International Journal of Systems Science and Applied Mathematics
2021; 6(3): 95-110
http://www.sciencepublishinggroup.com/j/ijssam
doi: 10.11648/j.ijssam.20210603.12
ISSN: 2575-5838 (Print); ISSN: 2575-5803 (Online)

Logistics Network Design for Vegetable Waste Reduction and Recycling System Based on Multi-dimensional Perspective

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To cite this article:
Juan Yang, Yongliang Liu, Haorui Liu. Logistics Network Design for Vegetable Waste Reduction and Recycling System Based on Multi-dimensional Perspective. *International Journal of Systems Science and Applied Mathematics.* Vol. 6, No. 3, 2021, pp. 95-110. doi: 10.11648/j.ijssam.20210603.12

Received: June 27, 2021; **Accepted**: July 22, 2021; **Published**: July 29, 2021

Abstract: Aiming at the problem of insufficient recycling and recycling of vegetable wastes, under the conditions of three different on-site processing capabilities, the logistics network design scheme of vegetable waste reduction and resource utilization system was discussed. the present study discussed a quantitative model of the VW-RRS that meets comprehensive benefits based on the theory of circular economy, combined with reverse logistics theory and life cycle theory, and further designed a logistics network of VW-RRS from multi-dimensional perspectives. For the systematic VW treatment, the efficiency of the circular economy system has an obvious promotion effect. Based on the functions and interrelationships of the various participants in the system and the goal of achieving sustainable development in the three dimensions of economy, environment and society, a logistics network model of a reduced resource system has been established. Take Shouguang City as an example to optimize and reconstruct the logistics network of vegetable waste reduction in this region. The research shows that: after the vegetable waste is reduced, the total cost of the system is reduced; when the vegetable waste resource utilization capacity remains unchanged, the ratio of vegetable waste recycling is increased, and the economic and environmental benefits of the system are improved accordingly; The resource utilization capacity, the system's economic and environmental benefits have also improved accordingly.

Keywords: Vegetable Waste, Reduction and Recycling System, Logistics Network Design

1. Introduction

The vegetable planting area and output are increasing year by year in China. In 2018, the planting area reached 22 million hectares and the total output was 817 million tons. China has become the world's largest producer and consumer of vegetables and with that comes the problem of vegetable waste (VW) [1]. In 2018, the VW in China was nearly 281 million tons, of which 234 million tons were recyclable. The waste mainly derived from vegetable production bases, distribution centers and processing sites. It not only takes up a lot of area, but also pollutes the environment seriously and further negatively affects the sustainable development of cities and supply chains. Thus, the harmless treatment and comprehensive utilization of VW has become an urgent problem in China [2]. Vegetable and straw wastes are explosively generated during the harvest season. Collection and storage are of problems and it is difficult to handle them in a short period of time by conventional procedures. VW in most vegetable production bases is randomly accumulated and burned on the spot and the waste is landfilled in urban. This traditional and widely used treatment method has caused serious waste of resources and environmental problems. There is an urgent need to scientifically manage the source, process and recycling of VW and establish a vegetable waste reduction network system. Recycling is an effective means to prevent pollution from the source. It is necessary to pay attention to the protection and rational allocation and utilization of resources while the economy is developing rapidly. Effective use of agricultural waste resources will help to promote the green development of rural areas and create a new pattern of harmonious development between man and nature.

"Agricultural waste" and "recycling utilization" have become the high-frequency emerging words in recent research. This not only reflects the transformation of the research objects of agricultural waste treatment, but also the continuous emergence of agricultural waste utilization under low-carbon constraints. Over the past two decades, scholars have conducted extensive and profound discussions and studies on agricultural waste management in China. Although some progress has been made, there is still a long way to go. The research mainly focuses on the recycling of agricultural waste, its impact on the ecological environment, development of animal husbandry, and its ecological compensation.

The cutting-edge research shows that deepening exploration of agricultural waste utilization under low-carbon constraints is a trend of agricultural waste. [3] There are complex practical problems in the utilization of resources (especially energy) and finding effective ways to use agricultural waste as resources. The Ministry of Agriculture of China proposed the "Guidelines for Ecological Circular Agriculture Projects in Comprehensive Agricultural Development Areas (2017~2020)" in 2016, aiming to promote the efficient use of resources, reduce agricultural inputs, recycle waste and standardize clean production processes. Vegetable waste management was begun to be studied in the late 1990s. At present, potential analysis, influencing factors and the measures for reducing VW and resource utilization have become the research focus and hotspot in this field. Ru et al. established a dynamic model to evaluate the economic effectiveness of vegetable waste management to provide guidance for relevant decision-making. Du et al. analyzed the advantages and disadvantages of various resource utilization methods of VW, indicating the potential for efficient use of the waste in China was huge. [4]

Since the 1980s, the waste treatment methods specifically for VW, mainly including aerobic composting, anaerobic digestion, aerobic-anaerobic combined treatment, etc. have begun to be studied in many countries. [5] At present, the VW treatment and utilization have become mature in the developed countries. It can be divided into two categories: one is the recycling through returning straw to the field. The other is the industrialized use of straw. The industrialized utilization mainly focuses on the new energy sources such as straw power generation, compact fuel and cellulosic ethanol. VW is also used to produce environmentally friendly straw panels and building in the United States, Canada and Europe. [6] In China, the waste is processed and reused mainly through anaerobic fermentation and high-temperature composting. [7] However, the recycling and comprehensive utilization of the waste need to be further studied. Du's research (2015) indicated that composting is the most effective way to achieve rapid resource utilization of VW in China. [4]

Contingent valuation method, social capital theory, ordinal probit model, circular economy theory are several methods used to study the comprehensive utilization and management of agricultural waste resources. [8-11] After the introduction of life cycle theory into the food industry in the 21st century, some scholars proposed to combine life cycle theory and system dynamics to establish the integrated management system and explore technical methods of food waste. Joel determined the boundaries and functional elements of the food waste management system based on the life cycle theory, and further discussed different stages of VW treatment, including collection, classification, transportation, recycling, reuse, landfill, and the energy balance produced by system. [12] Svanes Erik et al. investigated apple, sweet cherry, plum and other fruit nurseries in Norway, analyzed the orchard infrastructure and the full life cycle of the orchard, then evaluate the environmental life cycle of product waste generated through the value chain based on the life cycle theory. [13] At present, the comprehensive VW management using life cycle theory has not yet fully implemented.

With the increasing concern of environmental issues around the world, the widespread recognition and application of circular economy theories, many countries around the world have issued corresponding laws and regulations to encourage waste recycling. The theory of material recycling based on reverse logistics has become a hotspot. Sun et al. analyzed and summarized the Japanese quantitative measures and management systems that strengthened the management of food waste reduction and recycling, including quantitative management organization system, target quantitative system, a statistical investigation system, and a waste quantitative management system. [14] In addition, Song and Chai analyzed and compared the advantages and disadvantages of 4 different VW treatment and utilization modes in Shouguang city, China, as well as 3 off-field treatment modes from the perspective of economic benefits. They concluded that in terms of processing cost, processing volume and product quality, none of these treatment methods were the completely satisfactory solutions to the problem of VW pollution in China. [15] At this stage, the harmless treatment of VW in China is still relatively low. A large amount of waste is incinerated on-site and directly landfilled. Although on-site incineration can effectively kill pathogenic organisms and reduce their reproduction and spread, it will generate a lot of dense smoke, causing a series of serious air pollution such as haze weather. While direct landfilling is simple and low-cost, but it is easy to spread pathogens and aggravate continuous cropping obstacles. Besides, organic wastes are prone to produce bio-toxicity during the accumulation of landfill, leading to serious agricultural non-point source pollution and resource waste. At the same time, it also resulted to the problems such as pesticide residues, soil structure destruction and secondary soil salinization.

Therefore, increasing the recycling is the most reasonable and effective way to solve VW problem at present and in the future.

