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Research on Policy Optimization of Sichuan Kitchen Waste Recycling and Disposal Based on Game Theory Perspective

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Abstract: *The effective management of kitchen waste is crucial for advancing the construction of a Beautiful China. In recent years, Sichuan has made significant strides in managing kitchen waste, yet challenges persist, including inconsistent urban-rural collection and transportation coverage, a lack of environmental awareness among relevant parties, and considerable disparities in the capacities of disposal companies. Utilizing game theory, this study examines the behavioral strategies and interaction dynamics of various stakeholders in the kitchen waste management process, encompassing waste producers, legitimate and illegitimate disposal entities, and the government. Consequently, it suggests policy enhancements such as the establishment of a circular disposal system and the improvement of guidance and regulatory mechanisms to foster efficient, green, and sustainable kitchen waste management in Sichuan Province.*

Keywords: *Kitchen Waste, Game Theory, Policy Optimization*

1. Introduction

The management of kitchen waste is a crucial part of ecological civilization construction and food safety assurance. As a major province in terms of catering industry, Sichuan has witnessed a continuous growth in the output of kitchen waste. Although it has formulated policies such as the "*Three-Year Action Plan for Improving the Quality and Efficiency of Domestic Waste Classification Work in Sichuan Province (2023-2025)*" and developed models like "public transport-style collection and transportation" and "anaerobic fermentation + intelligent supervision", significantly enhancing its disposal capacity, prominent issues remain, including uneven urban-rural collection and transportation coverage, weak environmental awareness of relevant entities, and difficulties in profitability for disposal enterprises. This paper uses game theory as a tool to analyze the behavioral strategies of waste generators, legal/illegal disposal enterprises, and the government, aiming to identify the crux of management problems, propose optimized policies, and contribute to the efficient and green disposal of kitchen waste in Sichuan.

2. Current Situation and Challenges of Kitchen Waste Recycling and Disposal in Sichuan Province

The recycling and disposal of kitchen waste are crucial for ensuring food safety, achieving resource recycling, and advancing the construction of ecological civilization. In recent years, the government has consistently intensified its policies on the management of kitchen waste. Since the release of the "*Opinions on Strengthening the Rectification of Ditch Oil and the Management of Kitchen Waste*" in 2010, kitchen waste management has been elevated to a national strategy, with enhanced supervision through initiatives such as promoting pilot cities and establishing technical specifications. In 2017, the "*Implementation Plan for the Classification System of Domestic Waste*" was introduced, which for the first time mandated the classification of kitchen waste. Forty-six key cities were mandated to establish systems for classification, collection, and treatment, and catering establishments were required to enter into collection and transportation agreements with licensed enterprises. In 2020, the revised "*Solid Waste Pollution Prevention and Control Law of the People's Republic of China*" officially incorporated kitchen waste into the legal regulatory framework. Additionally, the 2021 "*14th Five-Year Plan for the Development of Urban Domestic Waste Classification and Treatment Facilities*" proposed to achieve full coverage of centralized treatment of kitchen waste in prefecture-level cities by 2025. This clearly indicates that China's kitchen waste management has transitioned from exploratory pilot projects to a

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phase of standardization and improvement.

2.1 The current situation of kitchen waste recycling and disposal in Sichuan Province

As one of China's provinces with the richest culinary culture, Sichuan's production of kitchen waste is escalating daily. In 2023, the Sichuan Provincial Department of Housing and Urban-Rural Development introduced the "Three-Year Action Plan for Enhancing the Quality and Efficiency of Domestic Waste Sorting in Sichuan Province (2023-2025)[1]." The plan aims to upgrade and transform a total of 90,000 domestic waste sorting collection points (stations) by the end of 2025. It seeks to establish a comprehensive system for the sorting, collection, transportation, and disposal of domestic waste. The goal is to achieve full coverage of intelligent supervision for sorting collection and transportation in prefecture-level and above cities, a domestic waste recycling and utilization rate of 42%, a kitchen waste sorting rate of 25%, a resource utilization rate of 85%, and complete coverage of waste sorting in residential areas. A domestic waste sorting management model with Sichuan characteristics is intended to be established nationwide. Additionally, various cities have recently issued policy documents on household waste sorting and disposal. Details are presented in Table 1.

