Residents' willingness to participate in domestic sewage treatment in rural China: Application of a multi-stakeholder perspective

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Residents' willingness to participate in domestic sewage treatment in rural China: Application of a multi-stakeholder perspective

Volonté des habitants de participer au traitement des eaux usées domestiques dans la Chine rurale : Application d'une perspective multi-acteurs

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Abstract

In the past decades, the focal point of environmental protection efforts has been on urban environments and controlling key sources of pollution, while rural environmental protection has not received commensurate attention in China. With the rapid development of agriculture and economy in China, along with the continuous increase in per capital disposable income and improvement in living standards among rural residents, significant advancements have been made in rural living conditions. However, in the process of rural-urban integration, the construction of rural living environment has not received corresponding emphasis. The implementation of the Beautiful Countryside Construction policy has presented a new direction and promising prospects for the development of rural areas. To realize this vision, it is imperative to have a scientific understanding of rural living environment management, especially the current status of rural domestic sewage treatment (RDST).

However, RDST in China faces the following three dilemmas. Firstly, while the domestic sewage treatment rate in urban areas in China is reaching up to more than 95%, the domestic sewage treatment rate in rural areas is relatively weak, at only 45%. Secondly, RDST projects involve multiple stages of construction and operation, requiring substantial financial investment and often leading to a lag in RDST capacity due to high costs. Thirdly, RDST projects have strong public welfare attributes, with relatively low direct economic benefits, resulting in weak financing capabilities. Reliance primarily on fiscal funds as the financing channel, rural residents participate insufficiently, coupled with insufficient mobilization of public or private sectors, exacerbates the pressure on government finances. Therefore, to better mitigate environmental pollution caused by rural domestic sewage and advance the process of rural living environment remediation, this thesis employs a framework that based on Life Cycle Cost Analysis (LCCA) and multi-stakeholders' participation. Focused on the theme of " Residents' willingness to participate in domestic sewage treatment in rural China: Application of a multi-stakeholder perspective," this thesis based on the current situation of China, selects provinces such as Jilin, Shandong, Gansu, and Henan as sample provinces to acquire micro-level research data on rural residents and public or private sectors cooperation projects. The study dissects the influencing

factors of rural residents' willingness to participate (WTPP) and willingness to pay (WTP), while also delving into and expanding the multi-stakeholder's participation mechanism of Public-Private Partnership (PPP) models involving government, rural residents and public or private sectors. This endeavor aims to ensure improvements in rural living environment and contribute insights for advancing rural revitalization efforts, thus providing significant implications.

To begin with, the study focuses on the research of PPP model in RDST. This research examines PPP projects in RDST, utilizing the Life Cycle Costs Analysis (LCCA) method to investigate the LCC involved at various stages. Based on case and empirical analyses, the results show that pipe construction and electricity expenses accounted for the highest share of construction and operation and maintenance costs, at 72% and 51%, respectively. In addition, scenario analysis is employed to analyze the potential influencing factors of LCC, and the results show that the operation lifespan and population changes have a significant effect on the LCC of the PPP projects in RDST.

Furthermore, this study delves into the mechanisms of rural residents' participation in RDST construction. As direct contributors to rural domestic sewage generation, rural residents' participation wield significant influence on the efficacy of sewage treatment in RDST. Based on the perspective of rural residents, and drawing upon survey data from rural areas, this thesis adopts binary Logit regression and Tobit models to analyze the willingness to participate (WTPP) and willingness to pay (WTP) of rural residents in RDST construction. The results revealed a higher percentage of rural residents with a positive WTPP of 79%. The WTP of rural residents ranged from 47.46 CNY/year to 63.13 CNY/year, and their affordability ranged from 16.28% to 21.65% of the construction costs of RDST facility. Moreover, it further explored key factors affecting rural residents' WTPP and WTP, including individual endowment and access to centralized water supply.

Moreover, this study investigates the impact of environmental regulations on rural residents' WTPP and WTP in the operation and maintenance of RDST. Firstly, the results indicated that more than 83.5% of rural residents demonstrated positive WTPP and WTP. The WTP for rural residents ranged from 8.14 CNY/month to 9.74 CNY/month, which was accounted to cover at least 47.55% of the operation and

maintenance cost for RDST. Secondly, by employing Logit regression model, this thesis verifies the heterogeneous effects of different environmental regulations on rural residents' WTPP and WTP, as well as the interaction effects between different environmental regulations. Thirdly, rural residents' cognition as the mediating variable is used to reveal the effect mechanism of environmental regulation on rural residents' WTPP and WTP.

Finally, integrating the normal and empirical findings from the above analyses, based on the LCCA of PPP projects of RDST, as well as the research results concerning rural residents' WTPP and WTP for RDST construction and the influencing factors, alongside the examination of how environmental regulations affect rural residents' WTPP and WTP for RDST operation and maintenance, the expansion and in-depth research of multi-stakeholders’ participation mechanism for RDST is formulated. The findings of this thesis are intended to address the fundamental problems of funding shortages and operational inefficiencies in RDST, and to provide reliable recommendations and references for other developing countries.

Keywords: rural domestic sewage treatment, rural residents’ participation, multi-stakeholders, Public-Private-Partnership, Life Cycle Costs, willingness to participate, willingness to pay, environmental regulations.

Résumé

n Chine, au cours des dernières décennies, les efforts de protection de l'environnement se sont concentrés sur les zones urbaines et sur le contrôle des principales sources de pollution, tandis que la protection de l'environnement rural n'a pas reçu une attention comparable. Avec le développement rapide de l'agriculture et de l'économie en Chine, ainsi que l'augmentation continue du revenu disponible par habitant, les conditions de vie en zone rurale ont enregistré des progrès significatifs mais les infrastructures de protection de l'environnement n'ont pas suivi cette tendance. Cependant, dans le processus d'intégration urbaine et rurale, l'introduction de la politique de « Construction des villages magnifiques » présente des perspectives prometteuses pour le développement des zones rurales. Pour opérationnaliser cette politique, il est impératif d'avoir une compréhension scientifique de la gestion de l'environnement rural, en particulier de l'état actuel du traitement des eaux usées domestiques en milieu rural.

Ainsi, le traitement des eaux usées domestiques dans la Chine rurale est confronté à trois défis principaux. Premièrement, bien que le taux de traitement des eaux usées domestiques en milieu urbain atteigne plus de 95%, ce taux est beaucoup plus faible en milieu rural, soit 45% seulement. Deuxièmement, les projets de traitement collectif des eaux usées domestiques en milieu rural nécessitent des investissements financiers importants pour leur construction et leur exploitation ; ce qui entraîne une capacité de traitement limitée en raison des coûts élevés. Troisièmement, ces projets ont une forte dimension de service public avec des bénéfices économiques directs limités ; ce qui réduit l'attractivité et les capacités de financements alternatifs. La dépendance vis-à-vis des fonds publics comme principal canal de financement, associée à une participation insuffisante des résidents ruraux et un manque de mobilisation des investisseurs, accentue la pression sur les finances publiques.

Par conséquent, pour mieux réduire la pollution environnementale causée par les eaux usées domestiques rurales et avancer dans le processus de réhabilitation du cadre de vie des populations rurales, cette thèse propose d'aborder la problématique sous l'angle de la participation des parties prenantes et de l'analyse du coût du cycle de vie. Dans cette perspective multipartite, cette thèse accorde une attention privilégiée à la

volonté des résidents de participer au traitement collectif des eaux usées domestiques en milieu rural en Chine. Les provinces de Jilin, Shandong, Gansu et Henan ont été sélectionnées comme provinces représentatives pour obtenir des données de recherche microéconomiques sur des projets de coopération entre les résidents ruraux et les investisseurs privés ou publics. L'étude analyse les facteurs influençant la volonté des résidents ruraux de participer ainsi que leur consentement à payer une contribution financière, tout en approfondissant le mécanisme de participation multipartite des modèles de partenariat public-privé impliquant le gouvernement, les résidents ruraux et les investisseurs privés ou publics.

Tout d'abord, l'étude se concentre sur une étude de cas basée sur un modèle de partenariat public-privé dans le traitement collectif des eaux usées domestiques en zone rurale en mobilisant la méthode d'analyse des coûts du cycle de vie pour étudier les coûts relatifs aux diverses étapes du process. Sur base de cette étude de cas empirique, les résultats montrent que la construction des canalisations et les dépenses d'électricité représentent la part la plus élevée des coûts de construction et de fonctionnement, soit respectivement 72 % et 51 %. En outre, l'analyse se prolonge par une analyse de sensibilité basée sur différents scénarii pour identifier les facteurs potentiellement les plus influents sur les coûts. Les résultats montrent que la durée de vie opérationnelle des infrastructures et les changements démographiques ont un effet significatif sur le coût du cycle de vie.

Cette étude examine ensuite les mécanismes de participation des résidents ruraux à la construction d'une installation de traitement collectif des eaux usées. En tant que contributeurs directs à la génération des eaux usées domestiques rurales, la participation des résidents ruraux exerce une influence significative sur l'efficacité de leur traitement collectif. Basée sur la perspective des résidents ruraux et s'appuyant sur des données d'enquêtes provenant de zones rurales, cette thèse adopte des modèles de régression Logit binaire et Tobit pour analyser la volonté de participer et le consentement à payer des résidents ruraux pour la construction des infrastructures de traitement collectif. Les résultats ont révélé un pourcentage élevé (79%) de résidents ruraux déclarant une volonté de participer positive, l'estimation du consentement à payer des résidents ruraux variant de 47,46 CNY/an à 63,13 CNY/an. Cette fourchette de capacité de paiement représente, après extrapolation, entre 16,28 % et 21,65 % des

coûts de construction des installations. De plus, l'étude a exploré les facteurs clés affectant la volonté de participer et le consentement à payer des résidents ruraux, notamment les niveaux de revenus des ménages et leur accès à l'eau de distribution centralisée.

En outre, cette étude explore l'impact des réglementations environnementales sur la volonté de participer et le consentement à payer des résidents ruraux dans la couverture des frais d'exploitation et de maintenance des installations de traitement collectif des eaux usées domestiques. Premièrement, les résultats indiquent que plus de 83,5 % des résidents ruraux déclarent une volonté de participer et un consentement à payer positifs, ce dernier étant compris entre 8,14 CNY/mois et 9,74 CNY/mois. Après extrapolation, ces montants ne représentent pas moins de 47,55 % des coûts d'exploitation et de maintenance des installations. Deuxièmement, en utilisant le modèle de régression Logit, cette thèse vérifie les effets des différentes réglementations environnementales sur la volonté de participer et le consentement à payer des résidents ruraux, ainsi que les effets d'interaction entre les différentes réglementations environnementales. Troisièmement, la connaissance des résidents ruraux en matière d'enjeux environnementaux et sanitaires liés aux eaux usées est utilisée en tant que variable médiatrice pour révéler l'effet des réglementations environnementales sur leur volonté de participer et leur consentement à payer.

Enfin, en intégrant les conclusions des trois volets de la recherche exposés ci-dessus, la discussion générale débouche sur l'élaboration d'un modèle de participation multipartite pour le traitement collectif des eaux usées domestiques en zone rurale. Les conclusions exposent comment cette thèse contribue à répondre aux problèmes fondamentaux des pénuries de financement et des inefficacités opérationnelles dans le traitement collectif des eaux usées domestiques en zone rurale et formulent des recommandations orientées vers les politiques de gestion des eaux usées domestiques dans les zones rurales chinoises pouvant également servir de références pour d'autres pays en développement.

Mots-clés : traitement des eaux usées domestiques en milieu rural, participation des résidents ruraux, les parties prenantes multiples, partenariat public-privé, coûts du

cycle de vie, volonté de participer, consentement à payer, réglementations environnementales.

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Jian JIAO

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List of abbreviations

A/O: Anaerobic/Oxic
A^2/O: Anaerobic/Anoxic/Oxic
AHP: Analytic Hierarchy Process
ATC: Average Total Cost
BOD: Biochemical Oxygen Demand
CM: Centralized Mode
CMP: Centralized Mode Provision
CNY: Chinese Yuan (currency in China)
COD: Chemical Oxygen Demand
CVM: Contingent Valuation Method
LCA: Life Cycle Assessment
LCC: Life Cycle Cost
LCCA: Life Cycle Cost Analysis
MBBR: Moving Bed Biofilm Reactor
NH_4^+-N: Ammonium Nitrogen
NPV: Net Present Value
PPP: Public-Private Partnership
RDST: Rural Domestic Sewage Treatment
SBBR: Sequencing Batch Biofilm Reactor
SS: Suspended Solids
TN: Total Nitrogen
TP: Total Phosphorus
WTP: Willingness to Pay
WTPP: Willingness to Participate

Chapter 1

Introduction

1. Research Background

1.1 Composition and characteristics of rural domestic sewage

The conceptual delineation of rural domestic sewage has been subject to scrutiny by numerous scholars from various perspectives. Regarding its sources, rural domestic sewage is construed as a composite effluent generated from small-scale processing enterprises, service industries, and household daily activities within rural living zones, with a predominant contribution from domestic household activities (Hou et al., 2012). Moreover, alternative perspectives contend that rural domestic sewage primarily emanates from household-based livestock and poultry farming, as well as sewage generated from the open-air accumulation and percolation of agricultural tools and waste (Wang, 2018a; Zhu, 2017). It should be noted that the breeding industry in China tends to be large-scale and centralized, and the breeding areas are usually distant from the living areas of the rural residents. Moreover, the government has very strict control on the sewage treatment of the breeding industry, and it will not be treated together with the domestic sewage. In terms of content, Ding and Yang (2019) identify key components of rural domestic sewage, including kitchen sewage (e.g., water used for washing rice and vegetables, as well as dishwashing water), domestic sanitation sewage (comprising phosphorus-containing sewage from personal hygiene, household sanitation, and domestic cleaning), toilet sewage (encompassing human and animal excreta with elevated concentrations of nitrogen, phosphorus, and BOD), and miscellaneous sewage (derived primarily from livestock and poultry farming, aquaculture, and other sources). Additionally, scholars have analyzed rural water pollution from the perspective of resource utilization, positing that the essence of rural water pollution lies in the underutilization of fertilizer resources, resulting in substantial loss into rivers, lakes, and other water bodies, thereby augmenting water pollution and diminishing the self-purification capacity of aquatic ecosystems, leading to severe ecological degradation (Tang et al., 2008).

From a pollutant perspective, most rural domestic sewage exhibits consistent characteristics, generally lacking heavy metals and toxic substances while containing moderate levels of nitrogen, phosphorus, and organic matter. The water quality demonstrates significant fluctuations, displaying robust biodegradability and seasonal variability (Huang et al., 2019). In terms of pollutant composition, rural domestic sewage encompasses blackwater and greywater. Blackwater primarily consists of mixed sewage with elevated nutrient content, including toilet flush sewage, feces, urine, and occasionally kitchen sewage with high pollutant concentrations. Greywater, on the other hand, consists of miscellaneous sewage from bathing, personal hygiene, and washing machines, with kitchen sewage typically categorized under greywater. Greywater is characterized by lower pollutant concentrations, such as suspended solids (SS), ammonium nitrogen (NH_4^+-N), total nitrogen (TN), and total phosphorus (TP) (Huang et al., 2012). In the classification of pollutants, rural domestic sewage pollutants mainly comprise organic pollutants, nutrient pollutants, inorganic suspended solids, biological pollutants, and detergent pollutants (Xu et al., 2017a). Concerning pollutant sources, kitchen sewage consists of dishwashing sewage, rinse sewage from cooking utensils, and vegetable washing sewage, collectively contributing to one-fifth of total domestic sewage. Dishwashing sewage and rinse sewage typically contribute high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) to domestic sewage. Vegetable washing sewage and rice washing sewage contain organic matter such as rice bran and vegetable debris, necessitating consideration for their removal during water treatment processes. Recent rural economic development and increased meat and oil consumption among residents have led to higher fat content and complexity in domestic sewage. Washing sewage comprises wastewater from personal grooming, bathing, and laundry, characterized by substantial discharge volumes and significant chemical content, such as ammonia nitrogen (NH_3-N) and TP, contributing significantly to eutrophication in rural water bodies. Toilet sewage refers to sewage generated from toilet flushing. Unlike urban domestic sewage, rural domestic sewage rarely includes industrial wastewater, making toilet sewage a primary contributor to rural domestic sewage pollution, particularly in economically developed rural areas with flush toilet systems, where toilet sewage contains elevated levels of COD, NH_3-N, and TP (Liu, 2015b).

1.2 Advances in RDST modes and technologies

1.2.1 Treatment modes

Presently, rural areas in China exhibit vast geographical distributions, characterized by significant regional disparities in climate, hydrology, topography, and socio-economic activities. Singular sewage treatment technologies fail to meet the emission requirements of RDST. Scholars have predominantly explored various sewage treatment modes from two perspectives: the classification of RDST modes and the classification of treatment modes involving different participating entities (Yu and Yu, 2019c). Regarding the classification of RDST modes, three main treatment modes for rural domestic sewage exist: decentralized, centralized, and unified urban-rural modes (**Figure 1-1**).

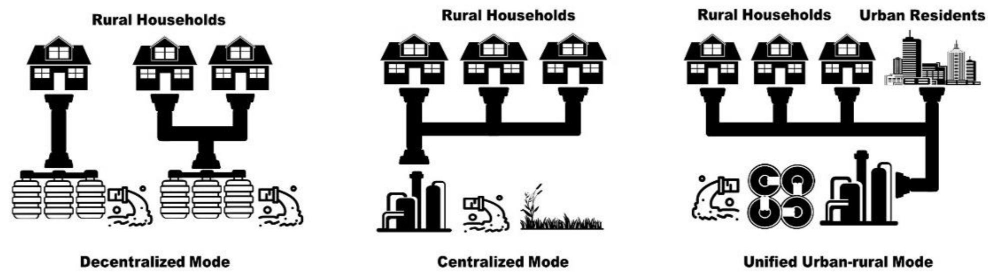

Figure 1-1 Schematic diagram of decentralized, centralized, and unified urban-rural modes of RDST.

Each mode is tailored to specific circumstances (Wang et al., 2012b). The decentralized treatment mode for rural domestic sewage is primarily applicable to villages where it is impractical to lay centralized sewage networks or establish centralized collection and treatment facilities, especially in sparsely populated mountainous or hilly areas. Typically, households construct individual sewage treatment facilities such as household biogas digesters within their courtyards to treat rural domestic sewage (Yu and Yu, 2019b). Li (2009) categorizes the decentralized treatment mode into decentralized treatment for segregated sewage and decentralized treatment for mixed sewage. Segregated sewage treatment in rural areas involves the collection, sorting, and separate treatment of sewage and waste at the source. On the other hand, mixed sewage treatment in rural areas combines various sewage streams from households for collective collection and treatment. The centralized treatment mode requires a higher degree of residential concentration, with households possessing conditions for laying sewage networks or constructing underground channels. Additionally, sufficient vacant land is needed to build corresponding anaerobic treatment tank, constructed wetlands, or simple sewage treatment facilities. Currently, this mode is widely applied in RDST in China. By constructing a centralized RDST facility near the village, all sewage from the village is collected, transported, and treated on-site (Yu and Yu, 2019b). Bai et al. (2010) further divide the centralized mode into small-scale centralized treatment and large-scale unified centralized treatment. Unified treatment refers to extending urban sewage treatment networks to nearby villages or rural areas, where rural domestic sewage is collected and then channeled into municipal sewage networks for centralized treatment in urban sewage treatment plants (Yu and Yu, 2019b). Drawing upon relevant research and considering the actual conditions of RDST in China, this study summarizes the advantages, disadvantages, and applicability of RDST modes in China, as detailed in **Table 1-1**.

Table 1-1 Advantages, disadvantages, and applicability of RDST modes.

Mode	Applicability area	Advantages	Disadvantages
Decentralized	Primarily applied in areas where rural residents are dispersed.	Eliminates massive pipe networks or culverts and lower costs.	Not convenient for uniform operation and maintenance.
Centralized	Rural residents are required to live concentrated and have the conditions to build pipe networks with RDST equipment.	More sophisticated technology.	Higher construction and maintenance costs and larger space requirement.
Unified urban-rural	Rural sewerage networks can be	Excellent treatment and	Higher geographic location requirements

	extended to villages close to urban or towns areas, generally not exceeding 5 kilometers.	high economic value.	and higher treatment capacity for the Town's sewage treatment plants.

Another focal point of research on RDST modes is the comprehensive evaluation of various sewage treatment modes. To systematically select RDST models with scientific objectivity, it is essential to establish an evaluation index system tailored to the development needs of different regions, while fully considering the principles of technical and economic feasibility as well as effectiveness. Through comprehensive evaluations of different RDST modes, followed by ranking the evaluation results, the optimal treatment approach can be selected, providing a scientific basis for the selection of RDST modes. Mainly employed methods include the fuzzy superiority and inferiority coefficient method, Analytic Hierarchy Process (AHP), hierarchical fuzzy integral model, and grey relational analysis method (Qu et al., 2012; Shen et al., 2014; Xia et al., 2012).

1.2.2 Treatment technologies

Developed nations have long prioritized environmental conservation and have been early adopters of RDST technologies. The United States initiated RDST research in the mid-19th century, while China, comparatively late in its focus, began exploring RDST technologies in the late 1980s (Jia et al., 2018). Currently, there is significant diversity in sewage treatment technologies employed domestically and internationally. Primarily five RDST technologies and processes are utilized worldwide. Firstly, Australia's "FILTER" sewage treatment system, proposed by experts from the Commonwealth Scientific and Industrial Research Organization (CSIRO), combines filtration, land treatment, and underground drainage. It aims to reuse sewage for crop irrigation, with treated sewage collected and discharged through underground pipes (Su et al., 2005). Secondly, Japan's Johkasou (purification tank) technology is an integrated treatment facility for decentralized sewage treatment in rural areas. Originating in the 1960s, it has evolved into a relatively sophisticated technical management system over the years, playing a crucial role in protecting Japan's rural water environment (Gan et al., 2013; Wu et al., 2010). Thirdly, the Activated Ecosystems, initially introduced in countries like the United States, Canada, the United Kingdom, and Australia, are used for industrial and domestic sewage treatment. This technology is based on activated technology, utilizing a combination of animals, plants, and bacteria for sewage treatment (Li et al., 2008b). Fourthly, the High-Efficiency Algae Pond Treatment Technology, proposed and developed by Oswald of the University of California, Berkeley, improves upon traditional stabilization ponds by maximizing the use of algae-produced oxygen for pollutant treatment. The first-order degradation kinetic constants in the ponds are relatively large due to the large utilization of oxygen produced by algae, earning it the title of high-efficiency algae pond (E. Gómez et al., 1995). Fifthly, the Constructed Wetland Sewage Treatment System is one of Germany's main RDST technologies. It forms a new "ecosystem" with a medium layer and wetland plants. In this method, rural sewage is directed through pipelines into settling tanks, where it undergoes screening before purification treatment in artificial wetlands. The treated sewage is then discharged up to standard or used for irrigation in farmland (Weng et al., 2014; Wu and Tang, 2016).

China embarked on research in RDST relatively late. However, in recent years, with the enhancement of economic strength, especially in developed provinces reaching a certain stage of economic development, there has been a gradual recognition of the importance of RDST issues. Consequently, some practical, reasonable, low-energy-consumption, and low-operating-cost technologies have been adopted for sewage treatment (Cao and She, 2009). Currently, sewage treatment technologies in China can be broadly categorized into three main types: biological treatment technology, ecological treatment technology, and bio-ecological combined treatment technology.

Biological treatment technology involves the use of microorganisms to remove pollutants under aerobic and anaerobic conditions. This technology occupies small land areas, produces low sludge volumes, and exhibits excellent shock load resistance, making it suitable for treating sewage with significant fluctuations in quantity and quality (Ma and He, 2014). Biological treatment technology primarily includes anaerobic biological treatment, also known as anaerobic digestion or fermentation, where various anaerobic or facultative microorganisms act together under anaerobic conditions to decompose organic matter and produce CH_4 and CO_2 (Liu et al., 2014). Common applications include household sewage purification biogas digesters, buried passive household sewage treatment devices, and anaerobic baffled filter beds. Aerobic biological treatment technology involves the degradation of organic matter by aerobic microorganisms in the presence of free oxygen. Traditional aerobic biological sewage treatment processes include A/O (Anaerobic/Oxic), A^2/O (Anaerobic/Anoxic/Oxic), oxidation ditches, biological rotating discs, biological contact oxidation, Sequencing Batch Biofilm Reactor (SBBR), and Moving Bed Biofilm Reactor (MBBR) (Ye, 2013).

Ecological treatment technology, based on land treatment methods, is an evolution and development of sewage land treatment systems. It emphasizes the natural purification function, focusing on the interaction between plants-microorganism systems or animal-treatment environment (such as soil) systems during pollutant degradation processes, with special attention to optimizing and controlling external conditions (Long et al., 2010). At present, ecological treatment technologies suitable for RDST mainly include land treatment technology, stable pond technology, and earthworm ecological filter bed technology. These technologies must be combined with tailored process designs that suit rural characteristics and conditions to achieve stable phosphorus and nitrogen removal effects at low costs (Lu and Xiao, 2009). The primary land treatment techniques encompass slow sand filtration, rapid sand filtration, constructed wetlands, and subsurface flow constructed wetlands (Dong et al., 2012; Ma et al., 2019). Stable pond technology harnesses aquatic flora (predominantly algae) and microorganisms within water to collectively degrade organic matter, purifying sewage as a natural remediation method. This approach is cost-effective, as it obviates the need for artificial aeration, incurs low construction and operational costs, and requires minimal technical expertise or specialized personnel for maintenance, rendering it particularly suitable for rural locales. However, conventional stable ponds necessitate extensive land occupation, exhibit prolonged hydraulic retention times, and are significantly influenced by factors such as temperature and light, resulting in diminished efficacy and susceptibility to emitting malodors and fostering mosquito and fly propagation (Wang et al., 2017). Earthworm ecological filter bed technology represents a burgeoning ecological sewage treatment innovation in recent years. Its premise lies in exploiting the earthworm's capacity to enhance soil aeration and permeability while catalyzing the decomposition and conversion of organic substances. Through the synergistic symbiosis between earthworms and microorganisms, this method treats and transforms sewage sludge (Sinha et al., 2008; Zhang et al., 2017a). Synthesizing global research findings and practical insights underscores that neither biological treatment nor ecological treatment in isolation adequately addresses the challenges of sewage treatment and phosphorus and nitrogen removal. An integrative approach, merging biological methodologies with ecological engineering, and tailored process design responsive to rural dynamics and conditions is imperative to achieve stable phosphorus and nitrogen removal while optimizing cost-efficiency (Lv, 2018).