The current resource utilization of vegetable straw waste is still in its infancy. Government agricultural departments, vegetable straw waste treatment enterprises and vegetable production and operation organizations need to continue to promote its development together. Reviewing the previous literature, a certain amount of explorations and studies have been carried out on the reduction and recycling of vegetable from different perspectives in recent years, and they have made some important achievement. A vegetable waste reduction and recycling system (VW-RRS) has been studied and discussed widely from the perspectives of economy, environment, and society. In order to achieve the coordinated development of economy, environment and society, more in-depth quantitative researches are needed. For example, using mathematical programming models, starting from the perspective of the combination of supply chain and system, integrate the economic, environmental and social benefits to investigate the VW resource reduction system.

In view of this, the present study discussed a quantitative model of the VW-RRS that meets comprehensive benefits based on the theory of circular economy, combined with reverse logistics theory and life cycle theory, and further designed a logistics network of VW-RRS from multi-dimensional perspectives. For the systematic VW treatment, the efficiency of the circular economy system has an obvious promotion effect.

2. Problem Description and Basic Assumptions

2.1. Problem Description

Vegetables generally show the characteristics of strong seasonality, short storage period, difficult to transport and perishable. The peak harvest period is generally in the high temperature season. Vegetable waste derives from every stage from seedlings to maturity, harvest to market, then to processing. The distribution of the waste is relatively concentrated, mainly in vegetable production areas, vegetable distribution centers and vegetable processing places (Table 1). [16].

Table 1. *Distribution of vegetable waste.*

Distribution area	Waste	Percentage
Vegetable production areas	Waster from pruning, pest damage and pulling seedlings	60%-70%
Vegetable distribution centers (mainly small and medium wholesale market)	Vegetables are perishable. Leafy vegetables cannot be transported over long distances. Eggplant fruit and vegetables organization no food value, variety and complexity.	10%-15%
Vegetable processing sites	The inedible or non-commercial parts of trimmings produced during the process of ordinary packaging (tray vegetables) and fresh-cut vegetables (clean vegetables) before entering the market, catering industry, and household pre-edible processing	20%-25%; The loss of leafy vegetables is the highest, with a loss rate of up to 60% in summer. [16]

The vegetable supply chain consists of a series of complex processes which produce a lot of waste including roots, stems and leaves with no commercial value, vegetables bitten by insects, bruise vegetables, rotten vegetables as well as that cannot be sold due to deterioration. The waste is generally treated by some basic methods with low economic and environmental value, such as animal feeding, anaerobic digestion, composting, incineration, land spreading and landfilling.

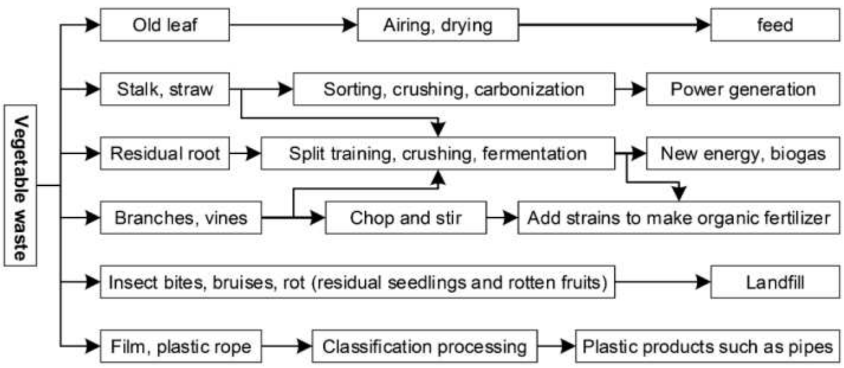

Figure 1. *Treatment methods and recycling of different types of vegetable waste.*

Different types of VW are treated and recycled by different methods. The leaves are shredded, sorted, screened and then processed into livestock feeds of varying specifications, thereby reducing the consumption of feed for the aquaculture industry. Roots and stems are chopped and reused as fuel. Treatment of straws is a focus of VW recycling. After crushing and screening machine on site, some straws are mixed with livestock manure and biological bacteria and directly returned to the field for fermentation to form organic fertilizer afterwards. Some are transported to renewable processing plants to produce various renewable materials and clean energy. Different VW treatment methods and the uses after treatment are shown in Figure 1.

VW can generally be divided into three types: First, recyclable waste. The waste can be kept intact, clean and arranged and then directly recycled for feeding livestock. Second, waste that does not meet the previous point, but can be converted into renewable energy or renewable raw materials through special processing such as crushing, mixing, stirring, drying, adding biological bacteria, fermentation, etc., is called recyclable VW. The renewable energy can replace traditional raw materials including biogas, organic fertilizer, straw carbonization, biomass oil, etc.. Third, non-recyclable VW. The wastes cannot be reused or recycled in the first two methods and are finally landfilled.

3R refers to the three principles of VW reduction in circular economy (reduction, reuse, and recycling) to guide the practice of VW treatment. Reduction refers to decreasing the amount of waste generated from the output of the system. For example, provide relevant training for production personnel or increase technical input to obtain high-quality vegetables, so that they can be used by consumers to the greatest extent thereby cutting down the waste. Recycling means the effective classification, simple cleaning treatment and recycle of VW so that they can be used again. Reuse refers to using wastes again after reprocessing in the output stage, such as making vegetable straws to organic fertilizer and on-site retting of straws to the field to save the final landfill processing capacity.

The process of VW reduction involves multi steps and various environments. Collection, classification, preliminary processing, loading, transportation, bagging, remanufacturing, sales and landfill are the major steps of VW treatment and essential considerations for establishing an overall system. And the system should include the elements of people, objects and environment:

People means the stakeholders involved in the VW-RRS, mainly include vegetable planting bases or farmers, transportation companies, renewable resource processing plants, landfill treatment sites and relevant personnel in the consumer market. The attitudes of the above-mentioned personnel play a vital role in the efficient operation of VW.

Objects refer to all facilities used in the process of plant and all steps of the waste treatment, namely collection devices, loading equipment, crushing equipment, auxiliary biological fungi, testing and screening and sorting equipment as well as transportation vehicles.

Environment includes political, legal, cultural, economic, ecological, and technological background.

The goal of the VW-RRS is to maximize the comprehensive benefits of the economy, environment and society through scientific and effective management of the elements in the system, related elements, and related links under the circular economy model. The key process of establishing the VW-RRS is summarized in Figure 2 based on the life cycle theory, combined with analysis of literature data. In the figure, the ellipse represents the node site which is the bases with on-site processing conditions for vegetable waste (osPCfVW). The waste can be classified in the node site, the recyclable waste can be recycled and the non-recyclable can be transported from or landfilled here. The square represents the function of the node site. However, bases with osPCfVW need to transport VW to the disposal site for storage, sorting, recycling and landfill. The bases that have the conditions sell the classified recycled waste to the market and the recycling processing plant offer the recycling-related products obtained to the demand market.

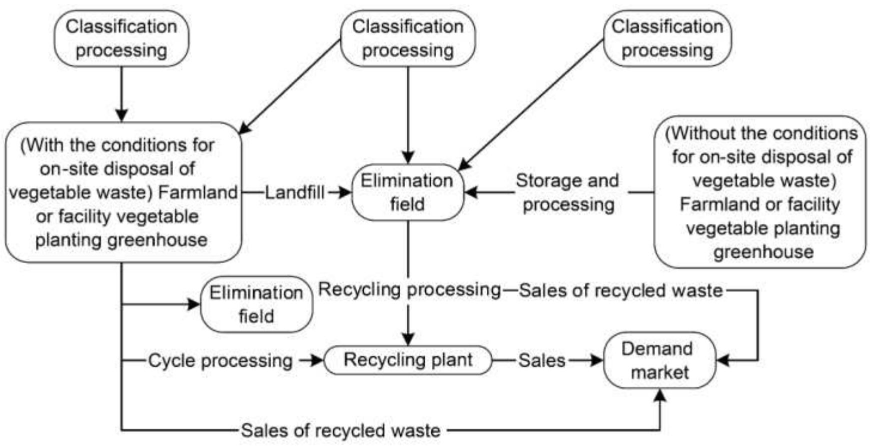

Figure 2. *Flow chart of vegetable waste life cycle management.*

2.2. Basic Assumptions

Based on literature review and the need to solve practical problems, the following hypotheses are proposed:

Assumption 1: the VW is disposed of in compliance with regulations, regardless of the situation of illegal landfill.