Table 1 Relevant policies issued by various cities and prefectures in Sichuan Province.

Document Name	Issuance Date	Issuing Unit
Regulations on Domestic Waste Management in Chengdu	July 1, 2021 (Revised in 2025)	Standing Committee of Chengdu Municipal People's Congress
Opinions on Standardizing the Construction Standards and Management of Rural Domestic Waste Collection Points	June 11, 2024	Chengdu Municipal Urban Management Committee
Measures for the Management of Domestic Waste Classification in Mianyang City	May 7, 2023	Mianyang Municipal People's Government
Regulations on the Governance of Rural Human Settlements in Mianyang City	April 7, 2025	Standing Committee of Mianyang Municipal People's Congress
Several Provisions on the Classification and Treatment of Municipal Domestic Waste in Ya'an City	March 1, 2025	Ya'an Municipal People's Government
Work Plan for Promoting the Source Reduction of Municipal Domestic Waste in Ya'an City in 2024	July 5, 2024	Jointly issued by the Housing and Urban-Rural Development Bureau of Ya'an City and the Urban Management Administrative Law Enforcement Bureau of Ya'an City
Regulations on Domestic Waste Management in Nanchong City	December 23, 2024	Standing Committee of Nanchong Municipal People's Congress
Regulations on Domestic Waste Management in Neijiang City	March 11, 2024	Standing Committee of Neijiang Municipal People's Congress
Implementation Plan for Domestic Waste Classification and Disposal Work in Zigong City	August 19, 2020	Zigong Municipal People's Government
Regulations on Domestic Waste Classification Management in Luzhou City	June 7, 2024	Standing Committee of Luzhou Municipal People's Congress
Special Plan for Domestic Waste Classification Work in Luzhou City (2023-2030)	May 18,2024	Office of Luzhou Municipal People's Government
Measures for Domestic Waste Classification Management in Deyang City	September 4, 2025	Deyang Municipal People's Government
Guidelines for Municipal Domestic Waste Classification in Deyang City	March 19, 2025	Housing and Urban-Rural Development Bureau of Deyang City
Measures for the Management of Municipal Domestic Waste Treatment Fees in Guangyuan City	December 14, 2021	Guangyuan Municipal People's Government
Measures for Domestic Waste Classification Management in Leshan City	June 30, 2025	Leshan Municipal People's Government
Measures for Domestic Waste Classification Management in Yibin City	September 1, 2023	Yibin Municipal People's Government
Implementation Plan for Domestic Waste Classification and Disposal Work in Guang'an City	October 26, 2020	Office of Guang'an Municipal People's Government
Implementation Plan for Domestic Waste Classification and Disposal Work in Dazhou City	September 15, 2020	Office of Dazhou Municipal People's Government
Measures for the Collection and Management of Municipal Domestic Waste Treatment Fees in Dazhou City (Trial)	July 14, 2025	Dazhou Municipal People's Government
Measures for Domestic Waste Classification Management in Bazhong City	April 1, 2023	Bazhong Municipal People's Government
Implementation Plan for Domestic Waste Classification and Disposal Work in Bazhong City	June 18, 2020	Office of Bazhong Municipal People's Government
Measures for Domestic Waste Classification Management in Ziyang City	September 28, 2023	Ziyang Municipal People's Government
Measures for Domestic Waste Classification Management in Meishan City	March 21,2025	Meishan Municipal People's Government