In response to the situation in China, scholars have conducted research on the selection of RDST technologies from various perspectives. Xu et al. (2017b) conducted a comprehensive evaluation of the main RDST processes in the Guangxi region. They concluded that the anaerobic-artificial wetland process had the highest economic and technological comprehensive evaluation value, making it suitable for RDST in rural areas of Guangxi. Cao et al. (2020b) conducted a comparative analysis of RDST processes in Jiangxi Province. They generally recommended oxidation ditch, constructed wetland, and MBR treatment technologies for centralized RDST, and soil infiltration, constructed wetland, composite tower biofilter, and stable pond technologies for decentralized RDST. For the removal of ammonia nitrogen, they recommended the A/O biological treatment process, while for the removal of nitrogen and phosphorus, they suggested the A^2/O biological treatment process. Yan et al. (2017b) reviewed the current status of RDST in different region and proposed RDST technologies tailored to the characteristics of each region.

1.3 Gradually attracting government's attention

In recent years, the escalating environmental issues resulting from rural domestic sewage have garnered attention from governmental authorities. The 19th National Congress of the Communist Party of China highlighted the Rural Revitalization Strategy, emphasizing the resolution of prominent environmental issues and the initiation of rural living environmental remediation actions. The Central Committee of the Communist Party of China and the State Council issued the "Opinions on Implementing the Rural Revitalization Strategy" in 2018, advocating for continuous improvement of rural living environmental conditions and the implementation of a three-year action plan for rural living environmental remediation, with a primary focus on RDST. In February 2018, the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the "Three-Year Action Plan for Rural Living Environmental Remediation," explicitly stating that improving rural living environmental conditions and constructing beautiful and livable rural areas are crucial tasks for implementing the Rural Revitalization Strategy. These tasks are vital for the comprehensive establishment of a moderately prosperous society, the fundamental well-being of the vast rural population, and the harmony of rural social civilization. The "Opinions on Adhering to the Priority Development of Agriculture and Rural Areas and Improving the Work Related to Agriculture, Rural Areas, and Farmers" issued in December 2019 reiterated the importance of implementing the three-year action plan for rural living environmental remediation. It called for comprehensive efforts focusing on RDST to ensure a significant improvement in rural living environmental conditions by 2020, with villages being generally clean, tidy, and orderly, and the environmental and health awareness of villagers being universally enhanced. In December 2021, the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the "Five-Year Action Plan for Rural Living Environmental Remediation Enhancement (2021-2025)," emphasizing RDST as a focal point. The plan aims to consolidate and expand the achievements of the three-year action plan for rural living environmental remediation, comprehensively improve the quality of rural living environmental conditions, and provide strong support for advancing rural revitalization, accelerating agricultural and rural modernization, and building a beautiful China.

2. The key problems and dilemmas of RDST in China

2.1 Relatively low rate of RDST

As of 2022, China has approximately 2.5 million natural villages, with a rural population of around 510 million (Li et al., 2022). With the improvement in rural living standards and the increasing prevalence of flush toilets, the volume of rural domestic sewage continues to expand, highlighting a deficiency in rural living environmental management (Zhang and Yu, 2023). According to statistical calculations, from 2013 to 2022, China's rural resident population decreased by 46.56 million people, while the annual discharge of rural domestic sewage increased by 39.3 billion cubic meters (**Figure 1-2**). However, as of the end of July 2024, China's urban domestic sewage treatment rate reached more than 95%, whereas the rate for rural domestic sewage treatment (RDST) was only 45%[1]. The vast majority of rural domestic sewage undergoes minimal treatment or no treatment at all before direct discharge, primarily through septic tanks, constituting a significant source of pollution affecting surrounding water environments (Yang et al., 2016). Influenced by China's rural geographical conditions, lifestyle, and level of economic development, the longstanding urban-rural dichotomy has resulted in significant disparities in sewage treatment between urban and rural areas (Li et al., 2008a). With the progress of rural urbanization and changes in rural lifestyles, the increasing volume of rural sewage discharge exacerbates environmental issues in rural areas. Most rural domestic sewage is discharged untreated, directly polluting rivers and causing deterioration in watershed water quality, eutrophication, and black and malodorous water bodies. Rural domestic sewage poses a threat to the residential environment and drinking water health of rural areas, emerging as a critical factor influencing national water environmental security.

[1] https://www.gov.cn/lianbo/bumen/202407/content_6965103.htm

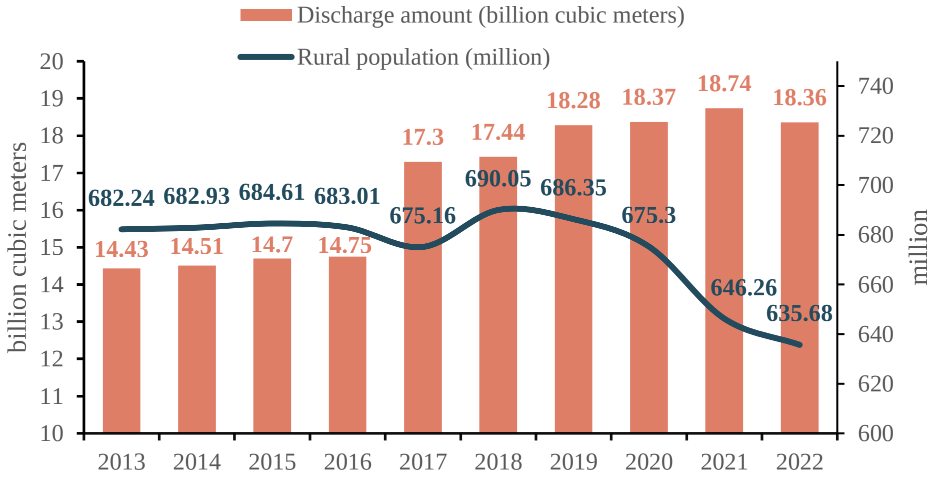

Figure 1-2 Rural domestic sewage discharge and rural population from 2013 to 2022 in China.

(*Data source: Ministry of Housing and Urban-Rural Development of the People's Republic of China*).

Scholars have investigated the patterns of sewage discharge in rural areas. Typically, sewage volume exhibits three peaks daily, occurring around 8:00 in the morning, 12:00 noon, and 18:30 in the evening. Generally, there is minimal sewage discharge between 23:00 in the evening and 6:00 in the morning. Variations in residents' activities such as cooking and laundry contribute to inconsistencies in daily sewage volume and timing patterns. Moreover, the patterns of sewage discharge vary across regions (Zhang et al., 2008). In terms of discharge standards, there are currently no national standards for controlling indicators and limit values of pollutant emissions from RDST facilities. Consequently, rural domestic sewage discharge lacks uniformity in practical operations, and the effectiveness of RDST varies (Yu, 2014). Given that sewage discharge standards directly influence water environment governance and quality, they shape the future development direction of the sewage treatment industry (Su et al., 2011). Scholars have proposed rural domestic sewage discharge standards from various perspectives. Xie et al. (2013)summarized and analyzed discharge standards in the United States, the European Union, and Japan, advocating for China's standards to be based on technological principles. Ding et al.

(2012) suggested that China's rural domestic sewage discharge standards should prioritize feasibility, foresight, and alignment with existing national laws and regulations.

2.2 Limited government funding

The construction, operation and maintenance of RDST facilities demand substantial and sustained financial investment over the long term. Both construction, operation and maintenance still rely heavily on fiscal inputs from various levels of government. The engagement of public or private sectors (in this thesis refers to public or private professional RDST enterprises or financial entities) in RDST is largely depends on sustained governmental financial support to ensure basic returns on investment. In 2021, investment in RDST facilities in China totaled 69.32 billion CNY, with a per capita investment of 81.16 CNY. By comparison, investment in urban sewage treatment facilities during the same period reached 121.96 billion CNY, with a per capita investment of 208.14 CNY. The total investment in rural areas was 56.84% of that in urban areas, and the per capita investment was only 38.99% of the urban area. Based on current statistics and county-level planning estimates, achieving the short-term planning goals (2020–2025) for each county necessitates annual RDST facility construction investments exceeding 70 billion CNY, with operation and maintenance expenses surpassing 3 billion CNY. The total investment level in 2021 is insufficient to meet the funding requirements for RDST construction (Liu, 2023).

In developed countries such as Europe, most regions already have more sophisticated financing mechanisms, such as the 3T (Taxes, Tariffs, Transfers), and legislation has been enacted to clarify the responsibility of rural residents to pay sewage charges and taxes (Brzusek et al., 2022; Cipolletta et al., 2021). In China, the funding mechanism for RDST primarily relies on local governments, supplemented by central government subsidies and public or private sectors participation. County-level governments bear the main responsibility for funding and expenditure. However, due to the scattered distribution, high quantity, small scale, complex construction conditions, and unpredictable returns of RDST projects, a mature investment return mechanism has yet to be established. Consequently, the enthusiasm of public or private sectors for participation remains low. Additionally, residents in almost all urban areas are currently charged a sewage treatment fee (included in the water bill). However, in order to develop rural areas in previous decades, the Chinese government provided tap water to most rural residents for free, regardless of sewage treatment fees. Therefore, there are currently very few areas where rural residents pay for RDST in China, and the rural resident payment rate and payment system for RDST is still in the exploratory stage. This makes the funding for RDST heavily reliant on governmental fiscal support, particularly at the county level. Counties with low urbanization rates, large rural populations, and heavy RDST tasks often face severe fiscal challenges and lack effective means of raising funds, making it difficult to ensure continuous and stable financial support. This issue is exacerbated by the fact that the operation and maintenance of many RDST facilities is managed by townships and villages, which are frequently unable to sustain the operation and maintenance costs of sewage treatment facilities over the long term. As a result, many RDST facilities are left idle after construction due to the lack of pipeline connections, overly simplistic treatment processes that fail to meet standards, and poor operation and maintenance management.

2.3 Inadequate public participation

RDST is a crucial component in improving rural living environments and constructing beautiful and habitable countryside, serving as a pivotal element in advancing comprehensive rural ecological civilization construction. Given its public goods nature, RDST cannot be supplied by the market and thus necessitates governmental provision. Rural residents, as the main stakeholders in RDST, should enhance their awareness and gradually cultivate a sense of responsibility and participation, facilitating the implementation of RDST and promoting the construction of beautiful and habitable rural areas (Yu and Yu, 2019b). However, as the construction of RDST facilities rapidly progresses, issues such as idle and abandoned facilities have become increasingly prominent. Particularly, the phenomenon of constructing demonstration RDST projects that remain unused or unattended is widespread (Liu and Gu, 2016). RDST facilities suffer from drawbacks such as a focus on construction over management and inadequate maintenance, highlighting the significance of ensuring the normal operation of RDST facilities to realize their full potential. Therefore, it is unrealistic to rely solely on government inputs for the fully realization of RDST, which requires the participation of the rural residents as well as public or private sectors. While encouraging rural resident involvement, exploring the establishment of a payment mechanism for rural residents is essential. Yet, due to the public goods nature of RDST facilities, rural residents generally hesitate to pay during the construction phase or offer relatively low levels of payment, which to some extent impedes the progress of RDST.

In addition, insufficient participation of public or private sectors also constrains the development of RDST. In July 2019, the General Office of the Central Committee of the Communist Party of China, the Ministry of Agriculture and Rural Affairs, the Ministry of Ecology and Environment, and other departments jointly issued the "Guiding Opinions on Promoting Rural Domestic Sewage Treatment." The document stipulates that the construction of RDST facilities should be government-led, with the establishment of a long-term management mechanism through local financial subsidies, village collective contributions, and appropriate payments from rural residents. Encouraging public or private sectors participation in RDST through government and public or private sectors cooperation has become an inevitable trend. The promotion and application of RDST projects using the PPP model has been advocated (Liu, 2015a). The PPP model can leverage the professional expertise of public or private sectors and mobilize its resources, while enabling the government to maximize social benefits. Therefore, exploring channels for public or private sectors participation in RDST and constructing a PPP model for RDST can effectively enhance the efficiency of funding utilization and alleviate fiscal pressures on local governments. However, PPP projects for public infrastructure discourage public or private sectors to participate in PPP projects in the RDST due to weak profitability, lengthy investment return period, as well as risks and uncertainties (Demirel et al., 2022).

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Chapter 2

Literature review

1. Public participation in RDST

RDST constitutes a fundamental public need, representing a focal point and challenge in improving rural living environments and bearing implications for the overall sustainable enhancement of water environments in China. To advance ecological civilization and create healthy and pleasant living environments in rural areas, RDST has been incorporated into urban and rural planning by local governments. However, in practice, government efforts alone are far from sufficient. RDST represents a systematic social livelihood project, necessitating the collaborative participation of governments, social organizations, and the public (Zhang et al., 2020a). As the primary beneficiaries of RDST projects, rural residents' involvement in RDST construction serves as a driving force (Han et al., 2018; Paola et al., 2018). Furthermore, the public has gradually become a leading force in environmental protection. However, due to the relatively late start of public participation in China, the involvement remains inadequate. In the RDST process, the public has yet to fully fulfill its functions and roles. Weak awareness, limited participation methods, and inadequate feedback channels are all hindrances to public participation. Therefore, establishing mechanisms for public participation is imperative for RDST, leveraging the combined efforts of the government and the public (Abramson et al., 2011; Zhang, 2017b).

With the widespread emergence of participatory democracy in the West during the 1980s, the theory of public participation gradually entered China. The term "public participation" first appeared in Chinese policy discourse in the report of the 16th National Congress of the Communist Party of China, emphasizing the gradual and explicit promotion of public participation in various sectors of society (Zhou, 2003). The Ministry of Ecology and Environment explicitly defined the scope, principles, methods, rights, and obligations of "public participation" in the "Measures for Public Participation in Environmental Protection" issued in 2015, proposing to establish a comprehensive system for public participation in environmental protection actions (Yan, 2017a). The "Opinions on Accelerating Ecological Civilization Construction" also proposed the improvement of the public participation system, encouraging active public involvement in "Beautiful Village Construction" and "Ecological Civilization

Construction" (Qiao, 2016). Over the past decade, citizen awareness and participation have been increasingly strengthened, and public affairs, social management, philanthropy, and other areas are no longer the exclusive domain of government departments, but rather increasingly involve public participation (Rashid and Pandit, 2020b; Zongo et al., 2015). As a result, scholars have produced many research results on public participation and conducted in-depth studies on public participation from various perspectives. Some representative studies include: Li (2015) discussed the responsibility of common beneficiaries in RDST, proposing that clear financial investment responsibilities and support and participation responsibilities of common beneficiaries are necessary to ensure the progress of RDST work. Liu et al. (2013) analyzed the current situation of RDST in the Dongjiang River Basin of Guangdong Province and provided corresponding countermeasures, mentioning the need to strengthen the pollution control awareness of rural residents and explore pollution control paths suitable for their own construction. Jiang et al. (2020) analyzed the current situation of RDST in East China, pointing out that the weak environmental awareness of the masses has to some extent exacerbated rural water pollution issues. It is necessary to enhance public environmental awareness and further improve public participation.

Some scholars have also conducted relevant research on RDST from the perspective of public WTPP. Hu et al. (2007) focused on public participation issues in the water pollution prevention and control in the Huai River/Taihu Lake Basin. Through surveys of public opinions, they found that public awareness and participation were relatively low, suggesting the need to further strengthen the establishment of public participation mechanisms. Wang (2015b) studied the current situation of rural residents' participation in water environment governance in Lishui City. A representative sample of rural residents aged 18 and above from 9 counties and districts was surveyed. The results showed that the overall level of environmental awareness among rural residents was good, but their environmental protection behavior was not proactive. The main reasons were weak subject consciousness, low level of understanding, and excessive reliance on the government. Therefore, it was proposed to continuously enhance the environmental awareness of rural residents and create a favorable environmental atmosphere. Fu et al. (2018b) analyzed the current situation of RDST in the Taihu Lake Basin and believed that the region's relatively developed economy and good social foundation for rural water pollution control led to strong WTPP among rural residents. However, actual actions lagged behind. It was suggested to strengthen the dissemination of environmental protection knowledge in rural areas through television, radio, slogans, etc., and combine it with typical demonstration and regular supervision and inspection to effectively improve the environmental awareness and sense of responsibility of rural residents, and promote the consistency between their attitudes and behaviors towards environmental protection. Mei and Bu (2020) believed that although rural residents hoped for RDST, the high cost of participating in RDST, high cooperation costs, and uncertain benefits, coupled with the influence of other rural residents' benefits, led most rural residents to passively accept it. Wei et al. (2022) conducted a survey on rural residents in Dongjiang River Basin and calculated through an economic model that the WTP of rural residents in the area for RDST facilities was 8.55 CNY/(month·household). Xie et al. (2016) conducted a survey in Sichuan Province and obtained similar results, with a WTP of 10 CNY/(month·household). However, due to weak economic foundations, most respondents in some remote rural areas expressed inability to pay. Fang et al. (2020) conducted field research in Kanas County, Xinjiang, and believed that the weak environmental awareness of rural residents was the main cause of serious rural domestic sewage pollution. After analyzing the research data, they concluded that the factors affecting rural residents' WTP for RDST mainly included cultural level, per capita income, frequency of participation in environmental protection training, age, and other factors. Finally, it was proposed that only by raising the cultural level of the next generation in rural areas and deepening their understanding of environmental protection could China's environmental problems be fundamentally addressed.

2. Life Cycle Cost Analysis

LCCA is an economic method that evaluates the costs of a project's entire lifecycle as a whole. In this approach, all costs incurred during the project's ownership, operation, maintenance, repair, and eventual disposal are considered as decision-relevant costs (Liu and Shen, 2014b). Initially proposed and utilized by the U.S.

Department of Defense, LCCA has since been widely applied in various sectors such as product and equipment production decisions, as well as infrastructure construction projects. After 1990, a series of U.S. laws explicitly required the calculation of LCC for all public facilities with a service life of more than two years. Numerous studies related to municipal infrastructure construction have also shown that LCCA is an effective decision support tool. Keoleian et al. (2005) conducted LCCA on two design schemes for cement bridge decks and found that the new scheme could save 37% of costs compared to the traditional one. The U.S. Department of Transportation has been introducing LCCA as a decision support tool since the 1970s and continues to advocate for its importance in effectively utilizing resources and providing various transportation services.

In the field of sewage treatment, both LCCA and LCA were first applied in the late 1990s. Over the past two decades, a growing amount of research has since examined the environmental and economic analyses of sewage treatment technologies, facilities, and processes (Ilyas et al., 2021b). Currently, in the realm of LCCA related to sewage treatment, evaluations are largely focused on urban treatment systems, with a lack of assessments in rural areas (Jiménez-Benítez et al., 2023). Xue et al. (2019) categorized urban sewage treatment systems into five parts: storage, transportation, extraction, treatment, and discharge, considering the costs of construction, operation, and replacement over three life cycle stages for each part, aiming to provide a scientific basis for decision-making through cost equations. Steer et al. (2003) evaluated the LCC of various decentralized RDST models by using LCCA, concluding that the operational lifespan of the treatment system significantly affects the cost-effectiveness of the models, suggesting that treatment methods should be chosen based on their effective lifespans. Wang et al. (2023) employed the LCCA method to analyze a RDST project in Wuzhong District, Suzhou City, and identified the length of the pipeline network as a crucial factor influencing LCC. Theregowda et al. (2016) combined external costs with LCC. Additionally, Hall et al. (2018) found that LCC is sensitive to discount rates, limiting long-term analysis.

3. Operation and maintenance mechanism of RDST

RDST is a highly public welfare-oriented endeavor, and fiscal investment is crucial. Only by continually increasing financial support can RDST be effectively advanced. In China, there are primarily three operational models for RDST: government-led construction, government service procurement, and government collaboration with public or private sectors (PPP) models (He, 2018). The government-led construction model requires sufficient fiscal funds for government-led construction, as well as high levels of professional technical expertise or operational management capabilities. However, meeting the operational requirements of RDST the majority of rural government levels is currently challenging due to the financial constraints. In the government service procurement model, since domestic sewage treatment falls under municipal engineering, it is not included in the government service procurement guiding catalog, leading to an inability to fully leverage social forces for governance. The government collaboration with public or private sectors model often involves the bundled construction of sewage treatment facilities and networks, requiring substantial capital investment and enduring long payback periods. Generally, only enterprises with strong financial capabilities or access to financing channels are willing to participate, facing significant profit risks (Kong and Zhang, 2019). Therefore, the construction and subsequent operation and maintenance of RDST facilities still rely heavily on government investment, lacking diversified RDST investment and financing mechanisms. Both the construction and ongoing operation and maintenance of RDST projects require substantial funding. The vast majority of RDST project construction funds come from the national, provincial, municipal, and county-level governments. However, due to inadequate financial resources in some cities and counties, insufficient matching funds result in poor project quality and incomplete pipeline systems. This inadequacy leads to ineffective sewage collection or low water collection rates, rendering RDST facilities unable to function properly (Zhou et al., 2019).

In recent years, with the rapid increase in the number of constructed facilities, various issues related to operation and maintenance have become increasingly severe. Some scholars have utilized the AHP to analyze the three major factors influencing the long-term operation and maintenance of RDST facilities. They concluded that post-construction management is the most critical factor, followed by engineering construction factors, and finally, population service factors (Song et al., 2014). Consequently, more and more local governments and scholars have begun to recognize the importance of effective operation and maintenance mechanisms. Some scholars have approached the organizational management of RDST facilities by comparing organizational management methods for RDST in the United States and Japan, and have emphasized the importance of the participation of professional third-party treatment organizations in operation and maintenance (Fan et al., 2009). They discussed the applicability of treatment processes and later operation and maintenance by applying the example of sewage treatment in Mexican towns (Belmont et al., 2004). They proposed viewpoints advocating government leadership, increased funding and policy support, improved operation and maintenance, establishment of coordinated feedback mechanisms, and enhanced public participation. Jia et al. (2019) systematically studied the successful experience of management in the Japanese RDST industry represented by purification tank facilities and proposed policy suggestions to enhance the marketization level and efficiency of RDST in China. Some scholars have also focused on the current situation in China and summarized the problems existing in the operation and maintenance of RDST facilities, including: non-standard facility construction (Wu et al., 2015), lack of a sound regulatory system (Yang, 2018a), unclear division of operation and maintenance responsibilities (Lin et al., 2012), and imperfect mechanisms for rural resident participation (Yu, 2017).

4. Application of PPP model

PPP refers to a project financing model for public infrastructure and other public service constructions. It denotes a collaborative relationship between the public sector and private sector, formed around a specific public project, and delineates the rights and obligations of each party through contractual arrangements. While providing high-quality services to society, the private sector can also gain reasonable profits (Chan et al., 2010). Due to the absence of specific provisions regarding the depth and form of collaboration between the public and private sectors, PPP manifests in various forms and contractual arrangements. Therefore, the precise interpretation often depends on specific circumstances, leading to some divergence in definitions and classifications by international organizations. For instance, the United Nations Training Institute categorizes models such as BOT, BOO, and BT are all concluded in PPP (Wu et al., 2013).

Since its inception, the PPP model has been widely applied across various industries in both developed and developing countries. It has effectively enhanced the supply capacity of public goods in these industries but has also brought about certain issues. Consequently, scholars have conducted research on the relevant issues arising from the practical application of the PPP model. Jong et al. (2010) proposed that the PPP model has shown favorable application effects in the construction of public infrastructure such as urban rail transit and municipal engineering. Papajohn et al. (2011) pointed out that different countries and regions should tailor PPP projects according to the legal, economic, and other fundamental conditions of the project site. Hong (2016) investigated the impact of public-private partnerships on the cost efficiency of urban rail transit operations in South Korea. The study found no evidence to suggest that privately operated projects lead to significant reductions in public costs compared to those entirely operated by the public sector. He (2018) conducted a study on the application of the PPP model in municipal solid waste management projects, advocating for increased collaboration between the government and social capital to provide scientific theoretical guidance for waste management through the improvement of relevant legal and institutional frameworks. Yu and Li (2019) investigated the current application of the PPP model in the provision of public goods in rural villages, proposing suggestions to optimize the operation of the PPP model, such as the establishment of a social supervision system. Hueskes et al. (2017) examined 25 Flemish infrastructure PPP projects and found limited effectiveness of sustainability factors in these projects. They identified the neglect of sustainability due to challenges in establishing standards for measuring social sustainability and proposed governance tools conducive to stimulating sustainability considerations based on case studies. Yu (2018) studied the application of the PPP model in the field of green agriculture in Hunan Province, suggesting that the PPP model could effectively address the shortcomings in the development of green agriculture in Hunan

Province. Pan and Liu (2019) analyzed the necessity and feasibility of introducing the PPP model in wetland ecological compensation in China. Wang et al. (2019a) examined 4560 PPP projects in 138 developing countries from 2002 to 2015, using the Tobit regression model to study the interactive effects of private partners on the governance environment responsibilities and risks borne by private investments.