Assumption 2: The processing sites are both the production location of VW and the demand point of renewable resources. It is assumed that the demand for renewable resources at different demand points can be met.

Assumption 3: There is no loss of recyclable VW during the treatment process.

Assumption 4: various costs and benefits are calculated from the perspective of the supply chain system.

Assumption 5: the unit prices of renewable resources from different processing sites of VW in the market are all the same, where the price refers to the average price.

Assumption 6: since renewable resources are not suitable for long-term storage and must be used in time, they are immediately transported to the corresponding demand point or processing station after the collection and classification and the produced renewable resources are quickly transported to the corresponding market. Therefore, the demand for the market, the storage and storage costs are not considered here.

Assumption 7: the unit classification cost of VW in processing stations is lower than that in a single vegetable planting area due to the advantage of scale effect.

Assumption 8: the capacity limits of different processing facilities are known in advance.

Assumption 9: the transportation cost of VW has a linear relationship with transportation volume, distance, and unit transportation cost.

Assuming 10: the operating cost of transport vehicles will remain unchanged for a certain period of time.

Assumption 11: congestion, congestion in transportation and failure of the vehicle itself are not taken into consideration.

Model Building

Definition of Model Parameters and Decision Variables.

Index

b , vegetable planting bases that do not have the osPCfVW.

$b^{'}$, vegetable planting bases with osPCfVW and can directly return the waste to the field.

$b^{''}$, vegetable planting bases with osPCfVW but cannot directly returned it to the field.

Rp , recycling processing station.

l, disposal field number.

M, renewable resource consumption market.

Parameter Setting

Q_b , the quantity of VW produced by vegetable planting bases without osPCfVW.

$Q_{b^{'}}$, the quantity of VW produced by vegetable planting bases with osPCfVW and can directly return the waste to the field.

$Q_{b^{''}}$, the quantity of VW produced by vegetable planting with osPCfVW but cannot directly return waste to the field.

$Fc_{b^{'}}$, fixed opening cost of indirect return VW to field.

$Fc_{b^{''}}$, fixed opening cost of direct return VW to the field.

Fc_{Rp} , fixed opening cost of recycling processing station.

Fc_l , fixed opening cost of the consumption market.

$S_{b^{'}}$, government subsidies for every ton of VW directly returned to the field.

S_{Rp} , government subsidies for every ton of VW processed in the recycling process.

S_l , government subsidies for every ton of VW buried in the waste disposal field.

$Pc_{b^{''}}$, the maximum processing capacity for direct return.

Pc_{Rp} , the maximum processing capacity of recycling processing station.

Pc_l , the maximum absorption capacity of the absorption field.

D_{bl} , the distance from the vegetable planting bases without osPCfVW to the waste disposal site.

$D_{b^{'}l}$, the distance from the vegetable planting bases with osPCfVW and can directly return waste to the field to the consumption field.

$D_{b^{''}l}$, the distance from the vegetable planting bases with osPCfVW but cannot directly return waste to the field to the consumption field.

D_{lRp} , the distance from the disposal site to the recycling processing station.

D_{lm} , the distance from the consumption yard to the demand site of renewable resources.

$D_{b^{''}m}$, the distance from the vegetable planting bases with osPCfVW but cannot directly return waste to the field to the site of demand for renewable resources.

D_{Rpm} , the distance from the recycling processing station to the site of demand for renewable resources.

$C_{b^{'}}$, unit classification cost of VW from vegetable planting bases with osPCfVW.

$C_{b^{''}}$, unit classification cost of VW from vegetable planting bases with osPCfVW but cannot be directly returned to the field.

C_l , unit classification cost in the disposal field.

C_{Rp} , unit processing cost of recycled VW at the recycling processing station.

Cl_l , unit landfill cost of VW in the disposal site.

w_1 , recycling rate of the recyclable VW directly returned to field.

w_2 , recycling rate of recyclable VW non-directly returned to field.

w_3 , the proportion of recirculated processing VW.

C_{wt} , the transportation cost per unit distance of VW per unit quantity.

C_{pt} , transportation cost per unit distance of renewable resources per unit quantity.

QD_m , the demand for renewable resources in the renewable resource consumption market.

P_u , average unit sales price of recycled VW.

P_{Rp} , unit sales price of renewable resources after recycling processing.

Decision Variables

M_j =10 =: 1, open direct return processing point. 0, do not open direct return processing point.

M_{Rp} =10 =: 1; open recycling processing station. 0, do not open recycling processing station.

M_l =10 =: 1, open a dissipating field, 0, do not open a dissipating field.

N_j, the amount of VW directly returned to the field.

N_{bl}, the number of VW transported from vegetable planting bases without osPCfVW to the disposal site.

N_{lRp}, the number of VW transported from the waste disposal plant to the recycling processing station.

$N_{b'Rp}$, the number of VW transported from vegetable planting with osPCfVW but cannot directly return waste to the field to the recycling processing station.

$N_{b'l}$, the number of VW transported to the disposal field from vegetable planting bases with osPCfVW and can directly return waste to the field.

$N_{b''l}$, the number of VW transported to the disposal field from vegetable planting bases with osPCfVW but cannot be directly return waste to the field.

$N_{b''m}$, the quantity of renewable resources transported to demand points from vegetable planting bases with osPCfVW but cannot directly return waste to the field.

N_{lm}, the quantity of renewable resources transported from the consumption yard to the demand point.

N_{Rpm}, the number of recycled resources transported from the recycling processing station to the demand point.

Model Building

The benefits of VW-RRS is evaluated by revenues and costs of each node site. To be specific, the revenue comes from the sale of renewable resources and the costs mainly include the purchase cost of the facility, the classification and processing costs of VW, the landfill cost and the total costs of transportation. In summary, the system revenues are measured from three dimensions: economy, environment and society.

Total start-up costs of the system (mainly including mechanical equipment costs which should be deducted from farm machinery purchase subsidies; land and management costs).

$$\sum_{j} Fc_j M_j + \sum_{Rp} Fc_{Rp} M_{Rp} + \sum_{l} Fc_l M_l \tag{1}$$

Total costs of classification (including labor costs, costs of renting or purchasing classification equipment, costs of straw collection, etc.), that is the classification costs of the storage field for disposal, the vegetable bases with osPCfVW and can and cannot directly return waste to the field.

$$\sum_{b}\sum_{l} N_{bl} C_l M_l + \sum_{b'} C_{b'} Q_{b'} M_j + \sum_{b''} C_{b''} Q_{b''} \tag{2}$$

Total processing cost (including raw materials costs, labor costs, drying costs, energy costs, equipment operation costs), that is, the processing costs of recycling processing plant.

$$\sum_{Rp} C_{Rp} \left(\sum_{l} N_{lRp} M_l + \sum_{b''} N_{b''Rp} \right) M_{Rp} \tag{3}$$

Total costs for landfill (landfill costs required by the market), is the landfill costs of the storage field.

$$\sum_{l} Cl_l \left(\sum_{b} N_{bl} \left(1 - w_1 - w_2 - w_3\right) + \sum_{b'} N_{b'l} M_j + \sum_{b''} N_{b''l} \right) M_l \tag{4}$$

Total transportation costs (including labor costs, fuel costs and transporting means costs). It includes expense of transporting VW form bases without osPCfVW to the storage field for disposal and of transporting recyclable VW to a recycling processing plant. For the vegetable bases with osPCfVW but unable to directly return waste to the field, the recyclable VW are transported to a recycling processing plant and then the recycled resources is to places with needs, while the non-recyclable VW are transported to the storage field for landfill, then the storage field for disposal will transport recyclable VW to markets with needs. As for the bases with osPCfVW and can carry out direct return to the field, the non-recyclable wastes are transported to the storage field for the landfill. The transportation process incurs the costs.

$$\begin{aligned} & C_{wt} \left(\sum_{b}\sum_{l} N_{bl} D_{bl} M_l + \sum_{l}\sum_{Rp} N_{lRp} D_{lRp} M_{Rp} + \sum_{b''}\sum_{Rp} N_{b''Rp} D_{b''Rp} M_{Rp} + \sum_{b'}\sum_{l} N_{b'l} D_{b'l} M_l M_j + \sum_{b''}\sum_{l} N_{b''l} D_{b''l} M_l \right) \\ & + C_{pt} \left(\sum_{l}\sum_{m} N_{lm} D_{lm} M_l + \sum_{b''}\sum_{m} N_{b''m} D_{b''m} + \sum_{Rp}\sum_{m} N_{Rpm} D_{Rpm} M_{Rp} \right) \end{aligned} \tag{5}$$