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Implementation Plan for Domestic Waste Classification and Disposal Work in Pastoral Areas of Ganzi Prefecture	July 8, 2023	Housing and Urban-Rural Development Bureau of Ganzi Prefecture
Implementation Plan for the Whole-region Waste-free Action in Ganzi Prefecture	September 14, 2023	Office of the Ganzi Prefectural Party Committee and Office of the Ganzi Prefectural People's Government
Three-year Promotion Implementation Plan for the Construction of Urban Domestic Sewage and Rural Domestic Waste Treatment Facilities in Aba Prefecture (2021-2023)	September 14, 2023	Office of Aba Prefectural People's Government
Action Plan for Solidly Promoting the Construction, Consolidation and Improvement of the Rural Domestic Waste Collection, Transportation and Disposal System in Aba Prefecture	September 14, 2023	Housing and Urban-Rural Development Bureau of Aba Prefecture
Three-year Promotion Implementation Plan for the Construction of Urban Domestic Sewage and Rural Domestic Waste Treatment Facilities in Aba Prefecture (2021-2023)	April 30, 2021	Office of Aba Prefectural People's Government
Regulations on Ecological Environmental Protection of Aba Tibetan and Qiang Autonomous Prefecture	June 5, 2025	Standing Committee of the People's Congress of Aba Tibetan and Qiang Autonomous Prefecture
Work Plan for Domestic Waste Classification and Disposal in Liangshan Prefecture	September 2, 2021	Office of Liangshan Prefectural People's Government
Regulations on the Management of Urban Appearance and Environmental Sanitation in Liangshan Yi Autonomous Prefecture	September 15, 2023	Standing Committee of the People's Congress of Liangshan Yi Autonomous Prefectur
Three-year Promotion Implementation Plan for the Construction of Urban Domestic Sewage and Rural Domestic Waste Treatment Facilities in Liangshan Prefecture	May 12, 2021	Office of Liangshan Prefectural People's Government
Implementation Plan for Domestic Waste Classification and Disposal Work in Panzhihua City	April 22, 2020	Office of Panzhihua Municipal People's Government

Guided by policies and systems, the recycling and disposal of kitchen waste have been conducted in an orderly manner across various regions, achieving remarkable results.

2.1.1 A leap in disposal capacity

With the acceleration of urbanization and the continuous growth of domestic waste generation, the construction and operation of kitchen waste treatment facilities across various regions have been expedited. The scale of treatment continues to expand, the coverage area is constantly broadening, and the overall disposal capacity has seen significant improvement. For instance, the third phase of the kitchen waste treatment project in the central urban area of Chengdu has been put into operation, with a daily treatment capacity of 521 tons, handling 1/7 of the city's total treatment volume[2]. The second phase of the kitchen waste treatment plant in Renshou County has been put into use. Once both phases are fully operational, the daily treatment capacity of kitchen waste in the county will reach 200 tons, achieving full coverage of all 27 townships and streets in the county.[3]

2.1.2 Technological model innovation

In the realm of kitchen waste management, diverse regions persistently seek out innovative technological paradigms and foster technological advancements in this domain. By implementing sophisticated processes and intelligent methodologies, they have enhanced treatment efficiency and resource utilization, transitioning from conventional methods to sustainable recycling models. For instance, Jianyang City employs the "anaerobic fermentation + intelligent supervision" approach. Through stages such as sorting, crushing, fermenting to produce biogas, and oil purification, it facilitates the transformation of kitchen waste into resources like biogas and biodiesel. This results in an annual treatment capacity of 36,500 tons of kitchen waste and a production value of 17 million yuan, thereby establishing a circular economy model that "transforms waste into treasure." [4]The kitchen waste treatment facility in Dayi County utilizes the "pre-treatment + anaerobic fermentation" process, achieving a resource utilization rate of over 95% and a daily treatment capacity of 50 tons, effectively ensuring the harmless treatment of kitchen waste.

2.1.3 Optimization of collection and transportation mode

Various regions in Sichuan have actively explored innovations in collection and transportation models, significantly enhancing the efficiency of kitchen waste collection and transportation. Chengdu, Suining, and other cities have established a "bus-like" collection and transportation system, which follows fixed routes and schedules to achieve precise and timely collection and transportation at designated locations. Among them, Suining has two centralized kitchen waste treatment facilities with a total design capacity

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of 260 tons per day. In 2024, a total of over 83,300 tons of kitchen waste were collected, transported, and disposed of in a standardized manner, effectively meeting the disposal demand.[5] Chengdu Tianfu New Area State-owned Platform Holdings has established Chengdu Tiantou Weilan Biotechnology Co., Ltd. to achieve integrated operation of "collection and transportation + disposal" of kitchen waste. The company has established cooperative relationships with several major rural catering units in the new area, and through a combination of fixed-point recycling at stores and on-site recycling, it has basically achieved the full collection of kitchen waste from rural banquets. It has also signed cooperation agreements with more than 3,000 catering businesses, achieving an average daily collection and transportation capacity of around 100 tons.[6]

2.2 Problems in the recycling and disposal of kitchen waste in Sichuan Province

Despite achieving phased results, the recycling and disposal of kitchen waste in Sichuan Province still faces the following prominent issues.