In addition to research on the application of the PPP model, many scholars have focused on the aspect of risk management within the PPP framework. Ke et al. (2010) found that the key factors leading to the failure of PPP projects were the adequacy of private capital and the fairness of risk-sharing mechanisms. They proposed that macro and micro risks in PPP projects should be borne by the public sector, the private sector, or shared between them, while meso-level risks should be borne by the private sector. Lam et al. (2007) suggested the establishment of quantitative standards for PPP project risk based on various criteria and rules applicable to participating parties, enabling risk evaluation and the design of quantitative indicators and analytical models accordingly. He and Lv (2014) analyzed risk-sharing issues in China's water PPP projects, emphasizing the importance of rational determination of risk-sharing methods and proportions between the public and private sectors to mitigate risks, while continuously enhancing the capabilities of both parties in PPP application. Wen et al. (2015) argue that the large-scale promotion of PPP projects is prone to fiscal risks, thus necessitating the establishment of a scientific and comprehensive fiscal risk supervision mechanism for PPP projects. They propose the formulation of effective regulatory systems, processes, and technical methods, along with policy recommendations for strengthening fiscal risk supervision in China's PPP model. Wang et al. (2015a) combined fuzzy analytic hierarchy process with DEMATEL method to analyze the comprehensive impact of various risk factors in PPP projects. The results indicate that stakeholders should pay particular attention to policy sustainability risk, financing risk, legal change risk, contract document conflict risk, and force majeure risk. Li (2017b) introduced the AHP and constructed a hierarchical structure model for PPP projects, demonstrating the effectiveness of this method through specific case studies. Owolabi et al. (2020) utilized a mixed-method approach to assess the political, sponsor, concession, and legal risks faced by emerging market countries in infrastructure development through PPP model. They proposed a "Risk and Bankability Framework" model, providing key parameters for emerging market countries to attract foreign funding when applying for loans for PPP projects. Liu et al. (2016) established a game model to investigate mechanisms encouraging investors to adopt a positive attitude towards government cooperation, thereby mitigating moral hazards of private capital in PPP model. They found that blindly increasing rewards and penalties is not an effective means to guide investor behavior. Instead, employing flexible incentive mechanisms at different stages of the project can effectively influence investors' willingness to collaborate with the government while maximizing the benefits they derive from the project. Hu et al. (2019) utilized a risk checklist approach to study infrastructure PPP projects in countries along the Belt and Road Initiative. They analyzed various risks inherent in the projects and proposed countermeasures such as enhancing political cooperation, establishing sound joint supervision mechanisms, and promoting international cooperation among regions.

Overall, the PPP model is regarded as a mechanism for public infrastructure development characterized by its effective utilization of private capital and management expertise, fostering a cooperative operational relationship between the public and private sectors. This model addresses the bottleneck of insufficient government funds for public utilities and operates more flexibly through market mechanisms, thereby enhancing the operational and managerial efficiency of infrastructure. The application of the PPP model is widely acknowledged to offer higher quality and more efficient public services and has been extensively adopted globally. By combing through the existing literature, it is found that the main problems in the current PPP model are how to avoid financial risks and ensure that public or private sectors can obtain a stable return on investment. Current research in this area is insufficient, requiring further exploration of the financial sharing mechanism and return mechanism in the PPP model.

5. Environmental regulation

Environmental regulation refers to the policy guidelines established by government agencies to reduce environmental pollution. It primarily aims to improve ecological conditions through the exercise of national or governmental authority, with specific regulatory measures including the establishment of relevant standards for pollutant emissions and the imposition of taxes (Stigler, 1971). Based on the differences in ways of restricting the polluting behavior of economic entities, environmental regulation can generally be classified into guiding regulation, incentive regulation, and binding regulation (Xu et al., 2023b). In terms of guiding regulation, the government mainly relies on environmental protection propaganda and education to inform polluters about the negative consequences of environmental pollution and the importance of environmental protection. These methods can enhance polluters' environmental knowledge and literacy, increase their understanding and acceptance of policies, thus reducing policy violations (Ren and Guo, 2023; Xu et al., 2023b). The design of incentive regulation criteria utilizes market mechanisms to encourage pollution control behaviors among polluters. Specific methods include increasing taxes on polluting products or implementing subsidies to promote clean production (Malueg, 1989). Binding regulation directly restricts the polluting behavior of economic entities. Its key lies in formulating policies, regulations, or issuing administrative orders to specify the pollution reduction targets, technological levels, and standards that polluters must meet. Under this regulatory mode, economic entities are obliged to comply with relevant institutional guidelines; otherwise, they will face strict supervision or hefty penalties (Xia et al., 2019). Compared to binding regulation, which entails higher regulatory costs, incentive regulation provides economic entities with more flexible measures, making it more effective in most contexts (Barbera and McConnell, 1990).

Furthermore, scholars have conducted research on the impact of environmental regulation on individual behavior. Based on studies of the influence of environmental regulation on agricultural production behavior, Lutz and Young (1992) found that both incentive and binding regulations significantly affect adjustments in farmers' agricultural production structures and pesticide application behaviors. Panoutsou (2008) investigated the diffusion of biomass energy technology innovation, revealing that formal environmental regulations such as government laws and economic incentives, as well as regulations from environmental organizations and local communities, play a significant role in promoting the adoption of new biomass energy technologies among Greek farmers. Jacquet et al. (2011) studied the reduction in pesticide use among French farmers with the goal of halving pesticide application. Using mathematical programming models, the feasibility of the policy objective was examined by simulating the pesticide tax levels required for different degrees of pesticide reduction. The results showed that government guidance and promotional policies could effectively reduce pesticide usage by 10-20%. However, achieving higher levels of pesticide reduction without reducing farmers' income requires complementary incentive regulatory policies such as taxation and subsidies.

6. Research commentary

The aforementioned findings hold significant implications and reference value for this study. However, existing research exhibits several shortcomings. Firstly, while scholars have used econometric analysis to explore the WTPP and WTP of rural residents in a certain region for RDST, as well as the corresponding influencing factors. However, there is a lack of large-scale empirical studies, as well as in-depth research on the influence mechanisms. Secondly, LCCA has been widely applied, but research on the impact of public participation on LCC is relatively scarce. Thirdly, although some scholars have proposed to advocate public participation in the operation and maintenance of the RDST, the relevant studies on participation methods and participation mechanisms are relatively weak. Fourthly, most of the existing research focuses on the risks faced by the PPP model, but the important factor in attracting public or private sectors to participate in the PPP model is the investment return and revenue, and there is relatively little research on how to attract public or private sectors and how to improve the revenue in the current studies. Finally, the majority of current research concerns the effectiveness of environmental regulations, while neglecting to further analyze their internal effective mechanisms, as well as the impacts between different environmental regulations.

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Chapter 3

Research objectives, contents and methods

1. Key issues and research objectives

1.1 Key issues

Strengthening RDST is an integral part of rural living environment improvement and a crucial component of building beautiful rural areas. RDST not only enhances the environmental quality of rural areas but also mitigates pollution. However, RDST projects involve multiple stages of construction and operation, requiring substantial financial investment and often leading to a lag in RDST capacity due to high costs. Furthermore, RDST projects have strong public welfare attributes, with relatively low direct economic benefits, resulting in weak financing capabilities. Reliance primarily on fiscal funds as the financing channel, coupled with insufficient mobilization of social forces, exacerbates the pressure on government finances. Therefore, to address these challenges, it is imperative to expand current financing mechanism and incorporate the participation of rural residents to develop a comprehensive, sustainable and public participation funding framework. This framework should also include enhanced fiscal support from various government levels, innovative financing strategies, and improved PPP projects. The expansion and in-depth research of this funding framework depends on the identification of the costs of the various processes involved in the RDST project. Furthermore, encouraging public participation and raising public awareness about the importance of RDST can support funding efforts by fostering a collective sense of responsibility and engagement in environmental protection. By adopting a multi-stakeholders' participation mechanism that combines government support, public or private sectors investment, and public payment, it is possible to ensure the effective and sustainable management of RDST facilities, thereby contributing to improved rural living conditions and environmental sustainability. Based on the realistic issues and research gaps in the previous chapters, the following key issues are proposed:

(1) how does public participation affect the LCC for the RDST project;

(2) as the main stakeholders, whether rural residents are willing to participate and paying for RDST projects; what is their WTPP and WTP level and what are the influencing factors;

(3) what are the impacts of government-imposed environmental regulations on rural residents, and what are the underlying mechanisms of these impacts;

(4) how does the participation of rural residents affect the financing framework?

1.2 Research objectives

In response to the above research questions, the following research objectives can be achieved in this thesis:

(1) to analyze and explore the costs and factors affecting the various processes in the RDST project (in Chapter 4);

(2) to identify the WTPP and WTP and their influencing factors of the rural residents on the construction of RDST projects (in Chapter 5);

(3) to identify the WTPP and WTP of rural residents for sustainable RDST and to explore the corresponding influencing mechanisms of different environmental regulations (in Chapter 6);

(4) to expand and analyze the multi-stakeholder funding framework from the perspective of rural residents' participation and to propose a win-win funding mechanism for the different stakeholders (in Chapter 7).

2. Research significance

2.1 Empirical significance

Firstly, the construction, operation and maintenance of China's current RDST projects are mostly provided by the government. Due to the influence of multiple factors such as the migration of rural residents and insufficient publicity on democratic participation and decision-making, rural residents' awareness has become rigid, their awareness of participation is insufficient, and they have not yet formed the awareness of active participation. In terms of this thesis on the RDST project, it has clarified the relationship between the government and rural residents, that is, which approaches should be adopted by the government as the leader to guide rural residents to participate. Therefore, this study used field survey data to explore rural residents' willingness to participate and pay in the supply of RDST projects, deeply analyze the internal mechanism, and further enrich the current theoretical system of public goods supply. Secondly, the government could leverage the strengths of public or private sectors in terms of capital, technology, management experience, etc., to cooperate in public services and achieve the effective supply of public goods and services. However, due to the public goods attribute and low profitability of the RDST project, it lacks the attractiveness for public or private sectors to participate. Therefore, it is proposed that rural residents' payment could effectively alleviate the pressure on government funds and improve the profitability of public or private sectors, thus improving the previous multi-stakeholder participation framework and proposed highly actionable recommendations. and also provides a useful exploration for the next step of more detailed and in-depth research on the PPP model for the RDST project.

2.2 Practical significance

At present, China's RDST mainly relies on policy incentives to promote the development of the industry. The main body of investment is still unbalanced, with the vast majority being government investment in construction, operation and maintenance. However, the rural residents who should be the main participants in RDST are actually excluded from the project. Therefore, the participation of rural residents in RDST could alleviate the financial and management pressures on the government. In this thesis, the proportion of costs that rural residents could afford currently is further calculated, which provide a reference and basis for government departments to explore the establishment of a payment mechanism for rural residents in RDST. Moreover, with the development of the PPP model, both the public and private sectors could cooperate in investing in and operating RDST projects. Attracting public or private sectors and involving rural residents could change the pattern of the government being the sole provider, creating a situation where multiple stakeholders collaborate to provide services. This is of great practical significance for improving the quality and efficiency of public services and reducing the cost of RDST projects. In addition, the introduction of the PPP model into RDST projects has solved the funding constraints of RDST facilities construction, operation and maintenance within a certain range, given full play to the efficiency advantages of public or private sectors, and completed RDST projects with high quality. This is also of great practical significance for environmental protection and other aspects.

3. Research contents

This study focuses on RDST and employs the theory of public goods as a guiding framework to include rural residents in the theoretical analysis framework for the multi-stakeholders' participation mechanism in RDST. It investigates the participation mechanisms of governments, rural residents, and public or private funding institutions from the perspectives of internal and external motivations. This study is based on the empirical realities of RDST and utilizes micro-level research data from surveyed regions to explore the LCC of PPP project of RDST and the multi-stakeholders' participation mechanism expansion in RDST. The research primarily encompasses the following aspects.

Firstly, it starts from the practical background of sewage treatment in rural China and the micro-level status of the government, rural residents, and public or private funding institutions, identifying key issues that need to be addressed. By reviewing relevant studies, it elucidates the main focuses of existing research and highlights important issues overlooked in the research process. It proposes the research perspective of this study and formulates scientific questions based on the condensed understanding of practical problems, particularly focusing on how to include rural residents in the multi-stakeholders' participation mechanism in RDST.

Secondly, as a common model of multi-stakeholders' participation, this study focuses on the research of PPP model in RDST. This research examines PPP projects in RDST, utilizing the LCCA method to investigate the LCC involved at various stages. Based on case studies and empirical analysis, the study proposes recommendations tailored to the current national conditions of China, aiming to provide practical insights for enhancing the application of PPP model in RDST.

Thirdly, this study delves into the mechanisms of rural residents' participation in RDST construction. As direct contributors to rural domestic sewage generation, rural residents' participation wield significant influence on the efficacy of sewage treatment in RDST. Based on the perspective of rural residents, and drawing upon survey data from rural areas, this research analyzes the WTPP and WTP of rural residents in RDST construction. It examines the impact of individual and household characteristics, treatment status, environmental awareness, and regulation cognition on the WTPP and WTP of rural residents during the construction phase of RDST. Furthermore, it identifies key factors affecting rural residents' participation. Addressing the current practical issues and impediments leading to low rural resident participation in RDST construction, this study proposes corresponding policy recommendations to establish mechanisms for rural resident participation and payment in RDST construction.

Fourthly, this study investigates the impact of environmental regulations on rural residents' WTPP and WTP in the operation and maintenance of RDST. Initially, the study will define the classifications of environmental regulations. Through field surveys and interviews, rural residents, village cadres, local governments, and relevant regulatory authorities within the research area will be surveyed by questionnaires. By employing methods such as CVM and mediation analysis, this study will analyze the heterogeneous effects of environmental regulations, providing a theoretical foundation and scientific basis for the formulation and decision-making of government policies.

Finally, combining the theoretical and empirical findings of the above analyses and based on the LCC analyses of PPP projects, the WTPP and WTP of rural residents on RDST, and the impact of environmental regulations on rural residents, an expansion framework for the inclusion of rural residents in the multi-stakeholder participation mechanism of RDST is proposed.

4. Thesis outline and analytical framework

Base on the research objectives and research content mentioned above, this thesis are illustrated in seven chapters.

Chapter 1 describes the current characteristics of rural domestic sewage and the problems faced by RDST, in addition, the objectives of this thesis are clarified. **Chapter 2** provides a review of the literature on RDST, including five aspects: public participation, LCCA, operation and maintenance mechanism, PPP model, and environmental regulation. In **Chapter 3**, the research content, analytical framework and research methods of this thesis are presented. **Chapter 4** employs LCCA to evaluate the LCC of the PPP project in RDST, identifies the primary influencing factors affecting the LCC, and conducts a case analysis based on field research data. **Chapter 5** empirically analyses rural residents' WTPP and WTP in RDST construction by applying CVM and field research data, thereby establishing a realistic foundation for rural residents' participation behavior. In **Chapter 6**, it constructs a mediation model to evaluate the influence of government-enacted environmental regulations on rural residents' WTPP and WTP for operation and maintenance of RDST project, and conducts empirical analysis by field research data. In **Chapter 7**, based on the theoretical analysis framework, methodological foundation, and empirical basis established in this thesis, it summarizes the theoretical analysis and empirical testing results, to expand the multi-stakeholders' participation mechanism in RDST. In addition, policy recommendations are provided in response to the empirical results as well as clarifying the limitations of this thesis.

The analytical framework of this thesis is illustrated in **Figure 3-1**.

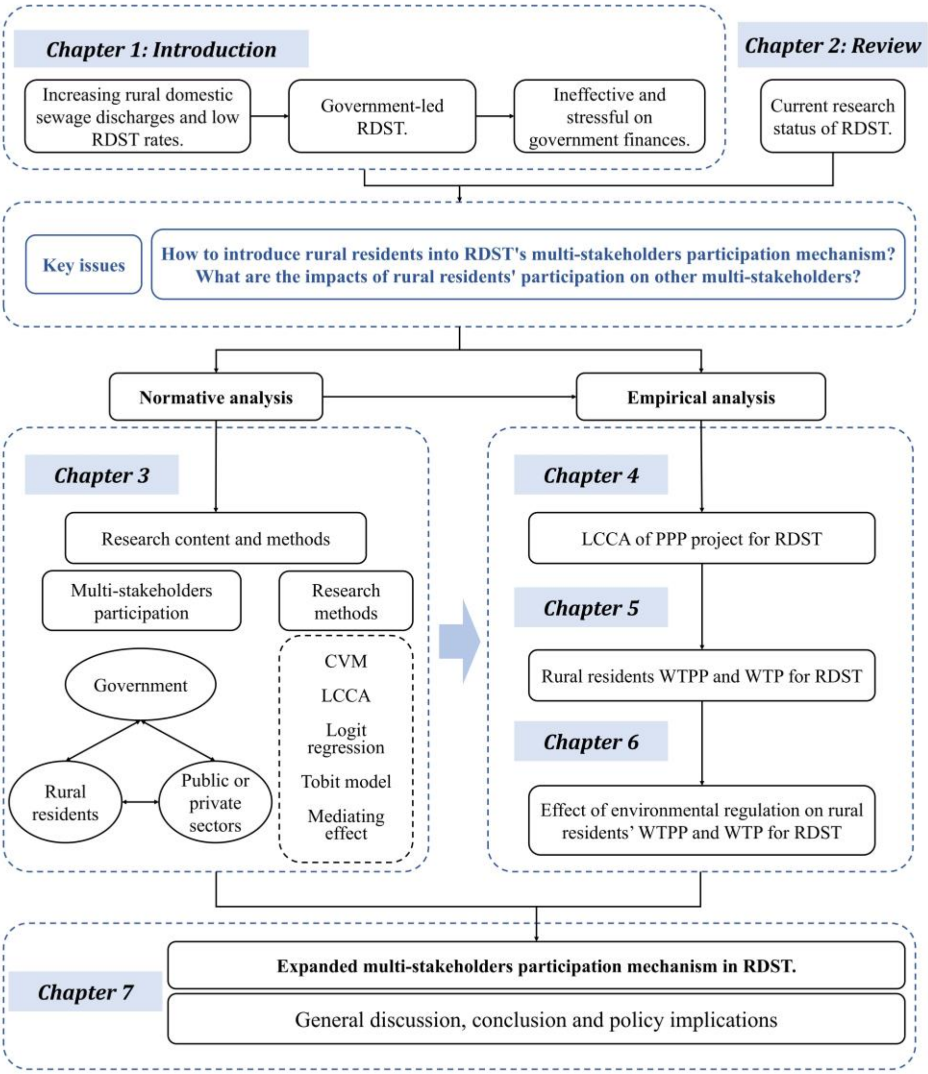

Figure 3-1 The overview of analytical framework.

5. Research methods

Firstly, the literature analysis method is employed. This involves synthesizing the latest research developments on RDST from worldwide scholars. It entails reviewing existing research perspectives, methodologies, and conclusions. Drawing upon theories such as resource and environmental economics and ecological economics, an in-depth analysis of the current status of RDST is conducted.

Secondly, questionnaire surveys and research interviews are conducted. In this study, the questionnaire survey adopts a stratified random sampling method. It targets regions with a high proportion of rural population in provinces such as Jilin, Shandong, Gansu, and Henan in China. Each province is divided into three income groups (high, medium, and low) based on the average income per capita of rural residents in each county. One county is randomly selected from each income group within each province. Within each selected county, three townships (or towns) are randomly chosen, and within each township (or town), three villages are randomly selected, from which 8-10 rural residents are sampled. This results in a sample size of approximately 800 individuals. Additionally, discussions and communications are held with relevant local government departments and RDST enterprises for data collection.

Thirdly, the case analysis method is employed. This research selects typical cases of PPP project of RDST to conduct in-depth analysis of their LCC in construction and operation, and identifies influencing factors. Based on the case analysis, the participation mechanisms of public or private funding institutions in RDST are summarized, and systematic experiences and policies that can effectively guide practice are extracted.

Fourthly, the combined method of quantitative and qualitative analysis is employed. In this study, concerning the participation of public or private funding institutions in PPP model, issues such as cost allocation mechanisms will be analyzed using methods like LCCA. Building upon this foundation, the rural residents' WTPP and WTP in RDST are examined to expand the multi-stakeholders' participation mechanism. The CVM and Logit regression model is utilized to analyze the WTPP and WTP of rural residents in RDST and the influencing factors. Furthermore, a heterogeneous analysis of environmental regulations from the perspective of rural residents is conducted, and the impact pathways of heterogeneous environmental regulations are analyzed by using the mediation effect.

This study primarily employs statistical software packages such as STATA, EVIEWS, SPSS, and R. These software packages are instrumental in conducting quantitative analyses and statistical modeling, facilitating rigorous data analysis and interpretation.

Chapter 4

Life cycle cost analysis of RDST project based on public-private partnership model

This Chapter is adapted from the following paper:

Jian Jiao, Zihong Yang, Thomas Dogot, Changbin Yin, Cost Effectiveness of Rural Domestic Sewage Treatment Based on Life Cycle Cost Analysis: A case analysis of PPP project in Jiyuan City China. (This paper will submitted to the journal in August.)

1. Introduction

Currently, sewage treatment stands as a pressing global environmental concern. Reports indicate that the global volume of sewage amounts to 359.4 billion m^3/year, with approximately 48% (172.5 billion m^3/year) being directly discharged without any treatment (Zhang et al., 2024a). In recent years, alongside the economic development in rural areas and the significant improvement in people's living standards, environmental shortcomings in RDST have gradually surfaced, particularly in rapidly urbanizing countries such as China and India, leading to a series of adverse effects on rural living environments(Huang et al., 2022; Sharma et al., 2022; Zhu and Pei, 2024). Statistical data reveals that in 2021, 35 million m^3 of sewage was discharged in rural areas of China, with a relatively low treatment rate of 31%(The State Council of the People's Republic of China, 2024). This issue has also garnered the attention of governmental authorities, leading to the joint issuance of the *Action Plan for Agricultural and Rural Pollution Governance (2021-2025)* by multiple Chinese government ministries. It is stipulated that "by 2025, the rural domestic sewage treatment rate should reach 40%". This objective will be pursued through a tripartite approach involving governmental intervention, market mechanisms, and community participation. (Xiang, 2022).

Presently, the principal funding for the design, construction, operation and maintenance of RDST primarily stems from local governments. However, the endeavor faces governance dilemmas such as significant funding shortfalls, unclear delineation of responsibilities, and a lack of specific governance measures. These challenges impede the widespread adoption of RDST, highlighting the urgent need to establish market-oriented mechanisms for RDST (Du et al., 2019; Zhang et al., 2024a). Furthermore, due to fiscal deficits, some governments lack the financial capacity to cover the operational and maintenance costs of completed RDST facilities. This has resulted in inadequate sewage treatment and hindered the sustainability of RDST (Ding et al., 2021). For efficiency purposes and to fill the discrepancy between the investment gap and the high demand for sewage treatment, the increasing involvement of private providers has given rise to PPP mechanisms over the past few decades (Tan and Zhao, 2019; Tang et al., 2021c; Wang et al., 2012a; Yang et al., 2017; Zhong et al., 2008). Some scholars argue that the PPP model introduces competitive markets into the provision of public services, which is considered a significant avenue for improving service delivery efficiency (Chan et al., 2017; van Slyke, 2003; Warner and Hefetz, 2008). China's central government has progressively adopted private financing for public goods and popularized the PPP model since 2013, in order to alleviate the pressure of the government's shortage of funds. Against this backdrop, public-private cooperation in China has expanded to an unprecedented scale (Tang et al., 2021c). However, previous research has mostly focused on areas such as public transportation, urban sewage, and urban waste management, with relatively limited studies on RDST projects in rural areas. Additionally, PPP projects incur additional costs such as financing costs and risk costs (Bel and Rosell, 2016; Hellowell, 2016; Spackman, 2002). Therefore, conducting cost analysis of PPP projects is essential, as well as identifying the factors influencing PPP project costs.

Considering that PPP projects typically involve long project cycles (mostly ranging from 10 to 50 years), studies focusing on a single time frame or single stage consistently face issues of generalization. Therefore, research on PPP model from the perspective of project life cycle has garnered increasing attention and response (Baker, 2016). LCCA is an important tool for clarifying the wider economic implications of design, construction and operational decisions. In fact, a series of laws in the United States explicitly require that public facilities with a lifespan of more than two years must incorporate LCC theory into cost-effectiveness calculations and become decision-making tools for various infrastructure construction projects (Button and Daito, 2014). LCCA involves considering all costs at each stage of the project lifecycle and conducting comprehensive evaluations (Liu and Shen, 2014a). Compared to traditional costs evaluation methods, it can more comprehensively and accurately reflect the overall effectiveness of the project as well as the individual effectiveness of each stage (Scott, 2009). In contrast to traditional project efficiency analysis methods, it can not only identify the cost-effectiveness of technologies but also analyze the dynamic changes in operating costs under different scenarios, thus contributing to decision-making optimization for the entire project or different stages.

Based on the above analysis, this study constructs a LCCA framework for RDST. In addition, through typical case studies, the cost-effectiveness of PPP projects is analyzed, and relevant influencing factors are identified. Based on the research findings, corresponding policy recommendations will be proposed. On one hand, it is possible to allocate costs reasonably across all stages under a consistent time scale, thereby minimizing instances where short-term effectiveness substitutes for long-term effectiveness, leading to situations where construction is useless or unused. On the other hand, analyzing cost variations in individual stages and their impacts on other stages can facilitate the optimization of decision-making mechanisms. Therefore, the study aims to provide insights for developing countries implementing RDST development through PPP projects.