Sales revenue of renewable resources:

$$P_u \left(\sum_{b'}\sum_{m} N_{b'm} M_j + \sum_{b''}\sum_{m} N_{b''m} + \sum_{l}\sum_{m} N_{lm} \right) + P_{Rp} \sum_{Rp}\sum_{m} N_{Rpm} M_{Rp} \tag{6}$$

Government subsidies:

$$\sum_{j} N_j S_j M_j + \sum_{l}\sum_{Rp} N_{lRp} S_{Rp} M_{Rp} + \sum_{b''}\sum_{r} N_{b''Rp} S_{Rp} M_{Rp} + \sum_{b}\sum_{l} N_{bl} S_l M_l + \sum_{b'}\sum_{l} N_{b'l} S_l M_l + \sum_{b''}\sum_{l} N_{b''l} S_l M_l \quad (7)$$

The Maximum Total System Revenues (Economic Dimension)

Total revenues for the reduction and resources recycle system of VW.

$$\begin{aligned}
Max = & \left[P_u \left(\sum_{b'}\sum_{m} N_{b'm} M_j + \sum_{b''}\sum_{m} N_{b''m} + \sum_{l}\sum_{m} N_{lm} \right) + P_{Rp} \sum_{Rp}\sum_{m} N_{Rpm} M_{Rp} \right] \\
& + \left[\sum_{j} N_j S_j M_j + \sum_{l}\sum_{Rp} N_{lRp} S_{Rp} M_{Rp} + \sum_{b''}\sum_{r} N_{b''Rp} S_{Rp} M_{Rp} + \sum_{b}\sum_{l} N_{bl} S_l M_l + \sum_{b'}\sum_{l} N_{b'l} S_l M_l + \sum_{b''}\sum_{l} N_{b''l} S_l M_l \right] \\
& - \left[\sum_{j} Fc_j M_j + \sum_{Rp} Fc_{Rp} M_{Rp} + \sum_{l} Fc_l M_l \right] - \left(\sum_{b}\sum_{l} N_{bl} C_l M_l + \sum_{b'} C_{b'} Q_{b'} M_j + \sum_{b''} C_{b''} Q_{b''} \right) \\
& - \left[\sum_{Rp} C_{Rp} \left(\sum_{l} N_{lRp} M_l + \sum_{b''} N_{b''Rp} \right) M_{Rp} \right] - \left[\sum_{l} Cl_l \left(\sum_{b} N_{bl} \left(1 - w_1 - w_2 - w_3\right) + \sum_{b'} N_{b'l} M_j + \sum_{b''} N_{b''l} \right) M_l \right] \\
& - \left\{ \begin{aligned} & C_{wt} \left(\sum_{b}\sum_{l} N_{bl} D_{bl} M_l + \sum_{l}\sum_{Rp} N_{lRp} D_{lRp} M_{Rp} + \sum_{b''}\sum_{Rp} N_{b''Rp} D_{b''Rp} M_{Rp} + \sum_{b'}\sum_{l} N_{b'l} D_{b'l} M_l M_j + \sum_{b''}\sum_{l} N_{b''l} D_{b''l} M_l \right) \\ & + C_{pt} \left(\sum_{l}\sum_{m} N_{lm} D_{lm} M_l + \sum_{b''}\sum_{m} N_{b''m} D_{b''m} + \sum_{Rp}\sum_{m} N_{Rpm} D_{Rpm} M_{Rp} \right) \end{aligned} \right\}
\end{aligned} \quad (8)$$

Where, the first three items are the restricted revenues of renewable resources, including various government subsidies, and the followed are the total costs spent on start-up, classification, processing, landfilling and transportation.

The Minimum Average Transportation Distance Per Unit of VW (environmental dimension)

The analysis of life cycle of VW indicates that transportation is the link that has the greatest influence on environment. Besides, it also pointed out that the energy consumed in the transportation process even exceeds the energy generated from recycle and reuse. At here, in some practices like drawing lessons from others, the impact of transportation on environment is measured by the average transportation distance.

$$Min \quad Md = \frac{\left(\begin{aligned} & \sum_{b}\sum_{l} N_{bl} D_{bl} M_l + \sum_{l}\sum_{Rp} N_{lRp} D_{lRp} M_{Rp} + \sum_{b''}\sum_{Rp} N_{b''Rp} D_{b''Rp} M_{Rp} + \sum_{b'}\sum_{l} N_{b'l} D_{b'l} M_l M_j \\ & + \sum_{b''}\sum_{l} N_{b''l} D_{b''l} M_l + \sum_{l}\sum_{m} N_{lm} D_{lm} M_l + \sum_{b''}\sum_{m} N_{b''m} D_{b''m} + \sum_{Rp}\sum_{m} N_{Rpm} D_{Rpm} M_{Rp} \end{aligned} \right)}{\left(\begin{aligned} & \sum_{b}\sum_{l} N_{bl} M_l + \sum_{l}\sum_{Rp} N_{lRp} M_{Rp} + \sum_{b''}\sum_{Rp} N_{b''Rp} M_{Rp} + \sum_{b'}\sum_{l} N_{b'l} M_l M_j \\ & + \sum_{b''}\sum_{l} N_{b''l} M_l + \sum_{l}\sum_{m} N_{lm} M_l + \sum_{b''}\sum_{m} N_{b''m} + \sum_{Rp}\sum_{m} N_{Rpm} M_{Rp} \end{aligned} \right)} \quad (9)$$

The numerator represents the total transport distance after optimization, and the denominator represents the total transport quantity.

The Maximum Comprehensive Ratio of Recycling and Re-circulation (Social Dimension)

The degree of utilization of the VW is indirectly represented by the sum of recycling and reused proportion (including waste directly returned to the field) as well as the recirculated and processed proportion. The higher the utilization rate, the smaller the negative impact on the society. So the sum of proportions is used to describe the social benefits of the system.

$$Max \, \rho_\theta \quad = w_1 + w_2 + w_3 \quad (10)$$

Where w_1 is the recycling rate of waste directly returned to the field, w_2 is the proportion of recycled waste non-directly returned to the field, w_3 is the proportion of recirculated processed VW.

Constraints

The model must meet the following constraints:

The quantity of VW that can be directly returned to the field is equal to the total amount of waste produced in all vegetable bases.

$$Q_{b'} w_1 = \sum_j N_j M_j, \forall j \quad (11)$$

The quantity of non-recyclable VW produced in the vegetable bases with osPCfVW and can carry out direct return to field is equal to the total amount of non-recyclable VW that are transported to all storage fields for disposal.

$$Q_{b'}\left(1 - w_1 - w_2 - w_3\right) = \sum_l N_{b'l} M_l, \forall b' \quad (12)$$

The quantity of non-recyclable VW produced in the vegetable bases with osPCfVW but unable to directly return waste to field is equal to the total amount of non-recyclable VW that are transported to all storage fields for disposal.

$$Q_{b''}\left(1 - w_2 - w_3\right) = \sum_l N_{b''l} M_l, \forall b'' \quad (13)$$

The quantity of all VW that are produced by the vegetable bases without osPCfVW is equal to the total amount of VW that are transported to all storage fields for disposal.

$$Q_b = \sum_l N_{bl} M_l, \forall b \quad (14)$$

The quantity of renewable resources that are generated by recyclable VW in the bases without osPCfVW is equal to the total amount of products that are transported to all renewable resource markets.

$$\sum_b Q_b w_2 = \sum_l \sum_m N_{lm} M_l \quad (15)$$

The total quantity of recyclable VW produced by the vegetable bases with osPCfVW but unable to carry out direct return to field is equal to the amount of recyclable VW that are transported to all recycling processing stations.

$$Q_{b''} w_3 = \sum_{Rp} N_{b''Rp} M_{Rp}, \forall b'' \quad (16)$$

The total quantity of recyclable VW that are transported to the storage field for disposal and produced in the vegetable bases without osPCfVW is equal to the amount of recyclable VW that are transported to all recycling processing stations.