2.2.1 Uneven coverage of collection and transportation in urban and rural areas

Overall, the urban collection and transportation system has been progressively enhanced through policy initiatives. Cities like Chengdu, Suining, and Nanchong have achieved a compliance rate exceeding 60% for catering establishments by promoting "bus-like" collection and transportation support measures. Chengdu has also set up a "Smart Supervision Platform for Kitchen Waste," which employs GPS to track collection and transportation vehicles and uses electronic ledgers to document disposal processes, markedly decreasing the response time for investigating and addressing illegal transfers. However, due to insufficient facility layout, subpar hardware configuration, and delayed equipment upgrades in rural areas, there is a considerable disparity in collection and transportation coverage, leading to an uneven development pattern between urban and rural zones. [7]Some remote counties, such as Shiqu County in Ganzi Prefecture and Rangtang County in Aba Prefecture, depend on the "village collection-township transfer" model, which has limited collection and transportation coverage. Many temporary kitchen waste disposal sites in township areas lack legal authorization, resulting in frequent incidents of illegal dumping. For instance, several temporary kitchen waste disposal sites in Leshan City have not installed odor gas collection systems, causing a high number of complaints from nearby residents about environmental issues.

2.2.2 The subject has weak environmental protection awareness

Certain regions in Sichuan have initially improved their awareness of waste sorting through promotional efforts. Large-scale catering enterprises have generally been able to recycle and dispose of waste in accordance with regulations, and most residential areas in cities have established designated sorting points as required. However, the environmental awareness of urban residents, small-scale catering businesses, and itinerant vendors remains weak. It is common for urban residents to mix kitchen waste with other types of waste. Although some residential areas have designated sorting points, the lack of dedicated guidance and effective supervision exacerbates the issue of mixed disposal, affecting the effectiveness of subsequent disposal processes. Illegal disposal by small-scale catering businesses and itinerant vendors remains a prominent problem. For instance, despite the Yajiang County Government's explicit prohibition on the illegal sale of waste oil, some restaurants still operate in violation of regulations.

2.2.3 Disparities in the capacity of disposal enterprises

A select few leading companies in the recycling and disposal of kitchen waste have managed to achieve self-sufficiency and even marginal profits through technological innovation. For instance, a company in Jianyang City employs the "anaerobic fermentation + smart supervision" model, processing 36,500 tons of kitchen waste annually and generating an output value of 17 million yuan, thereby establishing a profitable circular economy model. Nonetheless, there exists a considerable gap in profitability among enterprises, with limited market channels for resource products, and the industry as a whole heavily relies on government subsidies to sustain operations. Without these subsidies, many enterprises would face the predicament where disposal equates to loss. For example, the Dayi County Food Waste Treatment Plant processes 50 tons of waste daily and converts it into industrial oils and organic fertilizers. However, due to the absence of brand certification, the organic fertilizers struggle to penetrate the mainstream agricultural market. The sale of biodiesel is concentrated among a few enterprises, leaving small and medium-sized disposal companies with limited bargaining power, and the industry's marketization docking mechanism has remained unresolved for an extended period.