2. Methodology

2.1 Analytical framework

The life cycle stages and corresponding costs vary depending on different classification methods and application domains. Since the public or private sectors participation in RDST projects is mostly in the form of PPP model in China currently, this study takes the PPP model in RDST projects as an example. According to PPP operational practices, the entire process comprises project identification (project initiation and screening, value-for-money assessment, fiscal affordability certification), project preparation (organizational management structure, formulation of implementation plans), project procurement (qualification pre-assessment, negotiation, and contract signing), project execution (project construction, operation, and maintenance), and project handover. In light of the strengths and comprehensiveness of the LCCA method in analyzing project costs, the method could contribute to decision makers in analyzing the cost components at different stages and identifying the main contributors of the costs. Therefore, the LCCA method has an important contribution to analyzing the cost distribution and impact of PPP projects in RDST of China. In the Handbook of the National Institute of Standards and Technology of the United States, 1996 edition, the life cycle costs of PPP projects are defined as "the present value of costs incurred in owning, operating, maintaining, and disposing of a project over a period of time" (Fuller and Petersen, 1996). Hoppe and Schmitz (2013) propose that PPP phases encompass planning, design, financing, construction, and management processes, with construction and management being particularly core. Building upon existing studies by numerous scholars, this paper divides the PPP life cycle into four main stages: initiation, construction, operation and maintenance, and disposal (Li et al., 2016). The analysis process is shown in **Figure 4-1**.

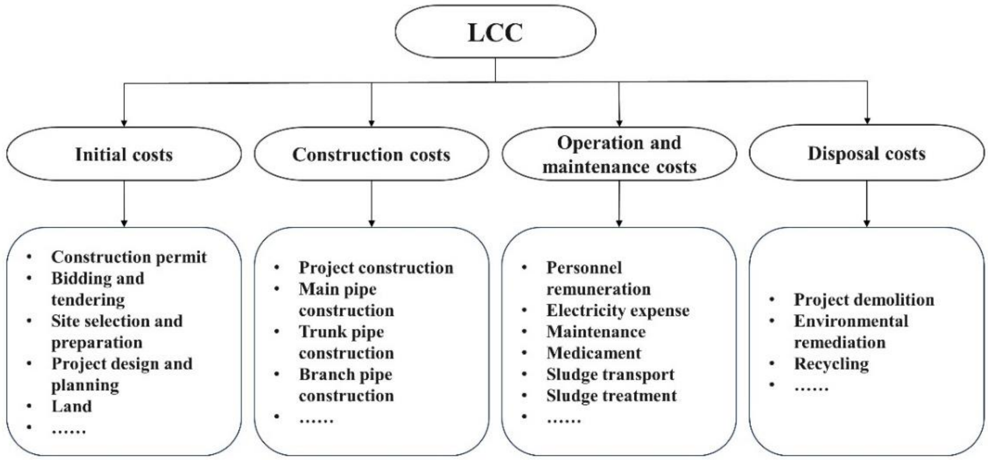

Figure 4-1 LCCA process of PPP project of RDST system.

2.2 Model

To account for the financial inputs of projects at different periods, the application of LCCA is customary to establish a discount rate r based on regional socio-economic conditions to compute the Net Present Value (NPV), thereby converting long-term costs into present values, enabling direct comparison of cost expenses incurred across different periods and projects. Therefore, based on the studies of Liu and Shen (2014a) and Du et al. (2018), the LCCA of RDST PPP projects can be described and computed using the following formula.

$$LCC = C_1 + C_2 + \sum_{n=1}^{N}(C_3 * \frac{1}{(1+r)^n}) + C_4 * \frac{1}{(1+r)^n} \quad (4\text{-}1)$$

$$ATC = LCC / \sum_{n=1}^{N} 365 * \mathrm{Q_n} \quad (4\text{-}2)$$

In Equation (4-1), LCC represents the total lifecycle cost of the project (unit: CNY), where C_1 denotes the initial cost (unit: CNY), C_2 denotes the construction cost (unit: CNY), C_3 denotes the annual operation cost (unit: CNY), C_4 denotes the disposal cost (unit: CNY), r represents the discount rate, and n denotes the contracted concession period. In Equation (4-2), ATC represents the average treatment cost of one ton of sewage from a life cycle perspective (unit: CNY/ton), where $\mathrm{Q_n}$ denotes the average daily water treatment volume in the nth year (unit: tons/day).

2.3 Data

2.3.1 Data collection

The research area is situated in Jiyuan City, Henan Province, with a rural population of 230,000 distributed across 11 towns and 452 administrative villages. In 2022, the average annual disposable income per rural resident in the area was 24,948 CNY. To address the issue of RDST, the government of Jiyuan City actively introduced public or private fundings through competitive negotiations in 2016. A project company was established with representatives from the Jiyuan municipal government as equity contributors, establishing a PPP cooperation model. The primary components of the project involve the construction of 100 village-level sewage treatment stations and associated pipeline networks. The sewage collection pipeline network spans 450.03 km, with a total sewage treatment capacity of 5,440 m^3/day. The project has a cooperation period of 30 years, and the annual investment return is 3.33% and the annual interest rate is 8%. The PPP project of RDST in Jiyuan City exhibits a high degree of typicality and representativeness. Prior to the introduction of public or private fundings, government-led comprehensive environmental remediation efforts regarding RDST yielded unsatisfactory results. Subsequently, the exploration of the PPP model has resulted in significant effectiveness, leading to its selection for inclusion in the national demonstration PPP project database. It serves as a model for governmental departments, media, enterprises, universities, and other institutions to visit, exhibiting a certain level of typicality.

This study utilizes the RDST project in Village W as a case analysis within the PPP project. Village W comprises 486 rural households with a total population of 2,000 individuals. The RDST facility in the village was put into operation in 2019, employing an A/O process coupled with sand filtration disinfection technology. The average daily sewage treatment capacity is 100 m^3/day, with a maximum sewage treatment capacity of 150 m^3/day.

The data used in this study were primarily acquired through field interviews, corporate financial reports, and government annual reports. Initially, in July 2022, the research team conducted field research in Jiyuan City, investigating the entire process of the PPP project of RDST, as well as its management and monitoring systems. Interviews and questionnaires were used to investigate key stakeholders, which included government officials, enterprise executives, township cadres, village cadres, and villagers. In-depth discussions and on-site observations were held in typical townships to further understand the actual operation of the PPP project. Subsequently, the textual materials for the PPP project were obtained through research and online databases, including various contract documents, financial reports, assessment reports, and statistical data, and data were obtained through textual analysis. Finally, field inspections of the RDST facilities in Village W were conducted with the project company personnel, and relevant data were obtained. To ensure objectivity and data integrity, multiple telephone interviews with relevant enterprises and government departments were conducted for accuracy during the calculation process.

2.3.2 Indicator selection and description

The LCC of the PPP project includes upfront costs, construction costs, operating costs, and disposal costs. Initial costs mainly entail expenses incurred during the pre-project phase, such as obtaining construction permits, bidding and tendering, site selection and preparation, project design and planning, and land costs. Construction costs encompass equipment construction, pipeline construction and loan interest. Equipment construction entails the purchase, installation, construction, and labor costs associated with integrated RDST facilities and supporting facilities. Pipeline construction includes material costs, construction costs, and labor costs for various pipelines. The land utilized for project construction is relatively small in scale, mainly consisting of communal land or wasteland along village roads, thus assuming a zero land acquisition cost. Operation and maintenance costs mainly include personnel remuneration, electricity expense, facility maintenance, medicament costs, sludge transportation costs, and sludge treatment costs. Regarding disposal or handover costs, if transferred to the government upon expiration of the concession period, it primarily involves project asset liquidation, performance testing, and performance evaluation, for which cost data are difficult to obtain support. In addition, previous studies have shown that the disposal costs of sewage treatment facilities represent only an extremely minor portion of the total LCC, ranging from 0.21% to 2.89% (Hao et al., 2021; Huang et al., 2013; Resende et al., 2019). Therefore, this study did not take disposal costs into account and assumed the disposal costs as zero. Further details are provided in **Table 4-1**.

Table 4-1 Description of cost indicators for each phase.

Cost categories	**Cost details**	**Description**	**Cost-bearing subjects**
Initial costs	Construction permit	Costs for obtaining project construction permit.	Government
	Bidding and tendering	Costs of bidding and tendering for the project.	Government
	Site selection and preparation	Costs of site inspection, site selection and preparation required for the project.	Government
	Project design and planning	Costs incurred for project design and planning, etc.	Government
	Land	Cost of acquiring the land required for project construction.	Government
Construction costs	Equipment construction	Costs of RDST facilities, including one set of A/O + sand filter disinfection integrated treatment facilities, one grating tank, one lift shaft, one regulating pool, etc.	Enterprise

	Main pipe construction	Costs of materials and construction of main pipes, with a total of 2427.3 meters.	Enterprise
	Trunk pipe construction	Costs of materials and construction of trunk pipes, with a total of 10,373.8 meters.	Enterprise
	Branch pipe construction	Costs of materials and construction of branch pipes, with a total of 5612.4 meters.	Enterprise
	Loan interest	Loan amount is 78.72% of the total construction cost and the interest rate of the loan is 8.66 %.	Enterprise
Operation and maintenance costs	Personnel remuneration	Salaries for facilities management and maintenance staff.	Enterprise
	Electricity expense	Cost of consumed electricity for facility operation.	Enterprise
	Facility maintenance	Costs of maintenance and repairs for facility operation.	Enterprise
	Medicament	Cost of medicaments required for facility operation.	Enterprise
	Sludge transport	Cost of transporting sludge generated by sewage treatment facility.	Enterprise
	Sludge treatment	Cost of harmless disposal of sludge generated by sewage treatment facility.	Enterprise
Disposal costs	Project demolition	Treatment facility demolition cost.	Enterprise
	Environmental remediation	Cost of remediation of the environment after demolition.	Enterprise
	Recycling	Cost of recycling the facility.	Enterprise

3. Results

3.1 LCC estimation

Based on the aforementioned analytical framework and data, the calculated results of the LCC for the RDST project in Village W are presented in **Table 4-2**. In the case of Village W, initial costs primarily include expenses incurred during construction permits, bidding and tendering, site selection and preparation, project design and planning, etc.. Due to data availability, only the total cost of the initial phase was obtained, and cost categories could not be further segmented, resulting in a total cost of 239,000 CNY. Within the construction costs, categories such as equipment construction, main pipe construction, trunk pipe construction, and branch pipe construction all include material and labor costs. Therefore, assuming a 30-year operational period, based on Equation (4-1), the total LCC of the PPP project of RDST in Village W can be calculated as 8,591,985 CNY (discount rate assumed at 5%), with a cost of ATC approximately 7.85 CNY.

Table 4-2 Costs of RDST PPP project in W Village.

Cost categories	Cost details	Expenses
Initial costs	Construction permit (CNY)	- [a]
	Bidding and tendering (CNY)	-
	Site selection and preparation (CNY)	-
	Project design and planning (CNY)	239,000
	Land (CNY)	0
	Total (CNY)	239,000
Construction costs	Equipment construction (CNY)	1,600,000
	Main pipe construction (CNY)	970,920
	Trunk pipe construction (CNY)	2,998,474
	Branch pipe construction (CNY)	1,152,652
	Loan interest (CNY)	458,252
	Total (CNY)	7,180,298
Operation and maintenance costs	Personnel remuneration (CNY/year)	14,600
	Electricity expense (CNY/year)	39,055
	Maintenance (CNY/year)	10,950

	Medicament (CNY/year)	8,030
	Sludge transport (CNY/year)	1,095
	Sludge treatment (CNY/year)	2,555
	Total (CNY/year)	76,285
Disposal costs	Project demolition (CNY)	0
	Environmental remediation (CNY)	0
	Recycling (CNY)	/ [b]
	Total (CNY)	0

[a] "-" indicates that the cost cannot be split.

[b] "/" indicates that the cost cannot be obtained.

From **Figure 4-2**, it can be observed that within the construction costs, pipe construction accounts for a significant proportion of the total construction costs, at 72%. Specifically, main pipe construction, trunk pipe construction, and branch pipe construction represent 14%, 42%, and 16%, respectively, of the total construction costs. The variation in pipe construction costs primarily depends on two factors, project location and road excavation difficulty. Although the site selection for the RDST project in Village W is relatively close to the village, the necessity to excavate hardened roads for laying the sewage collection pipeline results in higher costs for trunk pipe construction. Project construction costs also constitute a substantial portion of the total construction costs, at 22%, while loan interest accounts for a relatively smaller proportion, at only 6%.

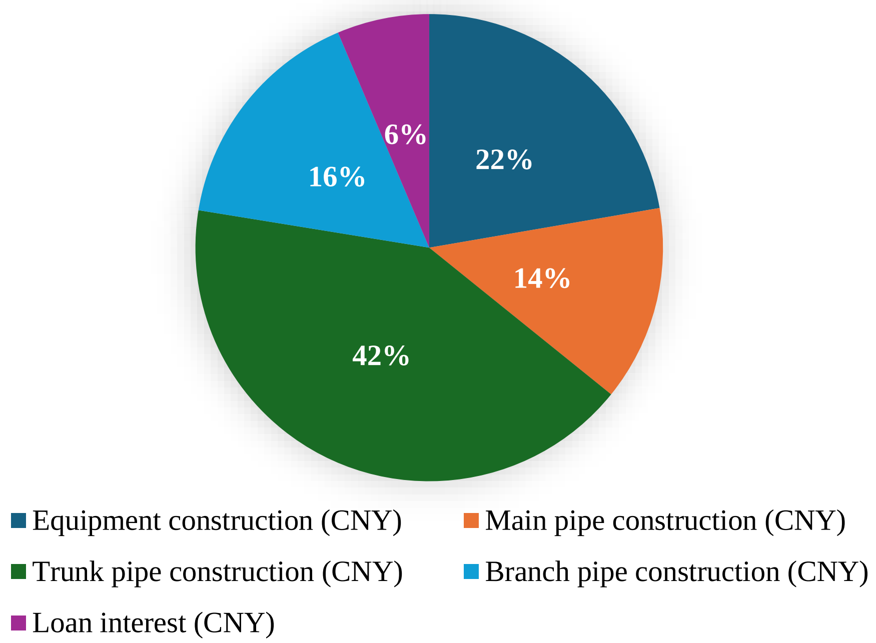

Figure 4-2 Construction cost distributions in PPP project of RDST.

In the category of operation and maintenance costs, electricity expenses constitute a significant proportion, reaching 51% (**Figure 4-3**). This is attributed to the integrated A/O + sand filtration disinfection process adopted by Village W, where electricity is the primary energy consumption. According to field research data, the average electricity consumption for treating one ton of sewage by the equipment is 1.74 kWh/ton, resulting in an average annual electricity cost of 39,055 CNY. The annual salary of maintenance personnel for the PPP project of RDST in Village W amounts to 14,600 CNY, representing 19% of the annual maintenance costs. Following this are maintenance expenses (including sewage treatment equipment and pipelines) and medicament expenses, accounting for 14% and 11%, respectively. Integrated RDST equipment generates a small amount of sludge, with sludge transportation and treatment costs representing a relatively small proportion of the annual maintenance costs, at only 2% and 3%, respectively.

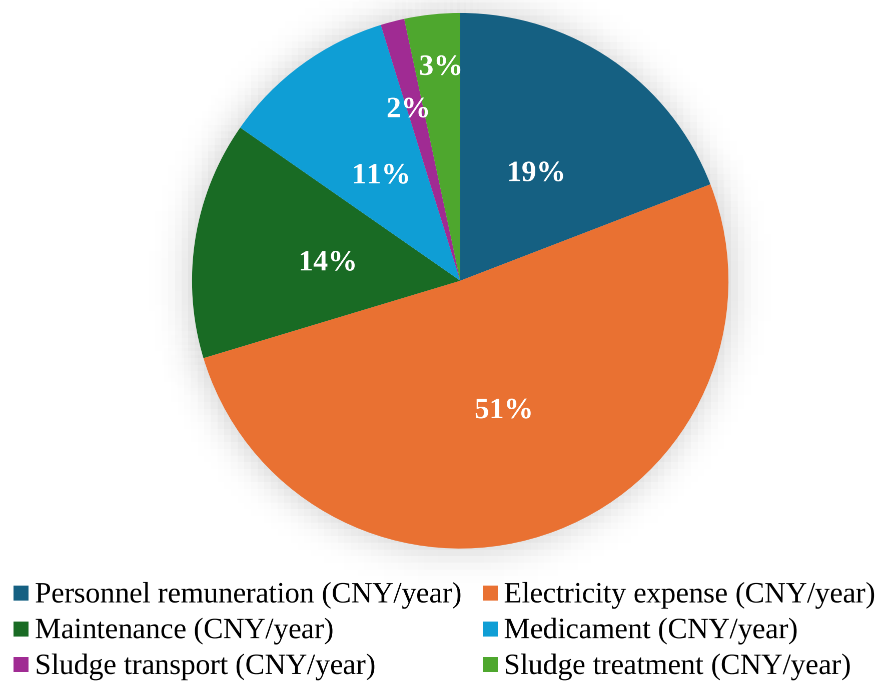

Figure 4-3 Operation and maintenance cost distributions in PPP project of RDST.

In addition, as electricity price varies depending on the place where the RDST project is implemented, a sensitivity analysis of the impact on operation and maintenance costs was conducted in this study with electricity price as the factor. It is assumed that the change in electricity price ranges of ±30% and contains six scenarios of -30%, -20%, -10%, 10%, 20%, and 30%. The electricity price fluctuation of ±30% resulted in a change in operation and maintenance costs of ±15.36% (**Figure 4-4**).

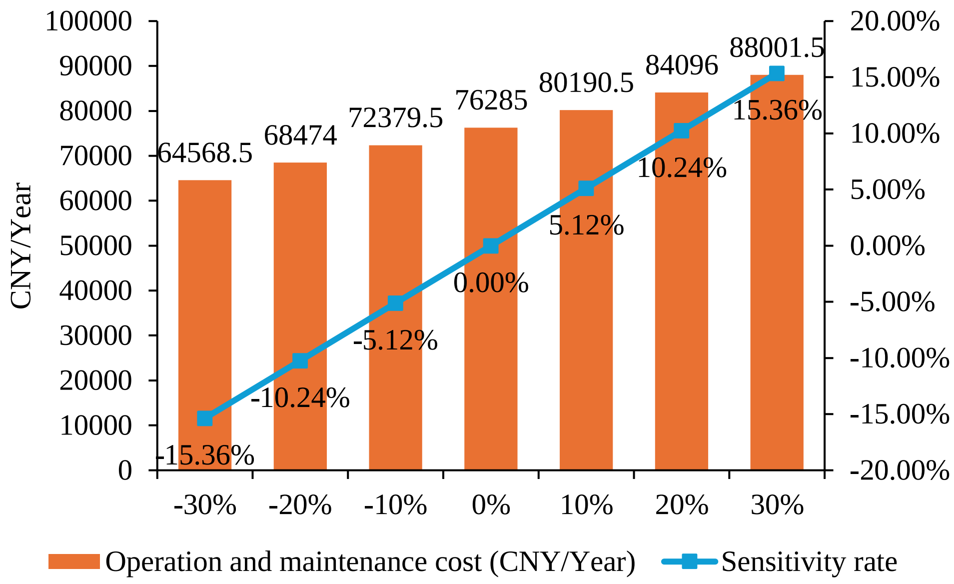

Figure 4-4 Sensitivity analysis of electricity price.

3.2 Impact of operational life

The LCC of RDST is closely associated with the effective operational lifespan of the facility. Generally, a longer operational lifespan leads to higher LCC but lower Average Total Cost (ATC). In the case of the W Village project, the operating company will transfer the RDST facility to the government after 30 years of operation. Thus, during the 30-year operation period by the operating company, its ATC can reach 7.85 CNY (Table 3). However, some RDST facilities can operate for up to 50 years with proper maintenance. Additionally, this study assumes that the RDST facility in W Village can operate for 10, 20, 30, 40, and 50 years, respectively, and calculates their respective ATC. From **Table 4-3**, it can be observed that the cost of treating one ton of sewage over an effective operational lifespan of 10 years is approximately 4.5 times higher than that over 50 years, a result consistent with the findings of Liu and Shen (2014a) and others. From the perspective of economic efficiency, these RDST projects, represented by W Village, would need to continue operating for an additional 20 years after the project company transfers them to the government to achieve more reasonable economic objectives.

Table 4-3 LCC under different operational lifespan.

	Operational lifespan				
	10 years	20 years	30 years	40 years	50 years
ATC (CNY/t)	21.94	11.47	7.85	5.98	4.83

3.3 Impact of population changes

China is currently undergoing rapid urbanization, with rural areas experiencing rapid population and economic flows between urban and rural areas. Some rural areas may become new central villages, attracting a large influx of migrants, with many rural areas near Shanghai having migrant populations several times larger than the local population. Conversely, some rural areas may rapidly hollow out and age due to the loss of young and middle-aged labor, particularly in remote areas, a situation commonly observed in Jiyuan City. The migration balance of rural populations in and out of these areas can greatly influence the operational lifespan and costs of RDST facilities.

Based on the varying degrees of influence from urbanization processes, it is assumed that three scenarios exist, and simulations are conducted to assess the impact of these scenarios on the LCC of RDST projects.

i. Scenario of rapid population growth: This refers to a situation where the annual growth rate of the rural resident population reaches 5%.

ii. Scenario of relatively stable population: This indicates a situation where the annual growth rate of the rural resident population ranges between -0.5% to 0.5%.

iii. Scenario of rapid population decline: This describes a scenario where the annual growth rate of the rural resident population is -5%.

Based on the calculation results in **Table 4-4**, it can be observed that urbanization has a significant impact on the LCC of RDST facilities. In scenarios of rapid population growth and rapid population decline, the ATC reaches as high as19.49 CNY and 14.97 CNY, respectively, which are substantially higher than the ATC in the scenario of population stability (approximating the design condition) ranging from 5.58 CNY to 6.79 CNY. The main reason is that, in both scenarios of rapid population growth and decline, the actual effective operational lifespan of RDST projects is significantly shortened. In areas experiencing rapid population growth, the increasing sewage discharge overwhelms the existing processing capacity of the projects, leading to a rapid reduction in their operational lifespan and thus elevating the ATC. Conversely, in areas with rapid population decline, although the operational lifespan of the projects may not decrease, the decreasing sewage discharge results in a substantial underutilization of the processing capacity of the projects, similarly leading to a significant increase in the ATC.

Table 4-4 LCC estimation under different scenarios of population change.

Scenario	**Population growth rate**	**Effective operational lifespan (year)**	**ATC (CNY/t)**
Rapid population growth	5.00%	9 [a]	19.49
Relatively stable population change	0.50%	50	5.58
	-0.50%	50	6.79
Rapid population decline	-5.00%	50	14.97

[a] When the project operated into the 9th year, the volume of sewage had exceeded the designed maximum treatment capacity, and the treatment project became ineffective.

4. Discussion and implication

This study utilizes the LCCA method to conduct a rigorous cost-effectiveness analysis of the PPP model within the context of RDST projects. Regarding construction expenditures, a predominant share of the total costs is attributed to the construction of pipeline infrastructure. Given the infrastructural inadequacies and dispersed settlement patterns prevalent in rural areas, which pose challenges to efficient sewage collection, pipeline investments constitute a significant portion of the overall construction outlay. Remarkably, in the majority of exemplified projects, pipeline expenses surpass one-third of the total project costs (Hao and Zhang, 2010), with certain regions witnessing pipeline-related expenditures exceeding 60% to 85%

of the overall expenses (Dogot et al., 2010; Liu and Shen, 2015). In the case analysis of Village W, the construction costs associated with its pipeline infrastructure even constitute as much as 72% of the total construction expenditure. Consequently, mitigating pipeline construction expenses can effectively reduce its LCC, thereby enhancing cost-effectiveness and optimizing capital utilization. Under the precondition of maintaining quality standards and service life, the adoption of lower-cost pipeline materials is feasible. Additionally, leveraging existing drainage channels and other infrastructural features within the village for pipeline installation can significantly diminish construction and labor expenses incurred in pipeline deployment. In terms of operation and maintenance costs, electricity consumption constitutes 51% of the total operation expenditure, which is also corroborated by the results of Zhang et al. (2024b). During the operational phase of urban sewage treatment plants, energy expenses can surpass 60% (Yuan, 2008). Although eco-friendly sewage treatment processes such as constructed wetlands, which entail minimal energy consumption, have gained widespread adoption, they typically necessitate larger land areas and may exhibit comparatively inferior pollutant removal efficacy when juxtaposed with energy-intensive alternatives.

Furthermore, the operational lifespan constitutes a pivotal determinant of the LCC within PPP projects in RDST. A lengthened operational lifespan correlates with higher LCC but lower ATC , which is also verified in the relevant research of Ilyas et al. (2021a). Various factors such as inadequate engineering design and suboptimal maintenance practices can lead to impairments or non-functionality of RDST facilities in certain regions, resulting in a sharp escalation of ATC and consequent financial wastage. In addition, the operational lifespan of the RDST project will not only have an impact on the LCC and ATC, but similarly affects the environment accordingly (Gallagher and Gill, 2021). Thus, the formulation of scientifically sound RDST project planning strategies and the enhancement of operational maintenance practices stand to effectively extend the operational lifespan of RDST facilities, thereby reducing ATC and augmenting the efficiency of financial resource utilization.