$$w_3 \sum_b N_{bl} M_l = \sum_{Rp} N_{lRp} M_l M_j, \forall j \quad (17)$$

The amount of renewable resources that are converted by recyclable VW transported to the recycling processing stations is equal to the sum of the products transported by the recycling processing stations to all renewable resource markets.

$$\sum_{b''} N_{b''Rp} M_{Rp} + \sum_l N_{lRp} M_l M_{Rp} = \sum_m N_{Rpm} M_{Rp}, \forall Rp \quad (18)$$

The amount of renewable resources converted by recyclable VW produced by the vegetable bases with osPCfVW but unable to carry out direct return to field is equal to the sum of the products transported to all renewable resource markets.

$$Q_{b''} w_2 = \sum_m N_{b''m} M_j, \forall b \quad (19)$$

The quantity of recyclable VW that are transported to the recycling processing station shall not exceed its maximum disposal capacity.

$$\sum_{b''} N_{b''Rp} M_{Rp} + \sum_l N_{lRp} M_l M_{Rp} \le Pc_{Rp} M_{Rp}, \forall Rp \quad (20)$$

The quantity of non-recyclable VW that are transported to the storage field for disposal shall not exceed its maximum disposal capacity.

$$\sum_b N_{bl} M_l + \sum_{b'} N_{b'l} M_l M_j + \sum_{b''} N_{b''l} M_l \le Pc_l M_l, \forall l \quad (21)$$

The total amount of products transported to the market for renewable resources should be greater than its market demands.

$$\sum_l N_{lm} M_l + \sum_{b''} N_{b''m} + \sum_r N_{Rpm} M_{Rp} \ge QD_m, \forall m \quad (22)$$

Variable type constraints:

$$M_{Rp} \in \{0,1\}, \forall Rp; M_j \in \{0,1\}, \forall j; M_l \in \{0,1\}, \forall l; \quad (23)$$

$$N_{bl}, N_{lRp}, N_{b'Rp}, N_{b''Rp}, N_{b'l}, N_{b''l}, N_{b''m}, N_{b'm}, N_{lm}, N_{Rpm} \ge 0, \forall b, b', b'', Rp, l, m \quad (24)$$

3. Empirical Research

3.1. Relevant Data

The Shouguang City (Vegetable) Industry Revitalization Plan (2018-2022) showed that in 2016, the perennial planting area of vegetables in Shouguang City was 1.21 million mu, with a total annual vegetable production of 6.6 billion kilograms and an increase of 4.8 billion yuan in revenue. The amount of VW produced by the entire city reached 2.29 million tons. The Shouguang City Vegetable Wastes Recycling and Reutilization Measures and Implementation Rules were formulated and promulgated in 2019, according to the public data released by the Shouguang Vegetable and Agriculture Bureau. 17 enterprises participated in the project and planned to process 1.15 million tons of VW annually. At present, there are 15 enterprises dealing with VW in the city. The annual recycling and reuse of VW exceeds 150,000 tons and the rest of the waste is completely transported and cleared through environmental sanitation integration. [17] Shouguang City has explored and established a mode of socialize service + market-oriented operation that relies on professional management and service organizations to complete the recycling and reuse of agricultural wastes, such as VW and straw wastes. The government supports industrial development through service purchases, equipment ancillary and product subsidies and also adopt some technical operation modes such as the regional centralized and the block-based socialized treatment mode, considering the actual situation of agricultural production and the characteristics of VW generated in various regions, which have promoted the sustainable development of comprehensive utilization in VW.

The counties and districts under the jurisdiction of Shouguang City are taken as the objects to study the VW treatment, among which, a single district or county was considered as an independent object. Shouguang City has over 5 sub-district administrative offices, namely Shengcheng Street, Wenjia Street, Luocheng Street, Gucheng Street and Sunjiagi Street. Besides, it has 9 towns (Daotian Town, Hou Town, Jitai Town, Hualong Town, Shangkou Town, Tianliu Town, Yingli Town, Taitou Town, Yangkou Town) and 975 administrative villages, of which 483 are villages specially for vegetable planting, accounting for 50% of the county-level administrative villages. Due to urban planning and geographical location restriction, the northwest, southwest, central old urban area and eastern area of Shouguang urban do not have the condition to classify and dispose VW. In the western part of central urban area, the high-tech agricultural industries assemble in the area of about 2 square kilometers from east to the Western Ring Road, south to the Shengcheng Street, west to the Yangqing Road and north to the Northern Ring Road, which are committed to agricultural innovation, agricultural exhibition and related supporting service. The remaining sites located in the second, third and fourth layers are sufficiently large for the classification and disposal of VW. Some districts and counties are not only the production sites of VW, but also the consumption market of renewable resources. The number of recycling processing stations is assumed 15, the maximum processing capacity of each is 200,000 tons, and the fixed start-up cost is 3 million yuan. Four storage fields for disposal of VW are confirmed, located in Bohai Road, Shouguang City, Cui Jia Zhuang village, Sunjiagi Street, Yangkou Town and Daotian Town. Their maximum processing capacities are 1 million cubic meters, 200,000 cubic meters, 100,000 cubic meters and 500,000 cubic meters, respectively and the total amount of VW that can be disposed of is approximately 1.8 million cubic meters. The corresponding fixed start-up costs of them respectively is 1 million yuan, 300,000 yuan, 200,000 yuan and 600,000 yuan. In addition, other data involved in the model solution process come from the real data released by Public Information Network of Shouguang Statistics and the relevant published research reports.

The spatial distribution of vegetable specialized villages in Shouguang City is relatively concentrated, generally in the southwestern. The spatial distribution of each villages is quite different and the regional density is obvious, which indicates that the concentration degree of specialized villages in each town is different. The development degree in Jitai Town and Sunjiagi Street is high, followed by the Daotian Town and Luocheng Street. Hualong Town, Gucheng Street, Shangkou Town are relatively less developed. Shouguang City adopts five models to promote the disposal of VW recycling. The first is straw bio-oil model. VW are made into the biomass fuel and biochar powder through high temperature pyrolysis and liquefaction technology, and then to produce the biomass extracting solution and biochar fertilizers trough deep processing. The second is the straw organic fertilizer model. Vegetable straws are made into organic fertilizer through bio-fermentation technology so as to realize recycling. The third is straw carbonization model. Eggplant, pepper, tomato and other highly lignified vegetable straws are produced to charcoal by high-temperature sealing carbonization technology, thereby achieving pollution-free emission. The fourth is the straw methane model. Straw, livestock manure and other garbage are made into biogas, which is used in human production and daily life. The biogas residue and biogas slurry can be used as fertilizer for agricultural production. The last one is straw solidification model. After solidification the waste is sent to the biomass power plant to burn for power generation.

Shouguang City Vegetable Wastes Recycling and Reutilization Measures clearly stipulates the collection, transportation and recycling of VW and implements the operation mechanism supported by government and managed by enterprise. Besides, the government provides appropriate subsidies to enterprises in accordance with the amount of VW processed. A subsidy of 30 yuan is given to the recycling enterprises (producing organic fertilizer, straw carbonization, solidification, bio-oil making, biogas production) for each ton of nightshade (eggplant, pepper) wastes processed, 60 yuan for each ton of vines wastes. A subsidy of 20 yuan is given to the biological power plant for the burn of every ton of VW (Figure 3). [18-19]

3.2. Model Solution

Under the condition that the proportions of VW are directly returned to the field, recycled and recirculated, respectively (assuming the proportions are $w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.30$), the supply chain network model of VW is a traditional large-scale 0-1 mixed-integer nonlinear programming. The ideal point method is adopted to transport VW or renewable resources between different nodes by following the principle of the nearest distance.