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3. Game Analysis of Economic Behaviors of Various Subjects in the Process of Kitchen Waste Recycling and Disposal

3.1 Definition of participating entities in the recycling and disposal process of kitchen waste

The recycling and disposal of kitchen waste involve four principal entities. First are the generators of kitchen waste, mainly commercial restaurants (excluding residential and administrative canteens; the former are decentralized and not part of centralized collection and transportation, while the latter are non-profit and comply with government directives). The primary objective is to minimize disposal costs and maximize revenue from selling waste. Second are the legal entities responsible for collecting, transporting, and disposing of kitchen waste, which are government-licensed businesses operating for profit. They rely on income from these services and government subsidies. Third are the illegal entities involved in recycling and disposing of kitchen waste, which are unlicensed businesses or individuals seeking quick profits by illegally recycling waste oil and cutting corners on disposal to save costs. Fourth are the government entities, primarily environmental protection departments, which aim to ensure the harmless and resource-efficient treatment of kitchen waste[8], generate positive social benefits (SR1), and prevent the negative social impacts of illegal disposal (-SR2).

3.2 Analysis of the strategic set of various participants involved in the recycling and disposal of kitchen waste

3.2.1 Analysis of the strategic set of kitchen waste generators

The primary generators of kitchen waste are commercial restaurants. During the recycling and disposal process, as rational economic entities, they must consider the trade-offs between legal and illegal methods. Opting for legal disposal involves selling the kitchen waste to licensed collection and transportation companies, resulting in a unit revenue of R1. Choosing illegal disposal means selling to unlicensed entities, yielding a higher revenue of R2 (where R2 > R1), yet it also carries the risk of government fines if the activity is detected. The likelihood of detection ranges from 0 to 1. To simplify the variables, assuming the probability of detection and subsequent punishment by the government is factored in, the expected value of each fine imposed on the kitchen waste producers is P1 (P1 being the product of the fine amount and the probability of detection). Consequently, the strategic options available to kitchen waste producers are to earn revenue R1 through legal means or to earn revenue R2 minus the expected fine P1 through illegal means.

3.2.2 Analysis of the strategic set of legal entities involved in the collection, transportation, and disposal of kitchen waste

Under the market economy system, legal entities involved in the collection, transportation, and disposal of kitchen waste act as rational economic agents, with the pursuit of profit as their primary business objective. Their primary sources of income are revenue from resource utilization, R3, and government subsidies, S. Their costs encompass expenses for collection, transportation, and disposal, C. Consequently, the strategic options available to legal entities engaged in the collection, transportation, and disposal of kitchen waste are to operate and obtain revenue R3 + S - C, or to cease operations and obtain revenue 0.

3.2.3 Analysis of the strategic set of illegal kitchen waste collection, transportation, and disposal entities

The entities involved in the collection, transportation, and disposal of illegal kitchen waste are also rational economic agents seeking to maximize their own benefits. On one hand, they might take risks and engage in illegal business operations driven by the profits R4 they can gain from the illicit disposal of kitchen waste. Simultaneously, they also face the potential cost of fines P2 imposed by the government if their illegal activities are uncovered. Thus, their strategic set is (to gain profit R4 minus P2 from illegal business operations, or to gain profit 0 by refraining from illegal operations).

3.2.4 Analysis of the strategic set of government entities

Unlike the three previous economic entities, the government entity is not a rational economic person and does not aim to maximize economic benefits. The purpose of government supervision and management is to achieve positive social benefits from the harmless treatment of kitchen waste. Therefore, it hopes to guide market economic entities to conduct harmless treatment of kitchen waste through administrative and economic means. On the one hand, the government provides certain

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collection and transportation subsidies S to legal kitchen waste collection and disposal entities, guiding enterprises to carry out legal collection, transportation, and disposal activities through economic means, and generating social benefits SR1. If no subsidies are provided or the subsidies are too small, legal kitchen waste collection and disposal entities may face losses and be unwilling to enter the industry, resulting in illegal disposal of kitchen waste and generating negative social benefits -SR2. Therefore, the strategy set faced by the government entity is (subsidizing legal kitchen waste collection and disposal entities to obtain benefits SR1-S, or not subsidizing legal kitchen waste collection and disposal entities to obtain benefits -SR2). On the other hand, the government can crack down on illegal behavior through supervision and inspection. Assuming the cost of each inspection is F, the expected fines and social benefits brought by investigating and punishing illegal behavior are P2+SR1, which must satisfy P2+SR1>F. At this time, the strategy combination faced by the government is (net benefits after fining illegal collection and disposal entities P2+SR1-F, or obtaining benefits without carrying out investigation and punishment activities against illegal disposal -SR2).