Population changes also significantly impact the LCC of PPP projects in RDST, which also confirmed by the research of Liu and Shen (2014a). Primarily, rural population migrations alter the effective operational lifespan of treatment facilities. In regions experiencing rapid population growth, the resultant surge in sewage discharge can lead to facility overutilization and accelerated depreciation. Conversely, in areas witnessing rapid population decline, reduced sewage discharge may elevate ATC and potentially render RDST projects utilizing microbiological treatment techniques ineffective. Furthermore, the operation and maintenance facets are equally affected. Whether in regions experiencing rapid population growth or decline, inadequacies in the operation and maintenance of RDST facilities can compromise treatment efficacy, hasten depreciation, and substantially inflate LCC. In practical contexts across different regions, many treatment projects in rural areas have sequentially arisen, facing challenges in operational feasibility due to inadequacies in scale design and excessive operational expenses. Consequently, a substantial portion of the initial investment and construction outlay has become sunk costs, failing to meet the anticipated engineering design lifespan of 30 to 50 years. Hence, prior to embarking on PPP projects for RDST, thorough considerations of village planning are imperative. In rural areas characterized by significant developmental uncertainties or where substantial disparities exist between current conditions and long-term development plans, neither centralized nor decentralized treatment modes may satisfy the exigency of LCC effectiveness. In such contexts, pragmatic treatment approaches should be contemplated, prioritizing cost minimization in infrastructure, pipeline systems, and maintenance while ensuring the efficacy of preliminary treatment.

5. Conclusion

This study employs the LCCA method and, based on a case analysis, to conduct a thorough cost-effectiveness assessment of PPP project in RDST. The findings reveal significant cost allocations, where pipe construction commands a substantial 72% share of the total construction expenditure, while electricity expenses dominate operation and maintenance costs, comprising 51%. Furthermore, this study employs scenario simulation to further analyze the factors influencing the LCC within PPP projects for RDST. Primarily, operational lifespan emerges as a critical determinant. Holding other variables constant, a ten-year operational horizon incurs approximately 4.5 times higher ATC compared to a fifty-year operational lifespan. Additionally, population changes significantly impact LCC within RDST PPP initiatives. Rapid population growth precipitates a drastic reduction in the operational lifespan of RDST PPP projects, often resulting in project failure. Conversely, rapid population decline escalates the ATC within RDST PPP projects, leading to resource wastage.

However, this study has certain limitations. Firstly, it solely employs the LCCA method to assess the economic viability of PPP projects in RDST, without considering environmental benefits. It is recommended that future research adopts a comprehensive approach combining LCA and LCCA for analysis to gain a more holistic understanding of the benefits and impacts of RDST projects. Secondly, caution should be exercised when extrapolating the research findings to other geographical contexts, as the study primarily relies on data from Jiyuan City, China. Therefore, future investigations into the environmental and economic performance of RDST PPP projects in different regions worldwide would be insightful.

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Chapter 5

Rural residents' WTP for centralized mode provision of RDST

This Chapter is adapted from the following paper:

Jiao, J., Yang, Z., Zhang, Y., Shi, B., Dogot, T., Yin, C., 2022. Are Farmers Willing to Pay for Centralized Mode Provision of Rural Domestic Sewage Treatment? A Large-Scale Assessment in North China. Front. Environ. Sci. 10, 861871. https://doi.org/10.3389/fenvs.2022.861871.

Abstract

Evaluation of rural residents' willingness to participate (WTPP) and willingness to pay (WTP) for centralized mode provision (CMP) of rural domestic sewage treatment (RDST) is imperative to improve the rural environment as well as to alleviate government financial pressures. This study adopted the contingent valuation method as well as face-to-face interview questionnaires to assess rural residents' provision mode preferences, WTPP and WTP for CMP of RDST in China. Based on 761 samples collected in Shandong, Jilin and Gansu provinces of China, we applied econometric models to estimate rural residents' WTPP and WTP for CMP of RDST and explore the potential influencing factors, respectively. Results show that: (1) 81.87% of rural residents would be willing to contribute to CMP of RDST; (2) rural residents' perceptions of the necessity of RDST, pollution of rural domestic sewage, and government propaganda significantly and positively affect their WTP; (3) the expected WTP for CMP of RDST with the total respondents and the respondents with positive WTPP were estimated to be 47.46 CNY/year and 63.13 CNY/year (for a total of 20 years), accounting for 16.28% and 21.65% of construction costs, respectively. Based on these outcomes, it could be further estimated that the aggregate value was between 1.1 billion CNY/year and 1.2 billion CNY/year which implying that rural residents' WTP may be a potentially non-negligible funding source for the CMP of RDST. The enhancement of environmental awareness of rural residents and strengthening of propaganda should be the next priority of the Chinese government. Priority should also be assigned to villages closer to towns when the government formulates relevant strategies and policies. The results of this study provide references for policy formulation related to broadening the funding sources in RDST and exploring farmer payment mechanisms and implications for other developing countries.

1. Introduction

With economic development and population increase over the past decades, around 80% of sewage in the world has been directly discharged into the environment without treatment (Burket et al., 2018). The situation are even worse in rural areas due to limited investment, sanitation facilities and research (Huang et al., 2021). Organic matter, nitrogen and phosphorus, coliforms and pathogens are the main contaminants in rural domestic sewage (Latrach et al., 2018). A large amount of untreated rural domestic sewage discharged into surrounding ecosystems, may not only lead to environmental problems such as water and soil pollution and affect agricultural production, but also pose a potential threat to the health of rural residents and animals (Elahi et al., 2018; Elahi et al., 2017; Lam et al., 2015; Wang et al., 2016; Ye and Li, 2009). Globally, there are currently 4.2 billion and 2.2 billion people worldwide suffering from the lack of safe drinking water and safe sanitation facilities, and about 47% and 70% of them live in rural areas, respectively (WHO/UNICEF, 2019). Consequently, RDST is one of the crucial approaches to improve the rural sanitation environment as well as to achieve the Sustainable Development Goals (SDGs) proposed by the United Nations.

In response to the challenge of SDG 6: clean water and sanitation, RDST has aroused worldwide concerns, especially in developing countries (Ladu and Lü, 2014; Latrach et al., 2018; Rout et al., 2016). As for China, the Chinese government proposed a Three-Year Action Plan for Rural Living Environment Improvement in 2018, which took RDST as a priority and difficulty to be addressed (The State Council of the People's Republic of China, 2018). The annual investment of government in RDST is gradually increasing each year, reaching 27.6 billion CNY in 2019. In consequence, by the end of 2020, even though there was 25.5% of the administrative villages implemented RDST (China Agricultural Green Development Research Association, 2021), it still lags far behind developed countries. This implies that more extensive RDST facilities are required in the future to ensure the well-being of rural residents and further improve the rural living environment. However, owing to the high investment of RDST facilities, local budget constraints and fiscal deficit are proved to be the major impediments to improving RDST in developing countries (An et al., 2015; Massoud et al., 2009; Sbahi et al., 2020).

It is widely believed among scholars that both the centralized mode (CM) and decentralized mode (DM) of RDST were the predominant approaches (Hu et al., 2017; Yu and Yu, 2019a). Previous studies determined that CM was applicable to rural areas with high population density and clustered households, while DM was recommended for mountainous and hilly areas with smaller villages, scattered households and unavailability of sewerage collection networks (Li et al., 2020d; Song et al., 2020a; Wang et al., 2011). In reality, more than 60% of China's rural population resides in the relatively flat eastern and central regions, which account for only 20% of the national territory area (National Bureau of Statistics of China, 2020). In addition, due to the characteristics of congregated residence developed over centuries, households in rural areas of China have a relatively high residential concentration, and congregated villages account for approximately 80% (Lu, 2013). Accordingly, CM of RDST has stronger applicability and broader coverage in rural areas of China.

As a kind of rural public infrastructure with non-exclusive and non-rival characteristics, CM of RDST is a typical public goods, and its primary beneficiaries are governments and rural residents. However, CMP of RDST as a kind of environmental improvement exercise demands massive investment with limited direct economic benefits and a long-term payoff period. Thus, environmental improvement has not always been the priority of local governments' investment willingness under the government performance assessment system with economic development as the main indicator (Fu et al., 2018c). Therefore, in areas with relatively low economic development levels and insufficient financial resources of local governments, the local government may not be able to bear considerable investments in RDST. As the primary and most direct beneficiaries of RDST, rural residents are more prone to "free-riding" due to their large number of beneficiaries. Nevertheless, sociologists believe that under the influence of moral attitudes, social norms and collective identity, people will participate in the provision of public goods and make the provision optimum (Qian and Ying, 2014). Furthermore, studies on public goods provision revealed that the phenomenon of non-zero-value voluntary provision was significant and robust, that meant even though not all would contributed, there was a significant number of contributors, which typically contribute 40-60% of the optimal amount of public goods (Ledyard, 1995). Therefore, while the phenomenon of "free-riding" does occur, the strong “free-riding” hypothesis that "no one will contribute" was not valid (Dawes and Thaler, 1988). Fischbacher et al. (2001) demonstrated that the social preferences of participants in public goods provision were heterogeneous, and exhibited different levels of willingness to provide public goods. Relevant studies on rural public infrastructure provision have concentrated on two aspects. Firstly, it is aimed at different research fields, including agricultural water conservation facilities (Cai et al., 2016; Yang and Wang, 2020), rural environmental protection public goods (Han et al., 2019; Wang et al., 2014), rural disaster mitigation public goods (Luo and Levi, 2013) and rural public services (Dai and Du, 2017; Shono et al., 2014). Secondly, it is for diverse provision stakeholders, involving the government, cooperatives, rural residents as well as their collaborative provision (Wang et al., 2021a; Zhang et al., 2004). Therefore, previous studies provide a theoretical basis and robust sustentation for this study regarding rural residents' WTPP and WTP for CMP of RDST.

Since rural residents are the primary beneficiaries of rural public goods, their WTPP and WTP should be concerned when formulating relevant policies (Yi et al., 2011). Although studies on rural residents' WTPP and WTP in rural public goods provision have been extensively discussed in recent years, there are still some limitations. Firstly, most of the previous literature on RDST concentrated on treatment technologies or processes (Gao et al., 2017; Matos et al., 2019; Nandakumar et al., 2019), while lack of research on rural residents' willingness for CMP of RDST. Secondly, most studies focus on a specific area instead of national scale (Gu et al., 2016; Wang et al., 2021a). Additionally, the majority existing studies analyzed rural residents' willingness to provide/pay for public goods but without estimating the payment level (van Hoang et al., 2013; Wang et al., 2019b). Ultimately, and most importantly, most emphasis was devoted to the rural residents' socio-economic and demographic characteristics (Byambadorj and Lee, 2019; Elahi et al., 2022a; Jan, 2021) when exploring the influencing factors on WTPP and WTP. In areas such as rural waste management, infrastructure development, etc., rural residents' individual perceptions, government effects and distance between their house and towns/cities were shown to have significant effects on rural residents' WTPP or WTP (Han et al., 2019; Mukherji et al., 2016; Rashid and Pandit, 2020a; Su et al., 2020). Nonetheless, more influential factors should be included in this study, involving individual perceptions, government effects, and geographical factors.

As aforementioned, this study extended from two perspectives on rural residents' WTPP and WTP for CMP of RDST. Firstly, rural residents' perceptions and government effects as significant influencing factors are incorporated in the analysis. Secondly, this study quantitatively analyze rural residents' WTP regarding CMP of RDST by employing an econometric model. The objectives of this study are (i) to explore the rural residents' WTPP and WTP for CMP of RDST, (ii) to determine the influencing factors of their WTPP and WTP, (iii) to provide insights for the policy formulation regarding RDST as well as to promote the realization of SDGs. For the objectives of this study, we proposed the following research hypotheses:

H1: Rural residents' WTPP and WTP for CMP of RDST can be significantly and positively affected by their perception of the necessity of RDST.

H2: The higher the rural residents' perception on environmental pollution of rural domestic sewage, the more likely they tend to pay.

H3: Rural residents' perception of healthiness has a significant and positive effect on WTPP and WTP.

H4: Rural residents exposed to government propaganda about RDST demonstrate a higher possibility of WTPP and WTP of CMP of RDST.

H5: The distance of rural residents' houses from towns/cities has a significant effect on their WTPP and WTP.

H6: Socio-economic characteristics of rural residents and their households affects their WTPP and WTP.

2. Materials and Methods

2.1 Study area

China has a vast territory, where resource endowments are remarkably different, i.e. topographic features, climate characteristics, economic development levels and folk customs. Compared with South China, North China has a relatively low level of economy, which also leads to the fact that the governments in the northern region has more difficulty affording the expenses of the RDST project. In addition, North China has a high proportion of rural population, and the improvement of rural living environment needs to be further strengthened. In this study, Shandong, Jilin and Gansu provinces (**Figure 5-1**), were selected as the sample provinces in North China, which respectively represented the economically developed, moderate and underdeveloped areas of North China. All these provinces have implemented CM of RDST to a certain extent and the RDST percentage of administrative villages in 2016 was 18%, 5% and 7%, respectively.

Shandong province, located in the eastern coastal area of China, is one of the provinces with the largest rural population, high level of economic development and high concentration of residential areas, which is suitable for popularizing CM of RDST. Although the rural populations in Jilin and Gansu is comparatively small, the proportion of the rural population is relatively high, and the rural residences are similarly concentrated due to the fact that the two provinces are located in severe cold and arid regions of China, respectively, and portions of the area are uninhabitable. In addition, since the average annual precipitation is less, especially in Gansu province, CM of RDST is also beneficial for reusing rural domestic sewage, such as irrigation. In 2019, the rural population of these three provinces was 38.76 million, 11.23 million and 13.63 million respectively, accounting for approximately 11.5% of the national rural population. The per capita disposable income of rural residents was 17775.5 CNY, 14936 CNY and 9628.9 CNY respectively, which was less than the national average of 16020.7 CNY per year except for Shandong. The natural conditions and economic development levels of aforementioned provinces differ significantly. Therefore, the study area is representative and can generally reflect the general situation of China. In addition, it might provide reference for other areas of China to apply CM of RDST, as well as in other developing countries.

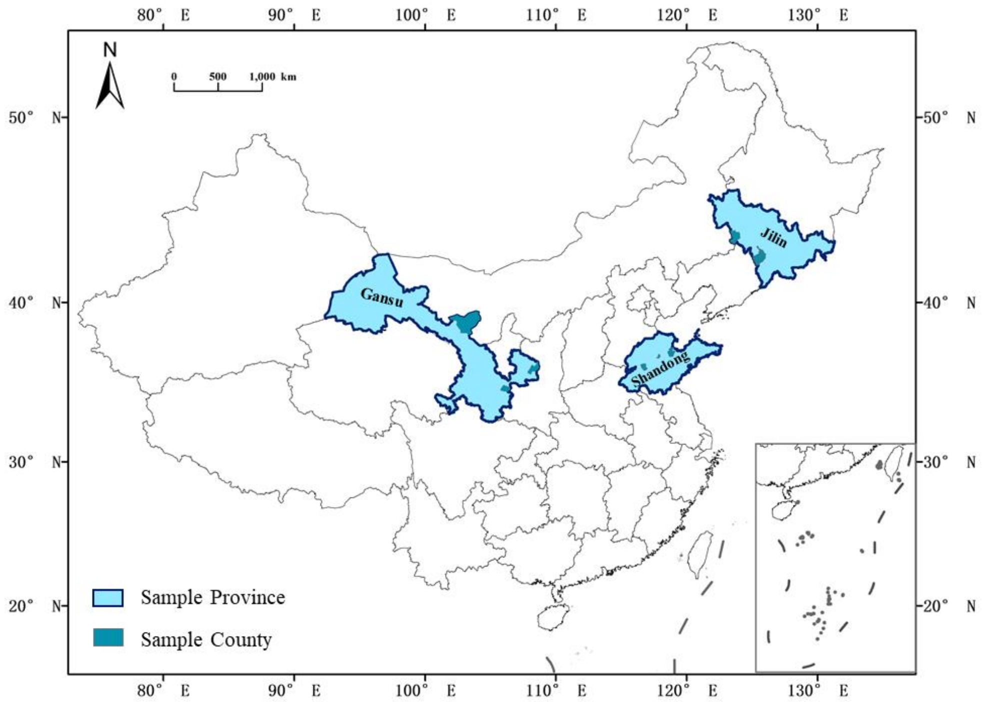

Figure 5-1 Distribution of study area in China.

2.2 Survey design and data collection

The data adopted for this study were obtained from field surveys conducted in Shandong, Jilin and Gansu provinces from September to November 2020. All of these provinces are located in the north of the Qinling-Huaihe Line, which is recognized as the geographical boundary between the north and south of China. The perception of rural residents in different regions about RDST has variability, which affects the rural residents' WTPP and WTP for CMP of RDST. In order to have a general understanding of rural residents' perceptions of RDST and rural residents' WTPP and WTP for CMP in China, and based on the principles of scientificity, accessibility and diversity, this study applied a combination of stratified sampling and random sampling method for data collection. With the consideration of topography, investigation cost and feasibility, as well as trying to cover both RDST demonstration and nondemonstration counties and districts, townships and villages, sample areas were stratified and randomly selected. Firstly, three sample counties and districts were stratified and randomly selected in each of the three sample provinces, including at least one RDST demonstration county. Secondly, three sample towns in each sample county, and three villages for each sample town were randomly selected by layers. The investigated villages were typical, for they presented dissimilar levels of socio-economic development, industries, topography and geomorphology, climate features and cultures. Lastly, 8-10 rural residents were interviewed by random sampling in each selected village. Furthermore, respondents of this survey were permanent residents of the village and the main members of their respective households, therefore most of them have the capacity to determine their WTPP and WTP for CMP of RDST.

With the objective of obtaining the data of rural residents' WTPP and WTP, this study employed a face-to-face survey questionnaire. The pre-survey was conducted in Hefei, Anhui province in August 2020, which belongs to the Central region of China. Based on the results of this pre-survey, the questionnaire was improved to ensure comprehensibility and clarity. Thereafter, modified questionnaire was applied to conduct the formal survey in the survey area. It should be emphasized that due to variations in questionnaire design and relatively limited amount of pre-survey data, the survey data of Anhui were excluded from this study. Eventually, a total of 798 questionnaires were collected by well-trained interviewers. 761 valid questionnaires were obtained after eliminating the missing values, with 95.36% effective response rate. Among them, 262, 229 and 270 questionnaires were collected from Shandong, Jilin and Gansu provinces, respectively.

2.3 Contingent valuation method and open-ended elicitation

According to Carson (2000), contingent valuation method (CVM), as a survey-based method, is generally applied for attaching monetary values to environmental goods and services that are untradeable in the market. As a typical stated preference evaluation method, CVM adopts a questionnaire that directly inquires about respondents' WTP of environmental goods or services, or their willingness to accept (WTA) when abandoning environmental goods or services (Peng et al., 2018).

Afterward, based on the respondents' answers, the use value or non-use value of environmental goods or services is evaluated by statistical analysis.

In previous studies, several scholars have applied different methods to elicit WTP of respondents, such as payment cards, iterative bidding games, dichotomous multiple-choice questions and open-ended questions (Boyle et al., 1996; Boyle and Bishop, 1988; Hanemann et al., 1991; Randall et al., 1974). In the questionnaire of this study, the WTP section adopts an open-ended questions approach. Respondents were directly asked, “What is the maximum amount of cash you are willing to pay?”, in an open-ended WTP elicitation approach. It is convenient to answer in an open-ended approach, which does not need an investigator and does not cause starting point bias (Walsh et al., 1984). The open-ended approach is valid for studies that aim to derive conservative estimates, as the conservative value provided by this approach is lower than the bidding game approach (Venkatachalam, 2004). Nevertheless, an open-ended question tends to have a high non-response rate and/or leads to many zero values and overestimated values as the respondents are inconclusive about how they should evaluate the environmental goods (Yang et al., 2020). After conducting the pre-survey by a face-to-face interview, the non-response rate for the open-ended questions obtained in this survey was meager. In addition, because RDST has been implemented in China for several years, rural residents are clearly aware that RDST is an essential approach to improving the rural living environment. Therefore, most of the respondents were able to indicate the recognition on RDST and reflect their expected WTP. For the above reasons, it is feasible to adopt the open-ended approach in this study. However, considering that CMP of RDST is generally an initial investment, the initial payment level of rural residents may be underestimated, which can therefore lead to biased results. In order to ensure and improve the reliability of the research results, this study proposes a method of inquiring rural residents' payment level by installment payment, and the number of years used for the installment payment is the facility service life of CM of RDST. Based on field investigation and literature review, we found that the service life varies for different technological processes and facility scales, but mostly concentrated on at least 20 years, and related studies also selected 20 years as the reference (Chen et al., 2009; Luo et al., 2016). Therefore, the same parameter is employed in this study as the number of years to estimate the WTP of rural residents' installment payments.

2.4 Models and variables

This study analyzed the determinants of rural residents' WTPP and WTP for CMP of RDST by synthesizing the binary logit model and the Tobit model, respectively. These two econometric models contain the same explanatory variables in order to provide an integrated analysis of their effects on WTPP and WTP.

The binary logit model is an econometric model, which is commonly applied to analyze the potential determinants, and requires rural residents to either accept or reject a hypothetical environmental goods or services (Lazaridou et al., 2019; Wassie and Adaramola, 2021; Wongsasuluk et al., 2018). In this study, rural residents were asked about the subjective probability of selecting the WTPP for CMP of RDST with only two alternatives, "willing" and "unwilling". The optimal decision will be determined by each farmer on the basis of a rational combination of influencing factors, which is a typical binary decision-making problem. Therefore, the binary logit model, which is widely used to analyze such problems, is chosen in this study to determine the influences of rural residents' WTPP for CMP of RDST. For the purpose of identifying the influencing factors of rural residents' WTPP for CMP of RDST, the following binary logit regression model was developed:

$$Ln\left(\frac{p}{1-p}\right) = b_0 + b_1x_1 + b_2x_2 + \cdots\cdots + b_nx_n + \varepsilon \qquad \textit{(5-1)}$$

where p represents the probability that rural residents' WTPP for CMP of RDST, b_0 is the constant term, b_i is the regression coefficient of the ith explanatory variable, and ε is the error term which assumed to be normally distributed with zero mean value and constant variance (Elahi et al., 2022b; Elahi et al., 2021).

It is believed that quantitative analysis regarding the factors affecting WTP enables to verify the effectiveness of rural residents' WTP, and also supports the government in formulating relevant policies (Ren et al., 2020). Since zero-response data is unavoidable in practical surveys, the parameters may be highly biased and incoherent if the factors affecting rural residents' WTP are estimated by OLS regression or Probit models. Therefore, due to the left-censored at zero, this study adopts the Tobit model proposed by Tobin (1958), which can well resolve this problem. Additionally, according to Yan et al. (2015), a comparison was made between two methods of estimating payment levels based on parametric and non-parametric estimation to test the robustness of the study results. According to Yang et al. (2018b), the Tobit model can be represented as follows:

$$WTP_i^* = X_i\beta + \varepsilon_i, \varepsilon_i \sim N(0, \sigma^2)$$
$$WTP_i = \begin{cases} WTP_i^*, & ifWTP_i^* > 0 \\ 0, & ifWTP_i^* \leq 0 \end{cases} \tag{5-2}$$

where WTP_i is the actual observational maximum payment amount of CMP of RDST which is censored at zero; X_i refers to the vector of explanatory variables, β is the vectors of regression coefficients and ε_i indicate a random disturbance term which is assumed to be normally distributed with the mean zero and constant variance sigma square (σ^2). According to Tobin (1958), the expected value of WTP_i can be expressed as follow:

$$\begin{aligned} E(WTP_i) &= Pr(WTP^* \leq 0) \cdot E(WTP_i \backslash WTP_i = 0) \\ &+Pr\ (WTP^* > 0) \cdot E(WTP_i \mid WTP_i > 0) \\ &= X_i\beta F(X_i\beta/\sigma) + \sigma f(X_i\beta/\sigma) \end{aligned} \tag{5-3}$$

where F denotes the standard normal random variable's cumulative distribution function, f means the normal density function, and σ refers to the standard deviation. Furthermore, for the observations with positive WTP, the expected value can be displayed as (Amemiya, 1973):

$$E(WTP_i \mid WTP_i > 0) = X_i\beta + \sigma\lambda(X_i\beta/\sigma) \tag{5-4}$$

The selection and definition of variables for the binary logit model and Tobit model which were adopted in this study are shown in **Table 5-1**. According to the different types of variables, they are divided into five categories. In addition to the core variable "Rural residents' Perception", the dependent variable is "Willingness", and the other independent variables are classified as "Government Intervention", "Individual and Household Characteristics", and "Regional dummy variables", respectively.

Table 5-1 ariable definitions and summary statistics.

Category	Variable	Definition	Mean	St. Dev.
Willingness	WTPP	Are you willing to participate in CMP of RDST? (1=yes, 0=no)	0.82	0.39
	WTP	How much do you willing to pay per year (for a total of 20 years)? (CNY)	48.16	57.55
Rural residents' Perception	NECESSITY	Do you think it is necessary to treat domestic sewage? (1=agree, 0=disagree)	0.71	0.46
	POLLUTION	Do you think the improperly treated domestic sewage affects the rural environment? (1=strongly disagree, 2=somewhat disagree, 3=neither agree nor disagree, 4=somewhat agree, 5=strongly agree)	3.22	1.19
	HEALTH	Do you think the improper treatment of domestic sewage affects the health of villagers? (1=strongly disagree, 2=somewhat disagree, 3=neither agree nor disagree, 4=somewhat agree, 5=strongly agree)	3.23	1.24

Government Intervention	PROPAGANDA	Does the government ever propagate RDST? (1=yes, 0=no)	0.91	0.28
Individual and Household Characteristics	GENDER	Respondent's gender (1=male, 0=female)	0.70	0.46
	AGE	Respondent's age	54.16	11.54
	EDUCATION	1=lower than primary school, 2=primary school, 3= junior school, 4=high school, 5=college and above	2.96	0.90
	CADRE	Whether you are the village cadre? (1=yes, 0=no)	0.20	0.40
	HOUSEHOLD SIZE	Household population	4.45	1.65
	INCOME	Annual disposable income of rural household (10,000 CNY).	5.32	6.02
	CENTRALIZED MODE	Whether you already have CM of RDST? (1=yes, 0=no)	0.40	0.49
	CENTRALIZATION OF WATER SUPPLY	Whether you already have centralization of water supply? (1=yes, 0=no)	0.82	0.38
	DISTANCE	Distance from your home to the town government. (km)	5.36	3.52
Province	SHANDONG	1=Shandong, 0=other provinces	0.34	0.48

JILIN	1=Jilin, provinces	0=other	0.30	0.46
GANSU	1=Gansu, provinces	0=other	0.35	0.48

3. Results

3.1 Descriptive statistics

Before estimating the influencing factors, it is imperative to determine the preference of rural households for differential mode selection of RDST. **Figure 5-2** illustrated about 80% of the respondents preferring CM of RDST. This result is also similar to the research results of Li (2017a) in Shaanxi province, China, which demonstrates that 73.0%-86.2% of rural residents desired CM of RDST. As a consequence of this discovery, following results will be more reliable and meaningful.