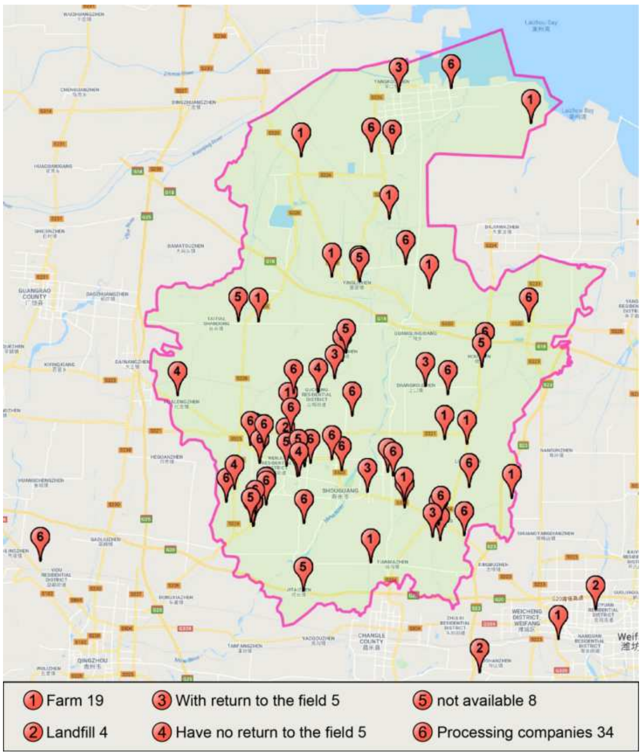

Figure 3. *Distribution of storage fields for vegetable wastes disposal in Shouguang City.*

The real data published by Shouguang Statistical Information Network and related public research report were collected and substituted into the model for building partial correlation formula, then the Lingo was used to solve the formula. The results are shown in Table 2 and Table 3. Table 2 shows that the total cost of the system is greater than the sales revenue of renewable VW products and the total revenue of the system is negative. One reason is the fixed startup cost when the system was initially established. Besides, even with the reasonable and effective reverse network design under the existing conditions, the transportation cost is still high, accounting for nearly 85% of the total cost. However, if the VW are directly filled into land without any treatment, the total cost (sum of startup cost, transportation cost and landfill cost of storage field for disposal) reaches 758.59 million yuan. By comparison, it can be found that the optimized system saves about 478.1 million yuan. For users downstream in the external supply chain of the system, the price of renewable resources with the same quality is much lower than the market price, which save the cost of purchasing raw materials. In 2019, the Central Finance in China highlighted the policy of green orientated, agricultural machinery purchase subsidy requirements released by the Ministry of Agriculture and Rural Affairs of the Peoples Republic of China from 2019 to 2020 which were developing green agricultural machinery in line with demands, including strong support for returning straw to/out of the field, promotion and application of green and efficient equipment such as resource utilization of VW and setting agricultural machinery purchase subsidy funds for green farm machinery.

Table 2. *Objective function, revenue and total cost.*

Revenue (Million Yuan)	Average transportation distance (km)	Sales revenue (Million Yuan)	Government subsidy (Million Yuan)	Total cost (Million Yuan)
-224.09	30.16	478.1	56.4	758.59

Table 3. *Costs of the vegetable waste reduction and recycling system.*

	Startup cost	Classification cost	Processing cost	Landfill cost	Transportation cost
Amount (Million Yuan)	34.7	50.8	30.57	4.52	638
Proportion	4.57%	6.70%	4.03%	0.60%	84.10%

In addition, as for VW-RRS, VW is used as straw fertilizer that can improve soil quality and promote the healthy growth of vegetables and minimize the occurrence and spread of vegetable pests and diseases, thereby reducing the amount of pesticides. It also decreases the use of traditional fertilizer and therefore cuts down the arisen pollution on land, air and water. In a word, recycle and reuse of VW can not only save natural resources but also effectively protect the environment.

It can be seen from Table 3 that in the cost structure of the VW-RRS, the transportation cost accounts for 84.10% and is the highest among all kind of followed by the classification cost, the startup cost and the processing cost. Therefore, taking effective measures to reduce transportation costs has become the further thinking and research direction of system managers.

4. Results Analysis and Discussion

The proportions of VW directly returned to the field, recycled and recirculated reflects the amount of renewable resources of VW entering the terminal of the system. With a certain amount of VW, the more renewable resources produced, the stronger people's awareness of environmental protection, the higher acceptance of renewable resources and the higher the technical level of the reduction system. Vegetable planting is scattered and there are many harvest periods, which means the VW are generated all the year. It is not conducive to unified recycle and treatment and causes high collection costs. The more VW is recycled, the more people will be involved in the recycle and disposal, that is to say, the more jobs the system creates. Besides, it cuts down the VW that are finally landfilled and cause less resources wasted. There are many other benefits like less pollution to air and soil caused by diffusion or leakage, less harm to sustainable agricultural production and human health, and greater comprehensive social benefits. Thus, the proportions of VW that are directly returned to the field, recycled and recirculated processing indirectly represents the social, economic and environmental benefits of the system.

The method of this article is different from the waste identification mechanism based on the average profit rate of the enterprise. The latter calculates the cost and benefit of different types of low-value waste based on the cost perspective of the whole process of recycling, transportation, and disposal, and then calculates the corresponding subsidy. To form a systematic low-value waste subsidy accounting method, both emphasize compliance with the operating laws of the market economy, attract enterprises to participate in the recycling of low-value vegetable waste, promote waste reduction and resource utilization, and then do a good job of national vegetables Waste separation and recycling work.

The Situations Where the Recycling Ability of VW Remain Unchanged.

Assuming that the sum of proportions of VW that are directly returned to the field, recycled and recirculated is 0.80, the sum of total proportion for direct return to field and recycled $w_1 + w_2$ is reduced from 0.50 to 0.30 and the proportion of recirculated processing w_3 will increase from 0.30 to 0.50, correspondingly. Based on this, the economic, environmental benefits and different cost changes of the reduction and recycling system are investigated.

Table 4. *Changes in the systems comprehensive benefits (total quantity of resources recycle is fixed, Million Yuan).*

Number	Proportion of wastes directly returned to field, recycled and recirculated processing	Benefits	Sales revenue	Government subsidy	Total cost
1	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.30$	-251.20	536.10	60.40	847.65
2	$w_1 = 0.1425$, $w_2 = 0.3325$, $w_3 = 0.325$	-241.70	516.00	59.00	816.73
3	$w_1 = 0.135$, $w_2 = 0.315$, $w_3 = 0.35$	-232.40	495.80	57.60	785.81
4	$w_1 = 0.1275$ $w_2 = 0.2975$, $w_3 = 0.375$	-223.00	475.68	56.21	754.89
5	$w_1 = 0.12$, $w_2 = 0.28$, $w_3 = 0.40$	-213.63	455.53	54.80	723.97
6	$w_1 = 0.1125$, $w_2 = 0.2625$, $w_3 = 0.425$	-204.27	435.39	53.39	693.05
7	$w_1 = 0.105$, $w_2 = 0.245$, $w_3 = 0.45$	-194.90	415.25	51.98	662.13
8	$w_1 = 0.0975$, $w_2 = 0.2275$, $w_3 = 0.475$	-185.54	395.10	50.57	631.21
9	$w_1 = 0.09$, $w_2 = 0.21$, $w_3 = 0.50$	-176.17	374.96	49.16	600.29

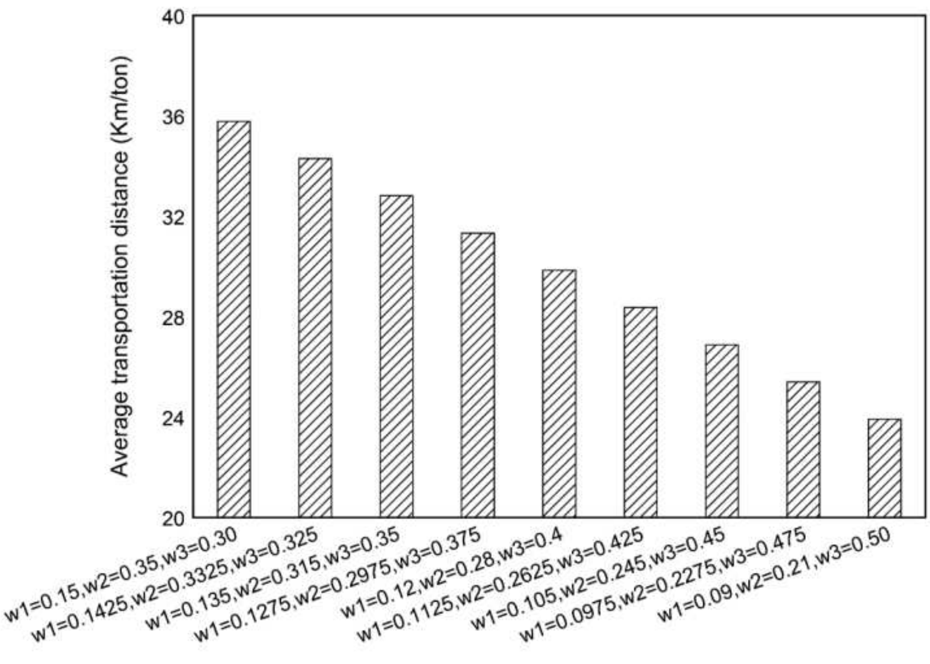

Figure 4. *Changes in average transportation distance of the system (total quantity of resources recycle remains unchanged).*