3.3 Game equilibrium analysis of various participants involved in the recycling and disposal of kitchen waste

3.3.1 Game analysis between the main body of kitchen waste generation and the main body of kitchen waste collection, transportation, and disposal

In the game between the main body of kitchen waste generation and the main body of kitchen waste collection, transportation, and disposal, the strategy of the main body of kitchen waste generation is (obtaining revenue R1 through legal disposal, and obtaining revenue R2-P1 through illegal disposal), while the strategy set of the main body of legal kitchen waste collection, transportation, and disposal is (obtaining revenue R3+S-C through operating collection, transportation, and disposal, and obtaining revenue 0 through not operating collection, transportation, and disposal), please refer to Table 1.

Table 1 Benefit matrix of kitchen waste generation and disposal entities

		Legitimate collection, transportation, and disposal entity	
		Operate	*Cease operation*
Kitchen waste generators	*Legal Disposal*	R1，R3+S-C	R1，0
	Illegal Disposal	R2-P1，R3+S-C	R2-P1，0

From the perspective of economic society, the ideal equilibrium state of the game should be one where the generating entity chooses legal disposal methods and legitimate enterprises carry out normal business activities. The corresponding equilibrium solution at this time is (R1, R3+S-C). To achieve this ideal equilibrium, two key conditions need to be met. First, the legal income of the generating entity should be higher than the illegal income, that is, R1 > R2 - P1 (where R2 represents the illegal disposal income, and P1 represents the cost of investigating illegal behavior). The core lies in ensuring that the actual income from illegal disposal is lower than the legal disposal income by increasing the illegal cost P1. Second, legitimate enterprises should have a sustainable income base for operation, that is, R3 + S - C > 0. In the early stage, subsidies S are needed to cover part of the operating costs C, while in the later stage, it is necessary to ensure that the basic operating income R3 can independently cover the costs C.

From the perspective of policy formulation, on the one hand, it is necessary to increase the penalties for illegal disposal behaviors of kitchen waste generating entities, raise their illegal costs, and guide them to sell kitchen waste to legitimate companies; on the other hand, the government needs to implement phased subsidies for legitimate enterprises. During the early stages of operation of legitimate kitchen waste collection, transportation, and disposal entities, the subsidy amount should be increased to ensure that they can reduce their actual operating costs during the early stages of operation, where investment in technology research and development, equipment procurement, and other aspects is large, and profit margins are low or even negative. This way, when their disposal revenue from waste resource utilization cannot cover the collection and transportation costs of kitchen waste, they can rely on the government subsidies to make up for the losses. When their investment period ends and they enter the normal operation period, their disposal revenue from waste resource utilization exceeds their collection and transportation costs, and their profit becomes positive. At this point, the government can stop subsidizing

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them, and the enterprises are also willing to choose to operate.

3.3.2 Game analysis between the government entity and the entity responsible for the collection, transportation, and disposal of illegal kitchen waste

In the game between the government entity and the illegal kitchen waste collection, transportation, and disposal entity, the strategy of the latter is to (arn revenue R4-P2 by illegally operating the collection, transportation, and disposal business, and to earn revenue 0 by not engaging in illegal operations. The strategy combination of the government entity falls into two scenarios. First, when the illegal kitchen waste collection, transportation, and disposal entity is operating, the strategy combination of the government entity is (to net revenue P2+SR1-F after fining the illegal collection, transportation, and disposal entity, and to earn revenue -SR2 by not conducting investigation and punishment activities for illegal disposal. Second, when the illegal kitchen waste collection, transportation, and disposal entity chooses not to operate, the strategy combination of the government entity is (to incur supervision and investigation costs -F, and to earn revenue 0 by not conducting investigation and punishment activities for illegal disposal), please refer to Table 2.