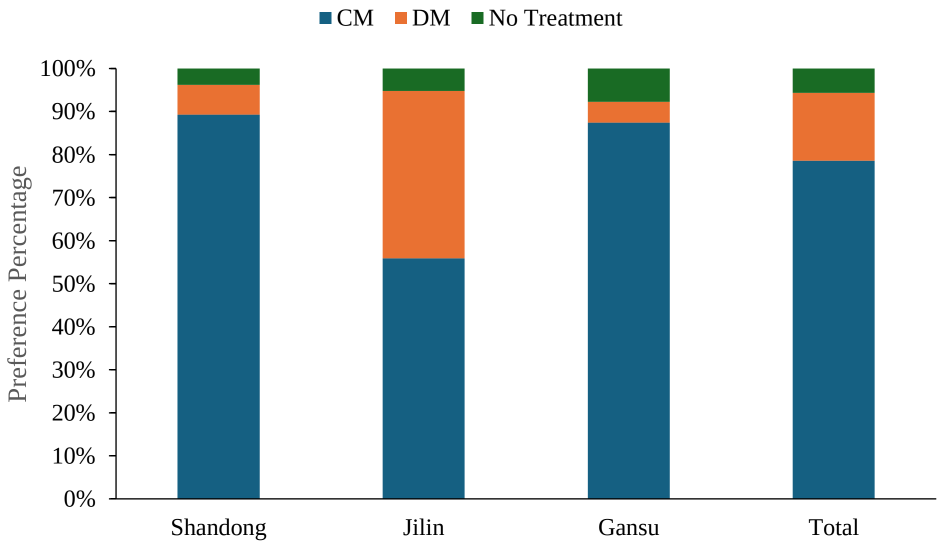

Figure 5-2 Distribution of respondents' preference for RDST.

In addition, rural residents' perceptions as key variables were also presented with descriptive statistics. **Figure 5-3** showed that approximately 71% of rural households perceived the necessity of RDST, which demonstrated rural residents in the study area had relatively high perception of rural domestic sewage. Similarly, both rural residents' perceptions of pollution and healthiness of RDST appeared at a relatively high level. Among all the respondents, 407 and 408 respondents strongly agreed or somewhat agreed that rural domestic sewage is polluting the environment and harming rural residents, which accounted for 53.48% and 53.61%, respectively. Additionally, rural residents' perceptions varied minimally among the three provinces.

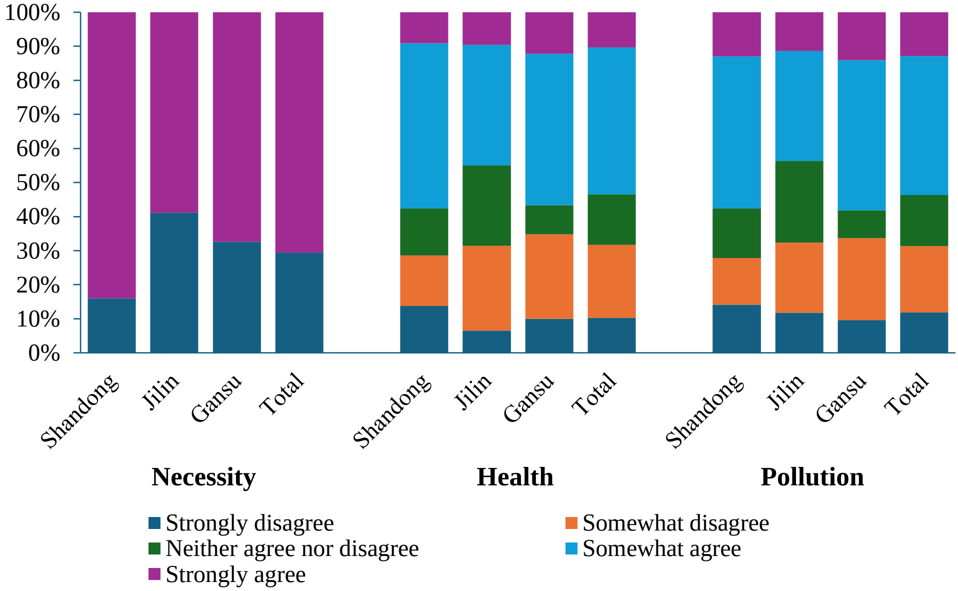

Figure 5-3 Distribution of rural residents' perceptions.

3.2 Rural residents' WTPP and its determinants

3.2.1 Responses of WTPP

As shown in **Table 5-2**, although most of the respondents demonstrate their WTPP for CMP of RDST, there are still 18.13% of the remaining rural residents explicitly refused. Among them, Jilin province has the lowest proportion of WTPP respondents, which is 72.05%, while Shandong and Gansu are relatively higher than that in Jilin, which is 88.55% and 83.70%, respectively.

Table 5-2 Rural residents' WTPP for CMP of RDST.

Province	Index	WTPP	
		Yes	No
Shandong	Frequency	232	30
	Ratio (%)	88.55	11.45
Jilin	Frequency	165	64
	Ratio (%)	72.05	27.95
Gansu	Frequency	226	44
	Ratio (%)	83.70	16.30
Total	Frequency	623	138
	Ratio (%)	81.87	18.13

3.2.2 Determinants of respondents' WTPP

The Stata 12.1 was applied to perform regressions. **Table 5-3** indicated the estimation results of respondents' WTPP for CMP of RDST by the binary logit model. After 7 iterations, the log likelihood has not varied at the value of -204.5383. The LR $\chi 2$ value of this model was 311.47, which is significant at the level of 1%, indicating that the coefficients are not equal to zero for the independent variables. There were 13 independent variables included in binary logit model, involving 9 independent variables indicated significant effects at 1% level, 5% level and 10% level respectively.

Table 5-3 Regression results for rural residents' WTPP for CMP of RDST.

Variable	Coefficient	z-Value	Average marginal effect
NECESSITY	1.2632***	4.14	0.1049
POLLUTION	0.5676**	2.14	0.0471
HEALTH	0.1223	0.49	0.0101
PROPAGANDA	1.2436***	3.17	0.1032
GENDER	-0.2445	-0.74	-0.0203
AGE	-0.0820***	-4.95	-0.0068
EDUCATION	0.3531**	2.05	0.0293
CADRE	1.1795***	2.94	0.0979
HOUSEHOLD SIZE	0.0363	0.46	0.0030

INCOME	0.3075***	4.58	0.0255
CENTRALIZED MODE	-0.0384	-0.09	-0.0032
CENTRALIZATION OF WATER SUPPLY	0.9455***	2.75	0.0785
DISTANCE	-0.0708*	-1.91	-0.0059
JILIN	-0.3110	-0.56	-0.0258
GANSU	0.2394	0.46	0.0199
Constant	-0.1140	0.08	
Log likelihood	-204.5383		
LR χ^2 (15)	311.47***		
Pseudo R^2	0.4323		
Sample size	761		

***, ** and * show significance levels at 1%, 5% and 10%, respectively.

"NECESSITY" and "POLLUTION" have a significant positive effect on rural residents' WTPP for CMP of RDST. It means that the greater the perceived necessity of domestic sewage treatment, or the more serious the pollution of domestic sewage, the greater the probability of rural residents' WTPP for CMP of RDST. Related studies also verified this result (Guo and Dong, 2011; Han et al., 2019; Mukherji et al., 2016). In addition, rural households who perceived higher perceptions of "NECESSITY" and "POLLUTION", the probability of their WTPP might be increased by 10.5% and 4.7%, respectively. Although "HEALTH" was positively correlated with rural residents' WTPP for CMP of RDST, it was not statistically significant.

"PROPAGANDA" shows a positive and significant influence on rural residents' WTPP for CMP of RDST, which has a consistency with Su et al. (2020), which means that rural residents who have been exposed to the government propaganda on RDST tend to show a stronger willingness. All these are attributed to the fact that government propaganda may improve public's environmental knowledge and awareness of the necessity of waste treatment (Han et al., 2019). The average marginal effect indicates that for rural residents who have been exposed to government propaganda, the probability of their WTPP for CMP of RDST is approximately 10.3% higher than that of rural residents who have not been exposed.

Regression results show that "AGE" has a significant negative influence on rural residents' WTPP for CMP of RDST. It can be explained that younger rural resident has greater the probability of WTPP. Oppositely, "EDUCATION" indicates a significant positive influence. This implies that the higher the education levels of rural residents, the greater the possibility of farmer's WTPP for CMP of RDST. In related studies by other scholars (Byambadorj and Lee, 2019; Zhang et al., 2020b), which also proved that "AGE" and "EDUCATION" have a significant effect on rural residents' willingness.

"CADRE" is another factor that significantly influences rural residents' WTPP for CMP of RDST with a positive sign. With responsibility undertaken as cadre, they are more likely to participate in CMP of RDST, and this finding is also corroborated by Zhang et al. (2020b). The average marginal effect demonstrates that the village cadre's WTPP probability for CMP of RDST was approximately 9.8% higher than rural residents with no political identities. This is probably because village cadres are the actual promoters and implementers for government policies in rural areas who may have higher ideological awareness and perceived value of RDST, and will accordingly be more rigorous in their compliance with government policies for the CMP of RDST.

As for "INCOME", it has a significant positive impact on rural residents' WTPP for CMP of RDST, which indicates that the more disposable income the rural residents have, the more likely they are willing to participate in CMP of RDST. As traditional experience reveals, wealthier rural households are more prefer to invest in pollution treatment (Afroz et al., 2009). The average marginal effect results show that when the rural residents' income increased 10,000 CNY and other variables were constant, the probability of rural residents' WTPP for CMP of RDST would increase by 1.6%.

"CENTRALIZATION OF WATER SUPPLY", also shows a significant positive influence on the rural residents' WTPP for CMP of RDST. Compared with rural residents who use other domestic water (such as phreatic water, spring water and etc.), rural residents who use centralized water supply (that is, domestic water is supplied centrally by the government) have stronger WTPP for CMP of RDST. This may be because the government provides rural residents with piped water supply while publicizing the concepts of water conservation, water resource protection, and sewage treatment for rural residents. This situation is also reflected in Mongolia (Byambadorj and Lee, 2019). Therefore, rural residents who benefit from centralized water supply by the government are more aware of the necessity of centralized treatment of domestic sewage.

Interestingly, "DISTANCE" shows a significant negative impact on rural residents' WTPP for CMP of RDST. This implies that the closer the rural residents reside to the town, the more likely they are willing to participate in CMP of RDST. There is a comparable finding in related studies in India (Rashid and Pandit, 2020a), that "DISTANCE" would be an essential influence factor.

3.3 Rural residents' WTP and its determinants

3.3.1 Estimation of construction cost

In this study, a construction cost analysis was performed for the CM of RDST that has been implemented in part of the study area. **Table 5-4** displays that with the rising number of households, the construction cost of each household shows a trend of increasing at beginning and then decreasing. Treatment capacity of 501-1000 households has the highest construction cost of CM of RDST, which reaches the range of 11,000-13,000 CNY per household. Construction cost varies accordingly due to the differences in construction scales, treatment techniques, and treatment standards adopted in each village. Therefore, for the existing CM of RDST in the study area, the average construction cost of each household is roughly calculated as 5832 CNY.

Table 5-4 Construction cost for CM of RDST.

Treatment capacity (household)	**Construction cost (thousand CNY)**	**Average cost per household (CNY)**
≦300	490-2900	2578-10139
301-500	1500-5000	4285-11820
501-1000	6240-8000	11356-13651
≧1001	6000-8500	3793-4040

3.3.2 Responses of WTP

According to the analysis results of the Tobit model (**Table 5-5**), the expected value of the total observations and the truncated observations (observations with positive WTPP for CMP of RDST) could be as high as 47.46 CNY/year and 63.13 CNY/year, respectively. Regarding provincial differences, the expected value of rural residents' WTP for CMP of RDST was 34.85 CNY/year and 44.66 CNY/year in Gansu province, which was lower than that in Shandong province and Jilin province. This difference echoes the identical tendency in disposable income of rural residents as shown in 2.1. It should be noted that a household normally adopts one mode of RDST, thus the number of rural households instead of the rural population is employed for calculating the aggregate value in this study. Based on the rural residents' WTP, the number of rural households and the non-response rate (**Table 5-2**), the expected aggregate value for mean value, the total sample and the truncated sample are estimated, respectively (**Table 5-5**).

Table 5-5 Mean and aggregate WTP value for CMP of RDST.

	Shandong	**Jilin**	**Gansu**	**Total**
Rural households (million)[a]	15.60	3.81	4.18	23.59
Mean value (CNY/year)	66.47	42.42	35.26	48.16
Expected value (CNY/year)[b]	66.80	38.81	34.85	47.46
Expected value (CNY/year)[c]	81.39	58.52	44.66	63.13
Aggregate value (million CNY/year)[d]	1036.93	161.62	147.39	1136.09
Aggregate value (million CNY/year)[e]	1042.08	147.87	145.67	1119.58
Aggregate value (million CNY/year)[f]	1124.31	160.64	156.25	1219.24

[a] Data from the 6th National Census of China 2010.

[b] Expected WTP for total observations.

[c] Expected WTP for truncated observations.

[d] Aggregate value for mean value

[e] Aggregate value for expected value[b]

[f] Aggregate value for expected value[c]

3.3.3 Determinants of respondents' WTP

The regression results of the rural residents' WTP for CMP of RDST with the Tobit model are shown in **Table 5-6**. In comparison to the regression results of the binary logit model of rural residents' WTPP for CMP of RDST, there are five variables that contributed significantly to the regression results of the Tobit model of rural residents' WTP for CMP of RDST, which are similarly significant in the aforementioned binary logit model.

"NECESSITY" was observed to have a significant positive effect on rural residents' WTP. Rural residents who believe that rural domestic sewage need treatment have a higher WTP value than those who ignore it. Compared with those who think RDST is unnecessary, the expected probability and payment level was 15.86%, 13.85 CNY/year and 19.51 CNY/year higher for truncated observations and total observations, respectively. Similarly, "PROPAGANDA" also revealed a significant positive influence on rural residents' WTP for CMP of RDST. The marginal effect indicated that rural residents who were influenced by government propaganda, the expected WTP might increase by 20.58 CNY/year for the truncated respondents and 29.02 CNY/year for the total respondents than those who have not propagated. It was necessary to emphasize that when rural households are exposed to government propaganda, it will increase the probability of WTP for CMP of RDST by 29.31%, holding all the rest variables remain at the mean values. "AGE" had a significant negative effect on rural residents' WTP at the level of 1%. This indicated that the younger the farmer, the more they prefer a higher WTP. Consistent with the regression results of the binary logit model, "EDUCATION" and "INCOME" also revealed a significant positive effect ($P < 0.01$) on rural residents' WTP for CMP of RDST. That means increased rural residents' education level and income are significantly promoted a higher WTP.

Table 5-6 Regression results for rural residents' WTP for CMP of RDST.

Variable	Coefficient	t-Value	Marginal effect		
			1	2	3
NECESSITY	27.17***	4.57	0.1586	13.85	19.51
POLLUTION	3.50	0.78	0.0193	1.88	2.63
HEALTH	5.32	1.25	0.0294	2.85	4.00
PROPAGANDA	45.82***	4.73	0.2931	20.58	29.02
GENDER	-4.80	-0.93	-0.0262	-2.59	-3.63
AGE	-0.71***	-3.21	-0.0039	-0.38	-0.53
EDUCATION	8.77***	3.11	0.0485	4.71	6.60
CADRE	7.47	1.35	0.0401	4.09	5.70
HOUSEHOLD SIZE	1.55	1.11	0.0085	0.83	1.16
INCOME	2.11***	5.47	0.0117	1.13	1.59
CENTRALIZED MODE	-5.15	-0.80	-0.0286	-2.75	-3.86
CENTRALIZATION OF WATER SUPPLY	8.43	1.32	0.0480	4.41	6.20
DISTANCE	-1.00	-1.59	-0.0055	-0.54	-0.75
JILIN	-18.28**	-2.16	-0.1049	-9.48	-13.35
GANSU	-22.73***	-3.19	-0.1298	-11.83	-16.63
Constant	-40.19*	-1.66			
Log likelihood	-3495.7304				
LR χ^2 (15)	271.46***				
Pseudo R^2	0.0374				
Sample size	761				
Uncensored observations	623				

***, ** and * show significance levels at 1%, 5% and 10%, respectively.

[1] Marginal effects on the probability of being censored.

[2] Marginal effects on the truncated expected value (observations with positive payment level).

[3] Marginal effects on the censored expected value (total observations).

4. Discussions and implications

Nowadays, people are becoming more concerned about environment with the development of the era and the improvement of living standards. However, due to the limitation of education level and other factors in rural areas, the environmental awareness of rural residents is relatively weak than that of urban residents. Interestingly, the effect of environmental awareness on rural residents' WTP for CMP of RDST in our study is positive but not significant. Therefore, the environmental awareness of rural residents should be further enhanced so as to increase the rural residents' WTPP and WTP for RDST. This recommendation is also consistent with that proposed by Uthes and Matzdorf (2016) and Su et al. (2018). Thus, it is recommended to promote rural residents' self-awareness of environmental protection by means of propaganda and education, so as to form a "soft constraint" of moral concepts. In addition, it is necessary to strengthen the external restraint mechanism, such as legislation and village regulations and other "hard constraints" to reduce rural residents' pollution behavior.

Although rural residents currently have perceptions of rural domestic sewage and environmental awareness to some extent, it is identified in our study that there is a relative lack of health awareness among rural residents at this stage, and a significant proportion of rural residents consider that rural domestic sewage has no or minimal impact on human health. This may be due to the fact that, although rural residents discharge domestic sewage directly into nearby water bodies would result in a certain level of pollution, this behavior does not affect the quality of domestic water in their daily lives. Therefore, they probably consider domestic sewage contaminating the environment, but not having much impact on their health. In fact, in order to guarantee the safe drinking water in rural areas, the Chinese government has invested in the construction of numerous drinking water supply projects since 2000 (Song et al., 2020b). By the end of 2019, more than 78% of villages in China had been supplied with piped water (MOHURD, 2020), which ensures the safety of drinking water for rural residents. According to Yang et al. (2018b), urban residents demonstrated a stronger awareness of health, since health conditions considerably influenced both successful career and quality of life, urban residents were increasingly inclined to allocate a certain amount of money for their health. Therefore, we recommend further raising the health awareness of rural residents, which would make them aware of the dangers of pollution to human health and contribute to the participation and willingness in environmental management.

As the initiator and promoter of RDST, government performs an indispensable role in the whole process of RDST, especially in terms of propaganda. For this reason, it is recommended that the government should incorporate propaganda as a priority in its subsequent efforts to improve rural residents' environmental knowledge, perception and awareness. Actually, since proposing the Three-Year Action Plan for Rural Living Environment Improvement, the central and local governments have formulated a series of policies, regulations and institutions, and have gradually increased their efforts to propagate RDST with rural households which have demonstrated initial effectiveness. The propaganda approaches should also be broadened, a variety of propaganda methods should be promoted for various regions with heterogeneous rural residents. Besides traditional posters and brochures, new media platforms should also be promoted and introduced to diversify the propaganda about environmental protection and RDST.

In addition, rural residents' socio-economic factors that affected their WTPP and WTP should not be ignored as for rural residents' age significantly and negatively influenced their WTPP and WTP for CMP of RDST. What is worrying is that the aging of the rural population in China continues to deepen, the aging rate in rural areas is predicted to reach 22.8% by 2030 (Fang et al., 2015; Li et al., 2020a). Moreover, the population in rural areas of China has been reduced by 164.4 million and 14.21% in the last decade (National Bureau of Statistics of China, 2021). This phenomenon is attributed to the large amount of rural laborers migrating to the cities (Xu and Zhang, 2021), of which mainly young people are eager for employment and further education. Thus, increasing aging population proportion and outmigration in rural areas of China imply that rural residents' WTPP and WTP for CMP of RDST might be diminished, which generates more pressure on government financial investments. The positive influences of income on WTPP and WTP demonstrate not only the affordability of high-income rural residents, but also shows that these rural residents are more eager to improve their living environment than those with relatively low-income. However, marginal effects reveal that when rural residents' income increases by 10,000 CNY, their WTP only increase by 1.13 CNY and 1.59 CNY, respectively. Therefore, in the short term, it seems that there is a limit to improving rural residents' WTP for CMP of RDST by increasing rural residents' income.

Interestingly, the distance from the rural residents' residence to the town had a significant adverse effect on their WTPP. This may be explained that rural residents who reside closer to towns are more likely to be affected by the lifestyles of urban residents, and demonstrate stronger desire for the living convenience of the town residents. In other words, this may also be due to the spillover effect of the improvement of urban public infrastructure on the surrounding rural areas. Therefore, villages and rural households that are close to towns should be prioritized when formulating policies related to CMP of RDST. In addition, villages are located within a 5-kilometer radius extension of the urban sewage network (Yu and Yu, 2019a), the rural domestic sewage network that can be designed to connect with the municipal sewage network, and thereby to collaboratively treat domestic sewage with the town. Interestingly, distance did not have a significant effect on the WTP of rural households, which may be influenced by multiple factors such as age, education, and income.

5. Conclusions

According to the survey data of 761 rural residents collected in Shandong, Jilin and Gansu provinces, this study estimated the probability of rural residents' WTPP and WTP for CMP of RDST, as well as identified the influencing factors. Our research results show that more than 79% of the investigated rural residents intend to participate in the CMP of RDST, and the expected WTP for CMP of RDST for the total respondents and the respondents with positive WTPP to be 47.46 CNY/year and 63.13 CNY/year, respectively. Accordingly, when the service life of RDST facilities is set to 20 years, rural residents' WTP can cover 16.28% and 21.65% of the construction costs, respectively. The present study explored and analyzed the factors influencing rural residents' WTPP and WTP for CMP of RDST in relation to the rural residents' perception, government propaganda and, individual and household characteristics. The results show that rural residents' perception of the necessity of

RDST has significantly and positively affected their WTPP and WTP for CMP of RDST, which verified H1. As another variable that significantly affected rural residents' WTPP, rural residents' perception of the pollution of rural domestic sewage has no significant impact on their WTP, which partially verified H2. However, as indicated by the results of the regression models, although rural residents' perception of healthiness positively affected WTPP and WTP, it was not statistically significant, so H3 was rejected. In addition to rural residents' perceptions, we also found that rural residents exposed to government propaganda about RDST showed relatively high levels of WTPP and WTP, which also confirmed H4. Interestingly, while rural households who resided closer to towns demonstrated a stronger WTPP, they did not show a higher WTP, thus H5 was partially validated. Simultaneously, the study results demonstrated that age, education, village cadres, income and centralized water supply have significant effects on WTPP, and age, education and income have also significantly contributed to their WTP. Accordingly, the H6 was partially corroborated, which means that not all the rural residents’ individual and household characteristics have an impact on WTPP and WTP.

Since most of the existing studies focus on rural residents' WTPP of RDST and the willingness to maintain RDST, this study contributes significantly to the current academic literature by dividing the financial investment in RDST into a provision phase and a maintenance phase, and reveals the influences of rural residents on the WTPP and WTP of CMP of RDST, which complements the existing literature. In the areas with financial shortages for the provision of RDST, the results of this study provide a reference for broadening the funding sources and exploring the participation and payment mechanism of rural residents. However, due to the current WTP of rural residents for CMP of RDST, the enhancement of environmental awareness of rural residents and strengthening of government propaganda should be the next priority of the Chinese government. Ultimately, these recommendations may be effective in helping developing countries create a favorable rural environment and achieve the SDGs.

There are several inevitable limitations of this study that existed as with most studies. Firstly, eliciting a farmer's WTP by open-ended questions is normally not the most appropriate approach. However, since there is little literature available to provide a reference for rural residents' WTP for CMP of RDST, and the economic development levels and geographic location vary from region to region, this study adopts open-ended questions as the first exploration in this study area. Therefore, more elicitation approaches are suggested to be employed in the subsequent studies. Secondly, the data analyzed in this study are only collected from China, so the results may not be applicable to all developing countries. Accordingly, performing relevant studies in different developing countries with dissimilar conditions and socio-economic characteristics may enrich the results of this research field.