It can be seen from Table 4 that when the sum of proportions of VW that are directly returned to the field, recycled and recirculated processing remains unchanged, increasing the recirculation ratio will improve the economic and environmental benefits of the whole system, but the income gained from the sales of recycled resources is declined. This is because in this case, some VW can be directly sold to the market with demands for renewable resources without being transported to recycling and processing stations for treatment, thus reducing the costs of processing and transportation. However, since the price of recycled vegetable products is much lower than that of renewable resources dealt after recirculated process, the increase of proportion accounted by VW recycling leads to a decline in sales income. The total income is negative, which further verifies that the total cost in the current VW reduction and recycling system is too high and it has not entered the profitability stage. The investment cost during early stage is too large and the transportation processing cost is too high, so it is necessary to further reduce corresponding costs.

Figure 4 shows that with the increase of recycling proportion, the average transportation distance of the whole system shows a continuous downward trend. That is, under the condition that the sum of the proportion is constant, the environmental benefits of the system enhance with the increase of recycling ratio.

Table 5 shows that when the sum of proportions of VW directly returned to the field, recycled and recirculated processing is fixed, the total startup cost of the system, the classification cost and the landfill cost remain unchanged. From the results presented by the program operation, 4 storage fields for disposal and 17 recycling processing stations need to be established in all 9 types of cases, so the startup cost is the same. However, the classification cost and the amount of VW generated are related to the location of classification disposal. Because the quantity of wastes produced by each planting base is fixed, the wastes produced in the planting bases without osPCfVW need to be transported to the storage field for classification and disposal; and the VW produced in the planting base with osPCfVW will be classified and disposed on the spot, so the total cost for classification of the system remains unchanged. In addition to direct return to field, recycle and recirculated process, the remaining VW (with the proportion of $1\text{-}w_1\text{-}w_2\text{-}w_3$) will be filled into the land. Therefore, if the proportions taken by direct return to the field, recycling and recirculated utilization remain unchanged, the total costs in landfill remain unchanged too.

After in-depth analysis, it can be concluded that when the sum of proportions of VW directly return to the field, recycled and recirculated processing remains unchanged, with the increase of proportions of VW directly return to the field and recycled, the ratio of each cost of the system to the total cost changes.

Under the condition that total quantity of recycling resources remains unchanged, it can be seen from Table 6 that the nine cases under research with different proportion of wastes direct return to field, recycled and recirculated processing, the transportation cost always accounts for the largest part of the total cost. But with the increase of recirculated processing ratio, the proportion of transportation cost decreases continuously. Among all kinds of costs, the proportions of classification cost and landfill cost changes greatly. In view of this, stakeholders can improve the recycling level of VW, at the same time, improve the classification level and landfill treatment efficiency, so as to control the total cost of the system more effectively.

Table 5. *Cost structure of the system (total quantity of resources recycle remains unchanged, million yuan).*

Number	Proportion of wastes directly returned to field, recycled and recirculated processing	Startup cost	Classification cost	Processing cost	Landfill cost	Transportation cost
1	$w_1=0.15$, $w_2=0.35$, $w_3=0.30$	34.7	50.8	42.01	4.51	715.63
2	$w_1=0.1425$, $w_2=0.3325$, $w_3=0.325$	34.7	50.8	40.75	4.51	685.97
3	$w_1=0.135$, $w_2=0.315$, $w_3=0.35$	34.7	50.8	39.49	4.51	656.31
4	$w_1=0.1275$, $w_2=0.2975$, $w_3=0.375$	34.7	50.8	38.23	4.51	626.65
5	$w_1=0.12$, $w_2=0.28$, $w_3=0.4$	34.7	50.8	36.97	4.51	596.99
6	$w_1=0.1125$, $w_2=0.2625$, $w_3=0.425$	34.7	50.8	35.71	4.51	567.33
7	$w_1=0.105$, $w_2=0.245$, $w_3=0.45$	34.7	50.8	34.45	4.51	537.67
8	$w_1=0.0975$, $w_2=0.2275$, $w_3=0.475$	34.7	50.8	33.19	4.51	508.01
9	$w_1=0.09$, $w_2=0.21$, $w_3=0.50$	34.7	50.8	31.93	4.51	478.35

Table 6. *The proportion of each cost in the system to the total costs (total quantity of resources recycle is fixed).*

Number	Proportion of wastes directly returned to field, recycled and recirculated processing	Start-up %	Classification %	Processing %	Landfill %	Transportation %
1	$w_1=0.15$, $w_2=0.35$, $w_3=0.30$	4.09	5.99	4.96	0.53	84.43
2	$w_1=0.1425$, $w_2=0.3325$, $w_3=0.325$	4.25	6.22	4.99	0.55	83.99
3	$w_1=0.135$, $w_2=0.315$, $w_3=0.35$	4.42	6.46	5.03	0.57	83.52
4	$w_1=0.1275$, $w_2=0.2975$, $w_3=0.375$	4.60	6.73	5.06	0.60	83.01
5	$w_1=0.12$, $w_2=0.28$, $w_3=0.4$	4.79	7.02	5.11	0.62	82.46
6	$w_1=0.1125$, $w_2=0.2625$, $w_3=0.425$	5.01	7.33	5.15	0.65	81.86
7	$w_1=0.105$, $w_2=0.245$, $w_3=0.45$	5.24	7.67	5.20	0.68	81.20
8	$w_1=0.0975$, $w_2=0.2275$, $w_3=0.475$	5.50	8.05	5.26	0.71	80.48
9	$w_1=0.09$, $w_2=0.21$, $w_3=0.50$	5.78	8.46	5.32	0.75	79.69

Changes in the Recycling Resources Capacity of VW.

The economic, environmental benefits and different cost changes of VW-RRS are further investigated in the situation t where he sum of proportions of VW in directly returned to the field, recycled and recirculated processing decreased from 0.80 to 0.60, the recycling proportion $w_1 + w_2$ remains unchanged of 0.50, while the proportion of recycling processing w_3 decreases from 0.30 to 0.10. It can be seen from Table 7 that with the decrease of the sum of proportions, the total benefits and sales income of the system are also gradually decreased and the average transportation cost also shows a linear decreasing trend. That is to say, bringing down the level of recycling, the overall benefits of the reduction and recycling resources utilization of VW are reduced. In opposite, the total cost of the system shows an increasing trend. On the one hand, the increased cost is reflected in the increase of landfill treatment cost due to the decrease of recycling ratio of VW. On the other hand, rising the proportion of wastes direct landfilled cause less need to transport VW to the recycling processing station or the consumption market, but greatly increases the transportation cost of landfills far away.

