + 48.15 \times 0.9183] \div 116.42 \\ &= 201.90 \div 116.42 \\ &\approx 1.73 tCO_2 / 10^4 CNY \end{aligned}$$

Therefore, the amplitude of variation of urban distribution carbon emission intensity of enterprises B and enterprises C after the pilot of the optimization program than that in the same period of last year is: $(UDCEI' - UDCEI) / UDCEI' \times 100\% = (1.95 - 1.73) / 1.95 \times 100\% \approx 11.28\%$.