Table 2 Benefit matrix between the government and illegal disposal entities

		Illegal collection and disposal entities	
		Operate	*Cease operation*
Government entity	*Supervise and investigate*	P2+SR1-F，R4-P2	-F，0
	Not supervise and investigate	-SR2，R4-P2	0，0

From an economic and societal perspective, the ideal game equilibrium state would be one where illegal kitchen waste producers do not operate, and government entities do not need to supervise or investigate. In other words, the game equilibrium solution would be (0, 0). To reach this equilibrium, the relationship between various parameters must satisfy: R4 - P2 < 0, which translates to R4 < P2. Given that the government is a non-profit entity, P2 + SR1 - F could be greater than, less than, or equal to 0. The goal is to minimize costs as much as possible while preventing illegal collection and disposal entities from operating. Consequently, from the perspective of game outcomes, the government needs to increase penalties and raise the illegal cost P2 for illegal collection and disposal entities, ensuring that P2 exceeds the revenue generated from their operations, thereby deterring this illegal disposal behavior.

3.3.3 Game analysis between legal and illegal entities involved in the collection, transportation, and disposal of kitchen waste

If we consider kitchen waste to be a recyclable resource, there exists a competitive game relationship between legal and illegal entities involved in the collection, transportation, and disposal of kitchen waste. In this game, the strategy of legal kitchen waste producers is (to earn R3+S-C by operating collection, transportation, and disposal, and to earn 0 by not doing so. Meanwhile, the strategy set of illegal kitchen waste collectors and disposers is (to earn R4-P2 by operating collection, transportation, and disposal, and to earn 0 by not doing so), please refer to Table 3.

Table 3 Benefit matrix of legal and illegal kitchen waste collection, transportation, and disposal entities

		Illegal collection, transportation and disposal entities	
		Operate	*Cease operation*
Legal collection, transportation and disposal entities	*Operate*	R3+S-C，R4-P2	R3+S-C，0
	Cease operation	0，R4-P2	0，0

From an economic and societal perspective, the ideal state of play is one in which legal entities are involved in waste collection, transportation, and disposal, while illegal entities are not. In other words, the equilibrium solution for the game is (R3+S-C, 0). To attain this equilibrium, it is deduced that the

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relationship between the parameters must fulfill the following conditions: R3+S-C>0 and R4-P2<0. This aligns with the results previously established. Consequently, as long as the first two types of games can achieve the anticipated equilibrium solution, the outcome of the game between illegal waste collection, transportation, and disposal entities and legal entities will also progress in the direction favored by society.

4. Policy measures to improve the current situation of recycling and disposal of kitchen waste

4.1 Optimize the coverage of waste collection and transportation across the entire region, and establish a circular disposal system

To address imbalances in urban and rural waste collection and transportation coverage, as well as the lack of qualifications for disposal sites in some areas, a "hierarchical disposal + responsibility loop" system has been established, centered around the principles of "reduction, reuse, and resource recovery" within the circular economy. In terms of waste collection and transportation network construction, the system relies on the existing urban and rural waste collection and transportation framework, adding small pre-treatment stations in areas with weak collection and transportation capabilities. Solid-liquid separation pre-treatment is conducted for kitchen waste, with the liquid components being converted into clean energy, such as biogas[9], locally, and the solid components being compressed and transported centrally, thereby reducing energy consumption and costs associated with cross-regional transportation. Regarding disposal site management, non-compliant disposal sites are mandated to complete rectification and ecological restoration within a specified timeframe. Temporary disposal sites are required to obtain legal qualifications, and a responsibility mechanism for waste collection, transportation, and disposal is established, with "county-level coordination and township-level implementation." Referring to the requirements of "integrated urban and rural waste treatment" in the "14th Five-Year Plan for Circular Economy Development,"[10] the effectiveness of kitchen waste collection, transportation, and disposal is incorporated into local human settlement environmental assessment indicators. Specific time nodes are set to achieve a collection and transportation coverage rate of over 90% across the entire region and full coverage of compliant disposal sites.