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Chapter 6

The effect of environmental regulation on rural residents' WTP for sustainable RDST

This Chapter is adapted from the following paper:

Jiao, J.; Yang, Z.; Shi, B.; Dogot, T.; Azadi, H.; Xu, K.; Yin, C. How Environmental Regulation Affects Rural Residents' Willingness to Pay for Sustainable Domestic Sewage Treatment: Mediating and Interaction Effects. Water 2024, 16, 761. https://doi.org/10.3390/w16050761

Abstract

Exploring the construction of effective payment mechanisms for rural residents could break the dilemma of single investment by the government in environmental governance and promote the process of sustainable RDST. Effects of environmental regulations have been roughly approved, however, its influence mechanisms on rural residents' WTPP and WTP for sustainable RDST have not been fully revealed. Based on a database of 744 respondents, an integrated model was developed to verify the heterogeneity of three environmental regulations on rural residents' WTPP, and further explore the corresponding interaction effects and impact mechanisms. In addition, there is an urgent necessity to explore the effectiveness of implementing different combinations of environmental regulations. Results indicated that, firstly, guiding regulation and incentive regulation promoted the probability of rural residents' WTPP and WTP, whereas binding regulation had a limited impact on individuals. Secondly, rural residents' cognition mediated the effect of environmental regulations on their WTPP and WTP. Lastly, guiding and incentive regulation indicated a substitution relationship, while both guiding and binding regulation, incentive and binding regulation revealed a complementary relationship. The corresponding implications were proposed to strengthen the publicity on the environmental and health hazards of rural domestic sewage, and effectively raise rural residents' environmental cognition and environmental protection awareness, thereby increasing their WTPP and payment for sustainable RDST. This study provided credible references and recommendations for environmental regulations formulation and policy optimization in RDST, the construction of payment systems for rural residents, and inspirations for rural environment management in other developing countries.

1. Introduction

A significant amount of waste that pollutes the environment has been created along with global economic progress, social advancement, and growth in population (Wang et al., 2018b). Currently, more than 80% of the total sewage is directly released into the environment on a worldwide scale (Burket et al., 2018). This phenomenon is more severe in rural areas due to the constraints of capital investment, limitation of residents' awareness and other aspects (Huang et al., 2021). In the case of China, more than 500 million people are living in rural areas (National Bureau of Statistics of China, 2021), accompanied by the improvement of living standards and transformed lifestyle, the raising use of washing machines and showers has intensified the generation of rural domestic sewage. Mu et al. (2023) demonstrated a 63.27% increase in rural domestic sewage discharge in China from 2010 to 2020. In addition, untreated rural domestic sewage may contain detergents, pesticides, antibiotics, and a variety of micropollutants (Liu et al., 2024; Venditti et al., 2022; Xing et al., 2022; Yi et al., 2021). Large amounts of untreated rural sewage released into the environment, will not only cause water bodies eutrophication, soil degradation, and other potential agricultural productivity risks, but also threaten animal and human health (Elahi et al., 2018; Lam et al., 2015; Wang et al., 2016). Therefore, RDST is an essential initiative to preserve the rural living environment and enhance the welfare of rural residents.

Nowadays, the Chinese government attaches great importance to RDST and proposed the “Three-Year Action Plan for Rural Living Environment Improvement” in 2018. Relying on government investment, by the end of 2020, there was nearly 25.5% of administrative villages established RDST facilities nationwide and expected to reach 40% by 2025 (China Agricultural Green Development Research Association, 2021). However, local governments in less economically developed regions are facing a dilemma in affording substantial RDST capital investment (Liao and Shi, 2018), resulting in a relatively slow growth of RDST rate. Due to fiscal deficits, some governments lacked the financial ability to cover the expenditure on operation and maintenance of completed RDST facilities, which led to substandard sewage treatment and impeded the sustainability of RDST (Ding et al., 2021). Therefore, on the basis of current RDST achievements and numerous constructed RDST plants, it is significant to broaden the funding channels to contribute to safeguarding RDST, and establishing a long-term operation and maintenance mechanism for sustainable RDST.

Rural residents are not only the "dischargers" of rural domestic sewage, but also the direct "beneficiaries" of RDST (Lin et al., 2022). Therefore, based on the "polluter pays" principle, exploring additional funding options, such as the rural residents' WTPP for environmental management has been regarded as an important way to break through the constraint of insufficient government financial investment (Cui et al., 2022). In addition, due to the relatively low level of Chinese rural residents' WTPP and payment for environmental management (Xu et al., 2023a), there is an urgent need for an in-depth analysis of their WTPP and payment influencing factors and mechanisms. Currently, exploratory studies have been conducted globally on the internal influencing factors of rural residents' WTPP and payment regarding RDST. These studies are mainly focused on individual and family characteristics (Jan, 2021; Wang et al., 2021a), peasant class identity (Lin et al., 2022), and capital endowment (Cui et al., 2022; Yu et al., 2022). In addition, the influence of rural residents' environmental cognition on their willingness to participate in rural environmental management has also been highlighted by academic interest, and it has been generally confirmed that the higher the rural residents' environmental cognition, the stronger their WTPP in rural environmental management (Su et al., 2020; Uthes and Matzdorf, 2016). Moreover, it is also suggested that the environmental cognition of rural residents should be improved through education and guidance and the formulation of environmental regulations, so as to form soft restraints at the moral level and hard restraints at the policy level (Jiao et al., 2022).

In RDST, rural residents who improperly treat rural domestic sewage will lead to environmental pollution and without compensating for the damage caused by environmental pollution, thus resulting in environmental negative externalities (Zhao and Liu, 2023). The government, as a representative of the public interest, could balance the marginal costs and marginal benefits of rural residents' participation in environmental management by implementing environmental regulations such as taxes or economic subsidies, thus to internalize the externalities of environmental pollution (Tang et al., 2021b, 2020). However, although Chinese governments at all levels have implemented a variety of environmental regulations in rural environmental management, the dispersed, hidden and lagging characteristics of surface pollution in rural environments, as well as the government's lack of financial resources and other factors, may result in a "regulatory failure" phenomenon (Li et al., 2019b; Xu et al., 2016). Therefore, it is particularly important to explore the effectiveness of the impact of different environmental regulations on rural environmental management. In terms of the impact of environmental regulation on rural environment management and particularly on sustainable RDST, the existing studies have following limitations. Firstly, most of the current research on the impact of environmental regulation focuses on domestic waste management (Xu et al., 2023a; Zhang et al., 2022) or livestock and poultry manure management (Li et al., 2020b; Wang et al., 2021c) , while studies on the impact of environmental regulation on RDST are relatively insufficient. Secondly, as the crucial influence factor of rural residents' WTPP and WTP regarding sustainable RDST, the impact paths and conduction mechanisms of environmental regulation on individuals have been relatively underexamined. Finally and most importantly, as the current RDST is a co-existence of environmental regulations, their interactions need to be further explored. Although some scholars analyzed the impact of individual environmental regulations on rural residents' participation in environmental management, or the interaction effects of environmental regulation with informal regulation and social norms (Hao et al., 2022; Li et al., 2021a; Shi and Zhang, 2021; Xu et al., 2023a; Xu et al., 2021), the interaction effects between diverse environmental regulations were neglected to be analyzed thoroughly.

In response to the above dilemmas, this study responds to the scientific questions of "What are the individual and interaction effects of diverse environmental regulations on rural residents' WTPP and WTP for sustainable RDST? What are the influence mechanisms of corresponding environmental regulations on rural residents' WTPP and WTP?" Therefore, the objectives of this study are as follows. Firstly, based on the on-site survey data, this study applied the binary logit regression model and Tobit model to indicate the heterogeneity impact of guiding, incentive and binding regulations on rural residents' WTPP and payment regarding sustainable RDST, respectively. Secondly, a mediation effect model was constructed, and the influence mechanism of environmental regulation on rural residents' WTPP and payment was revealed. Finally, based on the interaction effect model, the interaction effects of different combinations of environmental regulations on rural residents' WTPP and payment are further analyzed. This study contributes to clarifying the heterogeneous impacts of different environmental regulations on rural residents' WTPP and WTP regarding sustainable RDST, exploring the impact conduction mechanisms and realization paths of different environmental regulations, as well as providing references to the government's formulation of different environmental regulation combinations. Furthermore, study results could provide references for rural living environment management in other developing countries and contribute to the realization of the UN's Sustainable Development Goals, "clean water and sanitation for all" (SDG 6).

2. Literature review and hypothesis

2.1. Effects of environmental regulations

Due to the relatively low environmental protection consciousness and income level of rural residents, the majority of rural areas have not established a payment mechanism for rural residents of RDST (Xu et al., 2023a). Therefore, governments need to intervene, and environmental regulation is one of the main instruments. The theory of externalities could also provide the basis for environmental regulations implementation by the government. The environmental pollution caused by rural domestic sewage has negative externalities, so Li et al. (2019c) suggested that the externalities of environmental pollution should be internalized. Pigou (1920) emphasized the direct regulation of the government and advocated the internalization and elimination of negative externalities through taxation and subsidies, and has provided a direct basis to adopt environmental regulation. As an important instrument of government intervention in pollution externalities, environmental regulation has been found to have a significant impact on rural domestic waste sorting, livestock and poultry waste management, and other aspects (Jia et al., 2021; Wang et al., 2021b).

In terms of rural environmental management, the common environmental regulations are mainly guiding regulation, incentive regulation and binding regulation. Firstly, for guiding environmental regulation, the government mainly publicizes the negative consequences of environmental pollution and the significance of environmental protection to rural residents through environmental protection publicity and education. These approaches may raise rural residents' environmental knowledge and literacy, enhance public understanding and acceptance of policies, thereby reducing their policy violation behaviors, and thus improve their WTPP and WTP for sustainable RDST (Han et al., 2019; Su et al., 2020; Xu et al., 2023a). Secondly, in terms of incentive environmental regulation, the government directly reduces the transaction cost of rural residents' participation in sustainable environmental management to a certain extent by issuing pollution control subsidies and material rewards, and promoting them to form stable economic expectations (Luo et al., 2014; Zhou et al., 2021). Greater incentives enable rural residents to participate in sustainable RDST, which means that rural residents have a higher probability of WTPP and WTP. Lastly, in the aspect of binding environmental regulation, where penalties are the most common means of binding. Rural residents will be penalized by fines or other penalties if they deviate from the regulatory goal. Rural residents will be more probably to accommodate the regulatory objectives by economic rationality after trade-offs of the non-compliance cost, and will be driven by loss aversion to participate in sustainable RDST, thus increasing their possibility of WTPP and WTP (Guo et al., 2022). According to the above analysis, the following hypotheses were proposed:

H1a. The implementation of guiding regulation has a positive impact on rural residents' WTPP and WTP for sustainable RDST.

H1b. The implementation of incentive regulation has a positive impact on rural residents' WTPP and WTP for sustainable RDST.

H1c. The implementation of binding regulation has a positive impact on rural residents' WTPP and WTP for sustainable RDST.

2.2. Mediating effects of rural residents’ cognition on their WTPP and WTP

The cognition of rural residents is the foundation of their participation in environmental management, and their willingness and attitude to participate are formulated with certain environmental cognitions (Tang et al., 2020). It is believed that improving the level of rural residents' cognition has a significant impact on changing their environmental behaviors as well as increasing their WTPP and WTP for rural environmental management (Mukherji et al., 2016). According to Jiao et al. (2022), rural residents' cognition of rural domestic sewage is mainly reflected in three aspects, which are necessity cognition, pollution cognition and health cognition. Rural residents make judgments based on their cognition of the environmental problems caused by the discharge of untreated domestic sewage. The assessment of its necessity for treatment, pollution of the environment, and impact on human health leads to a decision on whether to implement environmentally friendly behaviors (Han et al., 2019; Jia et al., 2021). In addition, improving sustainable environmental management of rural residents is a long-term process. It mainly aims to encourage rural residents to establish the value of environmental protection and cognition of environmental protection by disseminating relevant sustainable environmental management knowledge and enhancing their environmental perception, so as to improve rural residents' WTPP and WTP (Frantz and Mayer, 2014). The implementation of environmental regulations contributes largely to residents' environmental cognition and may indirectly affect their WTPP and WTP for sustainable environmental management. Therefore, environmental regulations not only have a direct effect on rural residents' WTPP, but also indirectly affect rural residents' WTPP and WTP by influencing their cognition. Based on the above analysis, the following hypotheses were formulated:

H2. Rural residents' cognition is the mediator of the effect of environmental regulation on rural residents' WTPP and WTP for RDST.

2.3. Interaction effects of environmental regulations on rural residents' WTPP and WTP

In the current process of rural environmental management, different types of environmental regulation may interact mutually (Zhu et al., 2021a). In the context of the coexistence of multiple environmental regulations, the combination of different types of environmental regulation may result in certain functional overlaps or differences, thus presenting different interaction effects (Chen et al., 2023). Li et al. (2019a) concluded that the interaction of different formal institutions and different informal institutions had heterogeneous and significant effects on farmers' green production behaviors, in which the disciplinary supervision in the informal institutions showed a substitution relationship with the binding regulation in the formal institutions, and the value guidance in the informal institutions showed a complementary relationship with the binding regulation in the formal institutions. Specifically, the guiding regulation emphasizes raising the awareness of environmental protection among rural residents, as well as enhancing their understanding of incentive and binding regulation, thus reducing the understanding bias towards incentive and binding regulation among rural residents. This may increase the acceptance and recognition of incentive regulation and binding regulation by rural residents, which consequently may increase the promotional effect of incentive regulation and binding regulation on rural residents' WTPP and WTP regarding sustainable RDST. In addition, the incentive and binding regulation may award or penalize the rural residents to some extent, either financially or reputationally. When faced with the prospect of being rewarded or penalized, incentive regulation and binding regulation may motivate rural residents to pay more attention to the information and education provided by guiding regulation, which may strengthen the effect of guiding regulation on the promotion of rural residents’ WTPP and WTP for sustainable RDST. Therefore, different environmental regulations interact with each other to promote rural residents' WTPP and WTP for sustainable RDST. Accordingly, the following hypothesis is proposed.

H3. There is an interaction effect of different environmental regulations on rural residents' WTPP and WTP for sustainable RDST:

According to the above theoretical analysis and hypotheses development, the research framework covering the effects of three environmental regulations, rural residents' cognition and interaction effects on rural residents' WTPP and WTP for sustainable RDST has been conceptualized, and the influencing pathways shown in **Figure 6-1**.

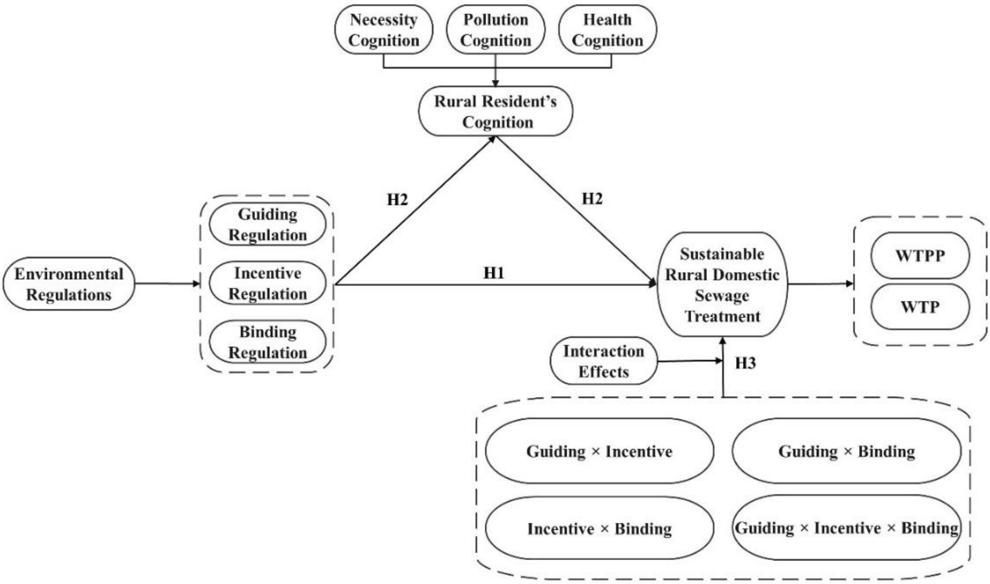

Figure 6-1 Framework of the relationship between environmental regulation and rural residents' WTPP and WTP for RDST.

3. Materials and methods

3.1. Data collection

Data adopted in this study were collected from the northern China from September to November 2020. Due to the relatively low level of economic development in northern China compared with southern China, the government's financial resources are relatively insufficient, and the funding shortage in RDST and other issues is more serious. In addition, the urbanization rate in northern China is relatively slow, with a relatively high percentage of rural population. Therefore, it is more practical to select the northern China to conduct the relevant investigations. Based on the per capita income of rural residents, the provinces in northern China are classified into three grades: high, medium and low, and in each grade, Shandong Province, Jilin Province and Gansu Province (**Table 6-1**) are accordingly selected as the study area for this research (**Figure 5-2**). These three provinces are all crucial agricultural development areas in China, with a relatively high proportion of rural population. In addition, these provinces are located in different geographical regions of northern China, which include the North China Plain, the Northeast China Plain, and the Loess Plateau. Therefore, obtained results could also provide experiences and implications for the entire North China, or even for developing countries with similar characteristics, such as India or other African countries.

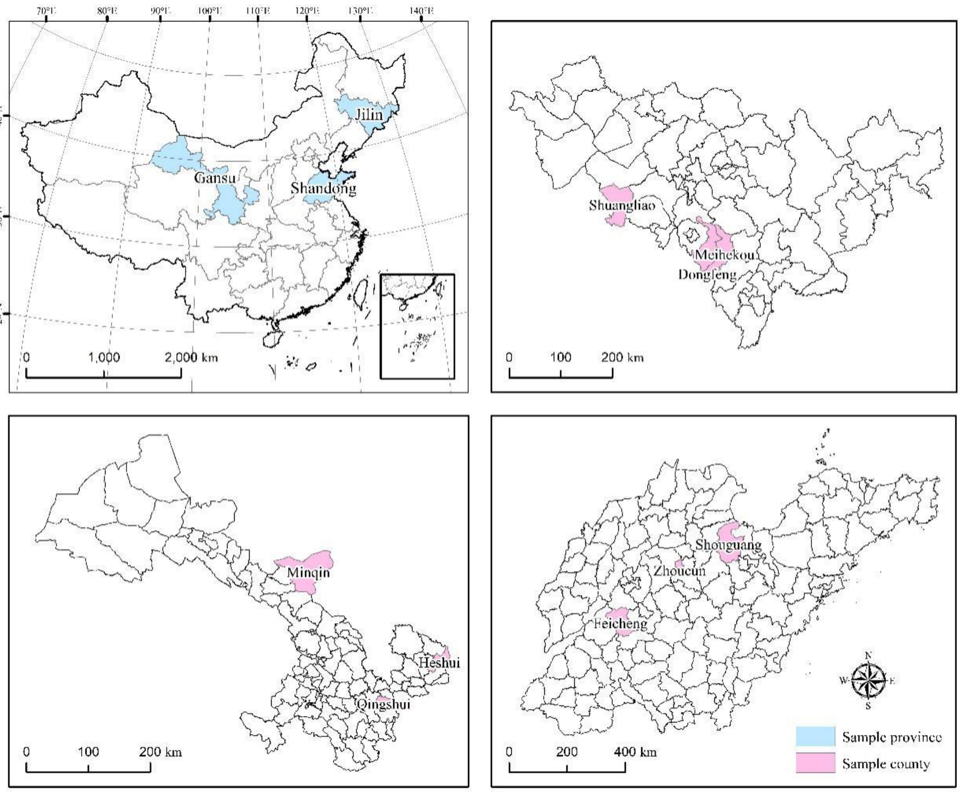

Figure 6-2 Distribution of study area in China.

Table 6-1 Socioeconomic statistics of study area in 2020.

Study Area	Rural Population (million)	Proportion of Rural Population (%)	Rural Disposable Income (CNY / person·year)
Jilin	8.99	37.47%	16067.0
Shandong	37.51	36.90%	18753.2
Gansu	11.95	47.78%	10344.0
China	509.79	36.10%	17131.5

In order to avoid sample selection bias, this study used a stratified random sampling method based on the level of economic development of each region. There were three counties selected in each province, three townships were selected in each county, and three administrative villages were identified in each township. For each village, interviewed 8 to 10 adult respondents who were permanent residents of the village. In consideration of the variability in respondents' educational levels, a face-to-face questionnaire interview for each respondent was required to ensure the data authenticity and validity. Eventually, a total of 798 questionnaires were collected, and after excluding the inconsistencies and missing value samples, 744 valid questionnaires were obtained for analysis, with a questionnaire effectiveness rate of 93.23%, and the distributions of samples in Jilin, Shandong and Gansu was 30.11%, 34.68% and 35.21% respectively.

The questionnaire consisted of four parts. The first section includes the individual characteristics of the respondents, including gender, age, education level, village cadres and household income. The second part is the core variable of this study, which is environmental regulations. The third part investigates the mediating variables of this study, namely the respondents' cognitions of RDST. Rural residents' cognition is mainly expressed by three sub-indicators, including rural residents' awareness of the necessity, pollution and health of RDST. The fourth part is to reveal the WTPP and WTP of rural residents, and the questionnaire in this part is used to assess the rural residents' WTPP and WTP of sustainable RDST.

3.2. Variable selection

In this study, the dependent variables are rural residents' WTPP and WTP of sustainable RDST, additionally, environmental regulations as core independent variables, rural residents' cognition as mediating variable, socio-economic characteristics variables and regional variables were considered (**Table 6-2**).

For the respondents in this survey, the average age was approximately 54 years, the average level of education was junior school level, and the average annual household income was approximately 54,000 CNY. This is also consistent with Chinese government statistics on rural residents (National Bureau of Statistics of China, 2020). Therefore, the samples of this study could broadly represent the characteristics of residents in rural areas of northern China.

Table 6-2 Variable definitions and descriptive statistics.

Variable	Definition	Mean
WTPP	Are you willing to participate in sustainable RDST? 0=No, 1=Yes	0.835
WTP	How much are you willing to pay per month? (CNY)	8.14
ENVIRONMENTAL REGULATIONS		
Guiding regulation	Does the government or village propagate the benefits of domestic sewage treatment? 0=No, 1=Yes	0.901
Incentive regulation	Does the government or village have material or verbal incentive measures to encourage rural residents to properly dispose of domestic sewage? 0=No, 1=Yes	0.628
Binding regulation	Does the government or village have any material or verbal penalties for the arbitrary discharge of domestic sewage by rural residents? 0=No, 1=Yes	0.224
RURAL RESIDENTS' COGNITION*		
Necessity cognition	Is it necessary to treat domestic sewage?	3.902
Pollution cognition	Does the domestic sewage pollute the environment?	3.362
Health cognition	Does the domestic sewage have an impact on health?	3.325
SOCIO-ECONOMIC CHARACTERISTICS		
Gender	Gender of the respondent. 0=Female, 1=Male	0.700
Age	Age of the respondent.	54.113

Education level	Education level of respondent. 1=Illiteracy, 2=primary, 3=junior, 4=high school, 5=college and above	2.956
Village cadres	Whether as a member of village cadres? 0=No, 1=Yes	0.202
Household income	Respondents' annual household income. (10,000 CNY)	5.354
REGIONAL CHARACTERISTICS		
Jilin Province	0=Other, 1=Jilin	0.301
Shandong Province	0=Other, 1=Shandong	0.347
Gansu Province	0=Other, 1=Gansu	0.352

*Corresponding respondents' answers were set to a positive five-point Likert-type scale (1=total disagree, 2=somewhat disagree, 3=neither disagree nor agree, 4=somewhat agree, 5=total agree). To reduce the collinearity between the indicators, the dimensionality reduction was performed for factor analysis, the results showed that the Kaiser-Meyer-Olkin statistic was 0.651 with 0.000 of the P-value of Bartlett spherical test. The obtained common factor was defined as "rural residents' cognition".

3.3. Empirical models

3.3.1. Baseline regression model

In this study, two main aspects are examined to explore the willingness of rural residents for sustainable RDST. Firstly, the binary logit regression model is applied to test whether diverse environmental regulations contribute to rural residents' WTPP for sustainable RDST. Since there are only two responses to the rural residents' WTPP, "Yes" and "No", it is a discrete choice problem, so based on the study of Xu et al. (2023a), a binary logit regression model is used for estimation (Equation 6-1).

$$WTPP_i = \alpha_0 + \alpha_1 ER_i + \alpha_2 Control_i + \varepsilon_1 \qquad (6\text{-}1)$$

where $WTPP_i$ represents rural residents' WTPP; ER_i denotes various types of environmental regulations; $Control_i$ is the control variable that may affect rural residents' WTPP; ε_1 is the error term.

Secondly, the response of rural residents regarding the WTP of sustainable RDST was the actual amount of money they were willing to pay per month, which was a continuous variable and therefore was more appropriate for the Tobit model. In addition, as there was left-censored at zero due to the fact that approximately 16.5%

of the respondents in the survey refused to pay, this issue could be well addressed by the Tobit model. And according to He et al. (2022), the equation is shown as follows.

$$WTP_i = \alpha_0 + \alpha_1 ER_i + \alpha_2 Control_i + \varepsilon_1 \quad (6\text{-}2)$$

where WTP_i represents the actual payment amount of rural residents regarding sustainable RDST; and the rest of the terms are the same as in Equation (6-1).