Table 7. *Changes of the comprehensive benefits in the systems with the change of proportion of recirculated processing wastes (total quantity of resources recycle is changed, million yuan).*

Number	Proportion of wastes directly returned to field, recycled and recirculated processing	Sales revenue	Subsidy	Benefits	Transportation cost	Total cost
1	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.30$	438.88	65.77	-160.74	623.75	750.89
2	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.275$	434.72	68.51	-167.30	628.85	756.03
3	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.25$	430.56	71.25	-173.85	633.94	761.16
4	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.225$	426.39	73.99	-180.41	639.04	766.29
5	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.20$	422.23	76.73	-186.96	644.13	771.43
6	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.175$	418.07	79.48	-193.52	649.23	776.56
7	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.15$	413.90	82.22	-200.07	654.32	781.70
8	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.125$	409.74	84.96	-206.63	659.42	786.83
9	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.10$	405.58	87.70	-213.18	664.51	791.96

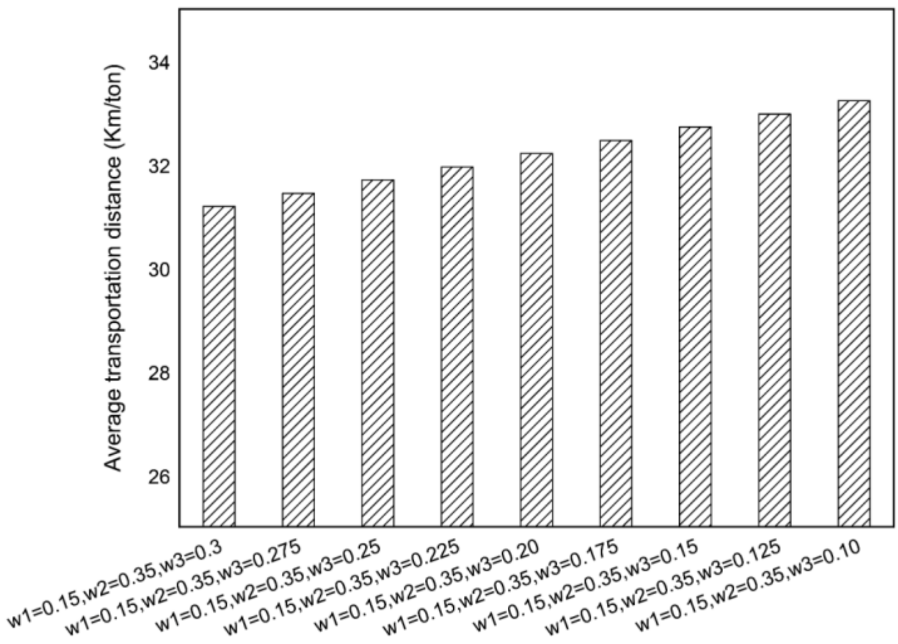

Figure 5. *Average transportation distance of the system (total quantity of resources recycle is different).*

As shown in Figure 5, when the proportions of VW directly returned to the field and recycled is fixed, when the proportion of recirculated processing gradually decreases, that is, the sum of three parts gets smaller, the average transportation distance shows an gradually increase trend, which reflects that with the decrease of economic benefits, the environmental benefits of the system are gradually improved.

Table 8 shows when the sum of proportions of VW directly returned to the field, recycled and recirculated processing changes, the total startup costs of the system and the classification cost remain unchanged. From the results presented by the program operation, in all 9 types of cases with different proportion of wastes direct return to field, recycled and recirculated processing, 4 storage fields for disposal and 17 recycling processing stations need to be established, so the startup cost is the same. The classification cost of VW is related to its quantity and classification sites. Because the quantity of VW produced by each planting base is fixed, at the same time, the VW produced by planting bases without osPCfVW are transported to the storage field for disposal and classification; and the VW produced by planting bases with osPCfVW is classified and disposed of on the spot. Therefore, the total classification costs of system remain unchanged. In contrast, the costs including landfill cost, direct return cost, processing cost and transportation cost for VW are changed. 1) all other VW except direct returned, recycling and recirculated (with the proportion of $1\text{-}w_1\text{-}w_2\text{-}w_3$) are disposed of by landfilling. So when the total proportions of these three kind of VW gets smaller, the proportion of other wastes treated by landfilling will increase, and the total landfill cost will also increase correspondingly. 2) With the decrease of proportions of recirculated processing, the processing costs decrease continuously; 3) The VW directly transported to the storage field for landfill is increased, there is no need to transport them to the recycling and processing station or the consumption market for recycled products, thus the transportation costs are arisen at the same time.

Table 8. *Changes of the cost structure in the systems with the change of proportion of recirculated processing wastes (total quantity of resources recycle is changed, million yuan).*

Number	Proportion of wastes directly returned to field, recycled and recirculated processing	Startup	Classification	Processing	Landfill	Transportation
1	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.30$	34.7	50.80	34.87	6.77	623.75
2	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.275$	34.7	50.80	34.34	7.34	628.85
3	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.25$	34.7	50.80	33.82	7.90	633.94
4	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.225$	34.7	50.80	33.29	8.46	639.04
5	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.20$	34.7	50.8	32.77	9.03	644.13
6	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.175$	34.7	50.8	32.24	9.59	649.23
7	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.15$	34.7	50.8	31.72	10.16	654.32
8	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.125$	34.7	50.8	31.19	10.72	659.42
9	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.10$	34.7	50.8	30.66	11.29	664.51

Table 9. *Proportions of each cost in the system to the total costs (total quantity of resources recycle is changed).*

Number	Proportion of wastes directly returned to field, recycled and recirculated processing	Startup (%)	Classification (%)	Processing (%)	Landfill (%)	Transportation (%)
1	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.30$	4.62	6.77	4.64	0.90	83.07
2	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.275$	4.59	6.72	4.54	0.97	83.18
3	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.25$	4.56	6.67	4.44	1.04	83.29
4	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.225$	4.53	6.63	4.34	1.10	83.39
5	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.20$	4.50	6.59	4.25	1.17	83.50
6	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.175$	4.47	6.54	4.15	1.23	83.60
7	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.15$	4.44	6.50	4.06	1.30	83.70
8	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.125$	4.41	6.46	3.96	1.36	83.81
9	$w_1 = 0.15$, $w_2 = 0.35$, $w_3 = 0.10$	4.38	6.41	3.87	1.43	83.91

In the case where the proportions of waste directly returned to field and recycled is fixed, while the proportion of recirculated processing is gradually decreased, the cost structure of the system and cost proportion of each cost are further analyzed. According to Table 9, in the nine cases under research, the transportation cost always accounts for the absolute largest proportion of the total cost. With the gradual decrease of the proportion taken by recycling of VW, the proportion of transportation cost shows an extremely slight upward trend, while the proportions of startup cost, classification cost and processing cost all show a slight downward trend. The proportion of landfill cost increases accordingly and the proportions of other costs change no more than 1%.

5. Conclusions

Aiming the problems existing in the VW management in China, combined with the concrete practice of Shouguang City, the logistics network structure of VW-RRS is reconstructed. In addition, through multi-objective nonlinear mathematical programming model, the benefits of the VW renewable supply chain system are investigated and evaluated scientifically from three dimensions: economy, society and environment. The main conclusions are drawn as follows:

Reducing and recycling VW save the total costs of the system. The transportation cost always accounts for the largest proportion of the total costs, therefore the design of the whole network should follow the principle of the shortest transportation distance.

When the reduction and resource recycle capacity of VW remain unchanged, increasing the proportions of recycling and recirculating VW will improve the economic and environmental benefits of the whole system, and the average transportation distance would decrease continuously.

When the reduction and resource recycle capacity decrease, both economic and environmental benefits of the reduction and recycling system become worse, but the economic, social and environmental benefits of the system have not shown the same trend.

In this paper, the optimal site selection as well as the distribution network of VW-RRS under the conditions of capacity constraints and node flow balance have application and promotion significance for the VW treatment in Shouguang City and other areas. The reduction and recycling system of vegetable wastes in this study is in its infancy and the actual data obtained is limited, so the system needs to be established based on the coordinating system of economy, society and environment. The effective operation of system needs to realize the real scale. It is necessary to improve the proportions of recyclable waste, management level of planting base and soil field in the specific work and also scientific research and development of agricultural products and planting technology. It is hoped that the theoretical analysis of this study can bring inspiration to the development of resource recycle and reduction of VW management in China. But the specific operating methods and suggestions need to be further studied in future.

Funding

This research was funded by the Shandong Social Science Planning Research Project, grant number 18CGLJ20; Humanities and Social Sciences Fund Project of the Ministry of Education, grant number 19YJCZH216 and the Annual Humanities and Social Sciences Project of Shandong Province, grant number 18-ZZ-GL-01.

Conflicts of Interest

All the authors do not have any possible conflicts of interest.

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