4.2 Strengthen the environmental awareness of the main body and improve the guidance and supervision mechanism

To address issues such as producers' weak environmental awareness, illegal disposal, and mixed collection, we have established a three-dimensional management system grounded in the game theory principle of "increasing the costs of illegality and enhancing the benefits of legality." At the publicity level, we conduct targeted campaigns to educate rural small-scale catering businesses, mobile vendors, and urban residents about the hazards and resource value of kitchen waste, popularizing legal disposal procedures and policy requirements. At the incentive level, we implement a "classification point exchange" system, allowing residents and business operators to accumulate points for correct waste classification, which can then be exchanged for daily necessities or services. Furthermore, we have established a reward mechanism for reporting illegal disposal activities, with the reward amount set at a certain percentage of the fines imposed. At the punishment level, we install intelligent monitoring equipment at designated disposal points to deter mixed collection. Repeat offenders will have their subsidies reduced, and illegal activities such as reselling waste oil will be subject to severe legal penalties, ensuring that the benefits of legal disposal exceed those of illegal disposal.

4.3 Solve the profit dilemma of enterprises and promote market docking and upgrading

Focusing on the game equilibrium conditions for the legal disposal of enterprises, we will invest in both subsidy regulation and market cultivation to assist enterprises in achieving sustainable profitability. In the short term, we will implement a "phased differentiated subsidy" policy. For newly operated small and medium-sized disposal enterprises, a higher standard subsidy will be given based on the disposal volume in the initial stage. As the maturity of enterprise operations and resource utilization efficiency improve, the subsidy standard will be gradually reduced. In the later stage, only enterprises that meet the resource utilization rate standards will be given incentive subsidies, guiding enterprises to reduce their dependence on government subsidies. In the long term, we will focus on the cultivation of the resource product market. The competent department will take the lead in establishing a brand certification and quality standard system for kitchen waste resource products (organic fertilizer, biodiesel, etc.). Qualified products will be included in the procurement catalogues for agricultural production materials, industrial

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energy, etc. We will promote enterprises to sign long-term supply agreements with large-scale planting bases, logistics and transportation enterprises, bus companies, etc., expand product sales channels, increase enterprise resource income, and ensure that small and medium-sized disposal enterprises gradually achieve comprehensive profitability.

4.4 Strengthen the regulatory coordination system and address the shortcomings in technical facilities

To meet the equilibrium demands between the government and entities involved in illegal waste disposal, a comprehensive regulatory network should be established, incorporating "data interoperability, cross-regional collaboration, and technological advancement." In line with the smart city construction master plan, a smart management platform for urban kitchen waste should be developed, adhering to regulatory standards and standardizing the system's construction norms. All corporate data must be integrated into the government's oversight platform, with real-time surveillance to monitor the standardized operational status of kitchen waste-related enterprises. This approach aims to achieve informatization and visualization in the collection, transfer, and disposal of kitchen waste, facilitating "data-driven communication, management, and decision-making," thereby enhancing the efficiency and quality of regulatory oversight.

Regarding cross-regional collaboration, an emergency disposal mutual assistance mechanism should be set up among regions, clearly defining the responsibilities, cost-sharing, and procedural norms for handling waste across borders, addressing the challenge of inadequate disposal capacity in certain areas[11]. In terms of technological infrastructure, financial resources should be pooled to upgrade outdated collection and transportation vehicles, install exhaust and wastewater treatment systems at disposal sites, decrease regulatory expenses, and ensure that the government's net income from fines for illegal disposal remains positive. Additionally, a timeline should be established for the nationwide upgrade and renovation of collection and transportation vehicles and disposal facilities.

5. Conclusion

The study finds that the core contradiction in Sichuan's kitchen waste management stems from interest conflicts among multiple subjects: waste generators tend to choose illegal disposal for higher profits, illegal enterprises seek arbitrage through violations, legal enterprises rely on subsidies, and the government needs to balance supervision costs and social benefits. To solve this problem, it is necessary to establish an interest coordination mechanism: on one hand, guide compliant behaviors by increasing illegal costs and improving legal benefits; on the other hand, address shortcomings in rural infrastructure, build an intelligent supervision platform, and foster a market for resource utilization. In the future, regional policies can be refined and technological R&D can be strengthened to promote the unification of the "three benefits" (environmental, economic, and social benefits) and provide a "Sichuan Solution" for the whole country.

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