3.3.2. Mediating effect model

Supposing that α_1 in Equation (6-1) and (6-2) is significant, the impact path of environmental regulations affecting rural residents' WTPP and WTP would be revealed by verifying the mediating effect of rural residents' cognition. Based on the mediating effect model of Baron and Kenny (1986) and Wen and Ye (2014) this study employed a stepwise regression model to test the influence relationship between rural residents' cognition in environmental regulation and WTPP.

$$Cognition_i = \beta_0 + \beta_1 ER_i + \beta_2 Control_i + \varepsilon_2 \quad (6\text{-}3)$$

$$WTPP_i = \gamma_0 + \gamma_1 ER_i + \gamma_2 Cognition_i + \gamma_3 Control_i + \varepsilon_3 \quad (6\text{-}4)$$

$$WTP_i = \gamma_0 + \gamma_1 ER_i + \gamma_2 Cognition_i + \gamma_3 Control_i + \varepsilon_3 \quad (6\text{-}5)$$

In the model, Equation (6-3) explains the relationship between rural residents' cognition and environmental regulations. If β_1 is significant, then it is tested whether both environmental regulations and rural residents' cognition are related to WTPP and WTP by Equation (6-4) and (6-5). If γ_1 and γ_2 is significant, it indicates that the mediation effect exists. In addition, since rural residents' cognition is a continuous variable, so Equation (6-3) is estimated by ordinary least squares (OLS) regression.

3.3.3 Interaction effect model

The effect of environmental regulation on rural residents' WTPP and WTP for sustainable RDST is not independent. Therefore, this study further explores whether there are interaction effects of different types of environmental regulation on rural residents' WTPP and WTP. Based on the approach of Sun et al. (2021), this study tests the interaction effects by incorporating the interaction terms of different environmental regulations into the model. The specific equations are as follows.

$$WTP_i = \theta_0 + \theta_1 ER_1 + \theta_2 ER_2 + \theta_3 ER_1 * ER_2 + \theta_4 Control_i + \varepsilon_4 \quad (6\text{-}6)$$
$$Payment_i = \theta_0 + \theta_1 ER_1 + \theta_2 ER_2 + \theta_3 ER_1 * ER_2 + \theta_4 Control_i + \varepsilon_4 \quad (6\text{-}7)$$

where $ER_1 * ER_2$ is the interaction term of different environmental regulations. θ_3 indicates the interaction effect of different environmental regulations on rural residents' WTPP and WTP, and if the coefficient of θ_3 is significant, then the existence of interaction effects is proved.

4. Results

4.1 Descriptive statistics

As can be seen in **Figure 6-3**, the percentage of rural residents with positive WTPP in the study area is relatively large reaching approximately 83.5%. In terms of willingness, a relatively high percentage of rural residents presented their willingness to pay for sustainable RDST, which provides a basis for the Chinese government to promote and implement the payment system at the later stage. In addition, the WTP of rural residents was also investigated. The average WTP for the total respondents and respondents with positive WTPP were 8.14 CNY/month and 9.75 CNY/month, respectively. In terms of percentage, 50.2% of the respondents are willing to pay less than 10 CNY per month for their households. In terms of percentage, 50.2% of respondents are willing to pay less than 10 CNY/month for their households, and 45.4% of respondents are willing to pay 10-20 CNY. There is only 4.4% of respondents who are willing to pay more than 20 CNY/month. The above statistics indicated that rural residents in the research area have a strong WTPP, but the WTP was relatively low, which was also consistent with the results of Yu et al. (2023).

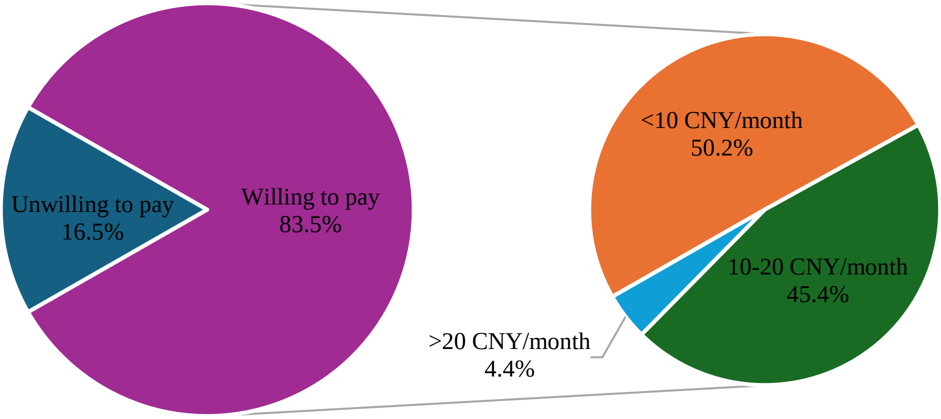

Figure 6-3 Distributions of rural residents' willingness to pay and proportions of different payment levels.

4.2 Impact of environmental regulations on rural residents' WTPP and WTP

Considering the possibility of variables' multicollinearity and ensuring the regression validity, it is necessary to diagnose the variables collinearly. As the results indicated, the variance inflation factor (VIF) of each variable was less than 2, indicating that a serious multicollinearity did not exist among the variables. Subsequently, this study employed the binary logit regression to analyze the determinants of rural residents' WTPP for sustainable RDST by Stata 17. **Table 6-3** presented the regression results of the effects of different environmental regulations as well as other control variables on rural residents' WTPP and WTP regarding sustainable RDST. In order to provide a convenient explanation of the impact of environmental regulations on the WTPP and WTP of rural residents, this table reported the results of marginal effects instead of regression coefficients.

Table 6-3 Binary logit regression results of government regulations affecting rural residents' WTPP and WTP.

Variable	Logit	Tobit	Logit	Tobit	Logit	Tobit
	WTPP	WTP	WTPP	WTP	WTPP	WTP
Guiding regulation	0.182***	4.225***	--	--	--	--
Incentive regulation	--	--	0.127***	1.096***	--	--
Binding regulation	--	--	--	--	-0.030	-0.468
Gender	-0.010	0.587	-0.002	0.723	-0.003	0.724
Age	-0.004***	-0.071***	-0.006***	-0.096***	-0.007***	-0.098***
Education level	0.048***	0.349*	0.073***	0.635***	0.076***	0.676***
Village cadres	0.099***	0.386	0.140***	0.672	0.131***	0.549***
Household income	0.021***	0.138***	0.027***	0.157***	0.029***	0.159***
Jilin Province	-0.038	-2.867***	-0.033	-2.930***	-0.041	-3.008***
Gansu Province	0.021	-2.461***	0.027	-2.401***	0.041	-2.240***
Observations	744	744	744	744	744	744
LR $\chi2$	229.31***	234.29***	222.81***	186.09***	191.68***	178.09***
Pseudo R^2	0.344	0.051	0.334	0.040	0.287	0.039

Note: *** p<0.01, ** p<0.05, * p<0.1.

Regression results illustrated that guiding regulation and incentive regulation had positive impacts on rural residents' WTPP and WTP for sustainable RDST, which verified H1a and H1b. This might be attributed to the fact that a clear and consistent guiding regulation enabled rural residents to better understand their responsibilities and obligations as well as to acquire environmental knowledge. On this basis, there was a corresponding increase in the probability of rural residents' WTPP and WTP for sustainable RDST. For incentive environmental regulation, subsidies, grants, and tax credits were usually the main approaches, which may reduce the cost of participation in sustainable RDST for rural residents, thereby increasing their WTPP and WTP. These findings were also consistent with the results of Tang et al., who concluded that guiding regulation could increase rural residents' environmental cognition and incentive regulation could reduce the participation cost, thus enhancing rural residents' willingness to participate in rural environmental management (Tang et al., 2020).

However, incentive environmental regulation is potentially a "double-edged sword". Governments should be aware that rural residents may not perceive the benefits of investing in sewage treatment systems if the incentives are deemed excessively limited or insufficient to cover the treatment expenditure. The marginal effect results revealed that the probability of rural residents' WTPP increased 18.2% and 12.7% in villages with the implementation of guiding and incentive regulations, respectively, as well as the level of payment increased by 4.26 CNY and 1.10 CNY. This may be due to the fact that while the incentive regulation may reduce the participation cost of rural residents for sustainable RDST, the guiding regulation is transforming the environmental cognition and enhancing the environmental knowledge of the rural residents so that they are internally more willing to pay for sustainable RDST.

Interestingly, there was a non-significant effect of binding environmental regulation on rural residents' WTPP and WTP for sustainable RDST. Thus, H1c was rejected, the same result was also verified by Huang et al. (2016). This finding was probably attributed to the following reasons. Firstly, this phenomenon was probably caused by the ineffective implementation of the government's environmental regulations and most of the regulations focus on prohibiting rural residents' behaviors rather than guiding them to participate in environmental management, which resulted in the "relative institutional failure" phenomenon of ineffective environmental regulations (Li et al., 2019c). Secondly, binding environmental regulation may also increase governance costs, the corresponding penalties may be unaffordable for rural residents for overly strict regulation. In addition, for the phenomena that the regulations were not effectively implemented, rural residents may not perceive the necessity for RDST investment and thus reduce their WTPP and WTP. However, in contrast to this study, some research has also found that binding regulations have a significant impact on rural residents' participation in rural environmental management and adoption of green production technologies (Guo et al., 2022; Xu et al., 2023a). Therefore, in order to further enrich the findings in this area, the implementation scope, application types and application conditions of binding regulation need to be further explored in future research.

In terms of control variables, there were four significant variables that affected rural residents' WTPP and WTP, including age, education level, village cadres and household income. In particular, respondents' age negatively affected rural residents' WTPP for sustainable RDST, which meant that the younger the respondents were, the higher the probability of their WTPP and WTP. The potential reason for this was that the younger the rural residents, the higher the level of cognition and awareness of environmental management practices such as RDST, and the more likely to participate, this finding has also been confirmed by other scholars (Tang et al., 2020). Respondent's education level positively influenced rural residents' WTPP and WTP for the sustainable RDST as education improved their awareness and perception of the importance of environmental conservation. Furthermore, He et al. (2015) believed that as a quasi-public good, education may contribute to the improvement of overall environmental protection awareness in the surrounding area through positive spillover effects, therefore promoting rural residents' WTPP and WTP. Village cadres had a significant positive effect on rural residents' WTPP and WTP, which might be because cadres represent the actual facilitators and practitioners of government policies in rural areas, who might demonstrate a stronger WTPP and WTP by exhibiting a higher ideological cognition and perceived value (Jiao et al., 2022). Annual household income also exhibited an effective positive effect on individuals' WTPP and WTP, as Afroz et al. (2009) indicated that wealthier rural residents were more inclined to invest in environmental management.

4.3 Mediating effect of rural residents' cognition

Preliminary results showed that there was a significant positive direct effect of both guiding and incentive regulation on rural residents' WTPP and WTP for sustainable RDST. According to theoretical analysis and research hypotheses, this section revealed the mediating effect of rural residents' cognition in the process of different environmental regulations influencing rural residents' WTPP and WTP, and the internal conduction mechanism of the influence of environmental regulations and rural residents' cognition on rural residents' WTPP for sustainable RDST were further verified. It should be noted that the test for the path of " binding regulation - rural residents' cognition - WTPP and WTP" was excluded since the binding regulation showed a non-significant effect on rural residents' WTPP and WTP in the above results.

In **Table 6-4**, both guiding regulation and incentive regulation positively affected rural residents' cognition and were significant at the 1% level, respectively. This suggested that the implementation of environmental regulation contributed to enhancing rural residents' cognition. When rural residents' cognition was included in the regression model of the impact of the guiding regulation on rural residents' WTPP and WTP, respectively, both the guiding regulation and rural residents' cognition were positively significant at the 1% statistical level. This indicated that rural residents' cognition positively and significantly mediated the effect of the guiding regulation on rural residents' WTPP and WTP, and that there existed the influence paths of "guiding regulation - rural residents' cognition - WTPP" and "guiding regulation - rural residents' cognition - WTP". Similar to the results with the guiding regulation, when rural residents' cognition was incorporated into the regression model of the effect of incentive regulation on rural residents' WTPP and WTP, all regression coefficients were significant at the 1% level, except for the incentive regulation on the WTP, which was significant at the 5% level. This illustrated that the influence paths of " incentive regulation - rural residents' cognition - WTPP" and "incentive regulation - rural residents' cognition - WTP" were also verified. This finding was similarly corroborated by Yang et al. (2022) who argued that rural residents have deepened their own environmental cognition in the process of enforcing environmental regulations, thus enhancing their WTPP for rural environmental management. Thus, rural residents' cognition had a mediating effect in the influencing process of guiding and incentive regulations on rural residents' WTPP and WTP, and H2 was partially confirmed, which meant that guiding and incentive regulations indirectly promote rural residents' WTPP by enhancing the rural residents' cognition.

Table 6-4 Mediating effect test of rural residents' cognition.

Variable	Guiding regulation			Incentive regulation		
	Rural residents' cognition (OLS)	**WTPP (Logit)**	**WTP (Tobit)**	**Rural residents' cognition (OLS)**	**WTPP (Logit)**	**WTP (Tobit)**
Guiding regulation	0.570^{***}	2.486^{***}	7.106^{***}	--	--	--
Incentive regulation	--	--	--	0.242^{***}	1.750^{***}	1.151^{**}
Rural residents' cognition	--	1.634^{***}	2.486^{***}	--	1.614^{***}	2.622^{***}
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Observations	744	744	744	744	744	744
LR $\chi 2$	9.57^{***}	388.68^{***}	334.02^{***}	8.61^{***}	383.07^{***}	295.19^{***}
Pseudo R^2	0.094	0.583	0.072	0.086	0.574	0.064

Note: *** p<0.01, ** p<0.05, * p<0.1.

As the traditional mediating effect calculation method is not applicable to nonlinear probability models, this paper also adopts the KHB method, which is proposed by Karlson et al. (2012) and Kohler et al. (2011) to measure the mediating effect and effect decomposition of rural residents' cognition. **Table 6-5** reported the results of the KHB model, and all results were positively significant at the 1% level. In terms of WTPP, the indirect effects of guiding regulation and incentive regulation on rural residents' WTPP by influencing rural residents' cognition accounted for 27.25% and 18.26% of the total effects. As for WTP, the indirect effects of these two environmental regulations accounted for 27.19% and 19.01% of the total effects. In other words, the implementation of these two environmental regulations led to a higher rural residents' cognition, which consequently converted to a higher rural residents' WTPP. These analyses were consistent with the previous test results, indicating robust results of mediating effects, and further verified the conduction mechanism of diverse environmental regulations and rural residents' cognition on rural residents' WTPP and WTP of sustainable RDST.

Table 6-5 Effect decomposition of positive regulations on the impact of rural residents' WTPP.

	Guiding regulation		Incentive regulation	
	WTPP	**WTP**	**WTPP**	**WTP**
Total effect	3.417***	1.872***	2.141***	1.136***
Direct effect	2.486***	1.363***	1.750***	0.920***
Indirect effect	0.931***	0.509***	0.391***	0.216***

Note: *** p<0.01, ** p<0.05, * p<0.1.

4.4 Interaction between diverse environmental regulations

Nowadays, in China's rural environmental management practice, the environmental regulation is not a single implementation, but a variety of environmental regulations coexist. Therefore, this section tested the interaction effects of different environmental regulations, and the results were presented in **Table 6-6**. Firstly, the interaction term between guiding and incentive regulation exhibited a significant negative effect on both rural residents' WTPP and WTP. This suggested that there was a substitution relationship between these two environmental regulations in terms of the impacts on rural residents' WTPP and WTP. This implicated that when guiding regulation was ineffective, incentive regulation could work as an alternative to guiding regulation. In this regard, a possible explanation might be that in weakly implemented areas of guiding regulation, the perception of rural residents might be at a relatively low level, thus limiting rural residents' WTPP and WTP regarding sustainable RDST. However, the implementation of incentive regulation could economically reduce the cost of rural residents' participation in sustainable RDST and thus increase their WTPP and WTP. Secondly, the effect of the interaction term between guiding and binding regulation was positively significant, and a parallel finding was found for the interaction term between incentive and binding regulation. This meant that the interactions of these two combinations of environmental regulation could promote rural residents' WTPP and WTP and present a complementary relationship. In other words, the implementation of binding regulation would contribute to the enhancement of guiding and incentive regulations. This was probably due to the fact that rural residents, as "rational economic man", were more inclined to accept government guidance and receive rewards in the face of the risk of penalties. The above findings were consistent with other scholars' related studies, who concluded that there was a significant interaction between the two of these three environmental regulations, which meant that they significantly moderated each other's influence on rural residents' willingness to engage in rural environmental management (Li et al., 2020c; Zhu et al., 2021b). Finally, no significant effect on rural residents' WTPP and WTP was found when the interaction term of the three environmental regulations was included, which also implied that there was no correlation between the three environmental regulations. It also meant that when environmental regulation was implemented in excessive types, it would be limited in its effectiveness. Thus, based on the above empirical results, H3 was partially validated.

Table 6-6 Interaction results of diverse environmental regulations.

Variable	WTPP	WTP	WTPP	WTP	WTPP	WTP	WTPP	WTP
Guiding regulation (X1)	1.799^{***}	7.336^{***}	2.189^{***}	8.789^{***}	--	--	1.820^{***}	7.722^{***}
Incentive regulation (X2)	1.198^{***}	1.604^{***}	--	--	1.637^{***}	1.668^{***}	1.308^{***}	1.334^{**}
Binding regulation (X3)	--	--	0.045	-0.989	1.073	-0.235	0.251	-0.246
X1*X2 (interactive item)	-1.805^{**}	-8.750^{**}	--	--	--	--	--	--
X1*X3 (interactive item)	--	--	2.679^{**}	8.242^{**}	--	--	--	--
X2*X3 (interactive item)	--	--	--	--	2.596^{**}	1.899^{*}	--	--
X1*X2*X3 (interactive item)	--	--	--	--	--	--	-2.004	-8.144
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Observations	744	744	744	744	744	744	744	744

LR χ2	260.63***	255.39***	237.15***	242.85***	231.95***	188.42***	256.51***	242.84***
Pseudo R^2	0.391	0.055	0.355	0.053	0.348	0.041	0.385	0.053

Note: *** p<0.01, ** p<0.05, * p<0.1.

5. Discussion and limitation

5.1 Discussion

This chapter demonstrates that the mediating effect of rural residents' cognition on diverse environmental regulations. The influence mechanism of this mediating effect consisted of the following two phases. Firstly, environmental regulations had a positive and significant impact on rural residents' cognition, which is consistent with similar findings in previous studies (Tang et al., 2020; Xue et al., 2021). Guiding environmental regulation is one of the main approaches for the government to publicize the governance of rural human living environment and rural ecological environment protection, and the regulation will strengthen rural residents' cognition of environmental management including RDST. In addition, rural residents would be equally motivated to implement the incentive regulation, so their understanding of the regulation would be relatively deeper, and their cognition would be correspondingly improved. Secondly, the impact of rural residents' cognition on their WTPP and WTP. Nowadays, with the progress of society and economic development, the awareness of environmental protection among rural residents is gradually increasing, and therefore the cognition of RDST is also simultaneously increasing. This finding is also in line with the "Knowledge-Attitude-Practice" theory (KAP theory), which states that any behavior is not generated from thin air, but evolves gradually after acquiring relevant knowledge and developing attitudes (Wang and He, 2020). In this study, rural residents' cognition about the environment and RDST was a significant influencing factor on their WTPP and WTP for sustainable RDST, and this view was also confirmed by the findings of Uthes and Matzdorf (2016), Yang et al. (2018b) and Su et al. (2018). In addition, since rural living environment improvement, especially RDST, has positive externalities and the general public benefits from the spillover effects of environmental improvement, it is prone to a "free-riding" mentality among villagers (Cao et al., 2020a). Therefore, enhancing rural residents' cognition of the environment and RDST is an imperative approach to eliminate the "free-riding" mentality, thus increasing the probability of rural residents' WTPP and WTP for sustainable RDST. Meanwhile, the governments are suggested to strengthen publicity and education for rural residents to enable them to recognize the relationship between environmental protection and economic development. Rural environmental improvements may contribute to the development of local tourism, attract investment, create employment opportunities, etc., thereby increasing the agricultural and non-agricultural incomes of rural residents (Li et al., 2021b; Tang et al., 2021a). As a consequence of this, rural residents will in turn appreciate the benefits of rural environmental management and strengthen their environmental cognition, which will further increase their WTPP and WTP for sustainable RDST.

In addition, the existence of both substitutional and complementary relationships between different environmental regulations was identified. Firstly, the results indicated that when the implementation of guiding regulation to disseminate and educate the rural residents about RDST remained relatively ineffective or failed, the impact of incentive regulation with financial stimulation and other means of reducing the transaction costs of sustainable RDST for rural residents became more prominent. Secondly, it was found that a single implementation of binding regulation had a non-significant effect on the WTPP and WTP of rural residents. However, it had a complementary effect when implemented in conjunction with other two environmental regulations. This is probably due to the fact that rural residents are rational economic person for maximizing benefits (Guo et al., 2022; Simon, 1955). Therefore, rural residents may be exposed to a greater risk of benefit loss when binding regulation is implemented more stringently. Meanwhile, in order to prevent benefit loss, rural residents may prefer to accept guiding regulation, which has less benefit loss, or incentive regulation, which may lead to additional benefits. Lastly, the interaction of the three environmental regulations had no significant effect on rural residents' WTPP and WTP. This implied that excessive varieties of environmental regulation implementation may have a crowding-out effect, thus limiting the effectiveness of environmental regulations, and this phenomenon is also confirmed by the impact of environmental regulation on technological innovation and green technology adoption (Guan and Li, 2020; Liu et al., 2021).

5.2 Limitation

However, there are still some limitations remain in this study. Firstly, it is inevitable that there will be zero responses in questionnaire surveys. This questionnaire has not covered questions that reveal the reasons for zero payment when respondents express a negative willingness to pay for sustainable RDST. Therefore, future studies are recommended to further explore the issue of zero payment, thus enabling more comprehensive and in-depth research in this field. Secondly, this study attempted to explore the effect mechanism of diverse environmental regulations on rural residents' WTPP and WTP for sustainable RDST. However, due to the complexity of the effects of environmental regulations, there might exist alternative effect mechanisms. Future studies are recommended to explore multiple effect mechanisms of environmental regulations on rural residents' WTPP and WTP for sustainable RDST for the purpose of enriching the research results in this research area. Finally, although this study analyzed the impact of different combinations of environmental regulations, it has not further examined their appropriateness in different regions. Subsequently, relevant studies are suggested to thoroughly explore the heterogeneity and appropriateness of the impacts of different combinations of environmental regulations according to the economic development level and the institutional improvement level of different regions.

6. Conclusion and policy recommendations

Based on the dataset from 744 rural residents in Jilin, Shandong and Gansu provinces in China, this study verified the impact of three environmental regulations on rural residents' WTPP and WTP for sustainable RDST. Subsequently, the heterogeneous and interaction effects of environmental regulations on rural residents' WTPP were examined. Finally, this study empirically demonstrated the impact mechanism with rural residents' cognition as the mediating variable. The primary findings are as follows. Firstly, rural residents in the research area showed a relatively high WTPP for sustainable RDST, and the proportion of rural residents with positive WTPP was 83.5%. In addition, the rural residents' WTP ranges from 8.14 CNY/month to 9.75 CNY/month, which has been calculated to cover at least 47.55% of RDST maintenance costs. Secondly, the effects of three environmental regulations on rural residents' WTPP and WTP revealed heterogeneity. Both guiding and incentive environmental regulations demonstrated significant positive effects on rural residents' WTPP and WTP, however, the effect of binding environmental regulation remained limited. In terms of effectiveness, the effect of guiding environmental regulation is more effective than that of incentive environmental regulation. Thirdly, there is a significant positive effect of rural residents' cognition on rural residents' WTPP and WTP for sustainable RDST. In addition, rural residents' cognition plays a mediating role in the effect of environmental regulation on rural residents' WTPP and WTP for sustainable RDST. For guiding and incentive environmental regulation, the mediating effect accounts for 27.25% and 18.26% of the total effect respectively in terms of rural residents' WTPP. For the WTP, the mediating effects are 27.19% and 19.01%, respectively. Lastly, it was found that the pairwise interactions of these three environmental regulations have significant impacts on rural residents' WTPP and WTP regarding sustainable RDST, but the interaction impact of the three environmental regulations is not significant. In particular, guiding and incentive regulation showed a substitution relationship, while guiding and binding regulation, incentive and binding regulation appeared a complementary relationship. Based on the above findings, this study constructed a theoretical model of the influence mechanism of rural residents' WTPP on sustainable RDST and the empirical model applied in this study to analyze the impacts of different environmental regulations could be widely employed to assess the impacts of different institutions on residents' behavioral decision-making. In addition, the results of this study might contribute to implementing policy optimization for the development of public participation systems in rural environmental management in regions or countries that are at the same latitude or in a similar situation as North China.

In light of the above results and discussions, this study proposes the following corresponding policy recommendations. Firstly, a payment mechanism for sustainable

RDST should be gradually established for rural residents, with the initial payment amount ranging from 8.14 CNY/month to 9.75 CNY/month as a reference standard. Secondly, the environmental regulation system for rural areas requires further improvement. In comparison with cities and towns, rural environmental management is relatively backward, the establishment of environmental regulations is still relatively imperfect, which might reduce the capacity and effectiveness of rural environmental management. Therefore, it is necessary to establish and improve rural environmental regulations based on the characteristics of rural areas. Thirdly, the government should emphasize the differences between various environmental regulations when formulating relevant policies and avoid the single implementation of binding regulation. Moreover, the combinations of diverse environmental regulations may contribute to improving rural residents' WTPP and WTP for sustainable environmental management, but it should be noted that excessive environmental regulations may lead to the phenomenon of "policy failure". Finally, promote the importance of rural environmental protection. The government is recommended to maximize the function of traditional media such as newspapers, radio and TV, as well as new media such as the internet and social media, to strengthen the publicity of the environmental hazards and the health hazards of rural domestic sewage. This is beneficial to effectively raise rural residents’ environmental cognition and environmental protection awareness, and thus increase rural residents' participation and WTPP in environmental management. These recommendations are expected to provide references and insights for underdeveloped regions in China and even other developing countries that are facing similar challenges.

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Chapter 7

General discussion, conclusion and policy implications

1. Conclusion

The enhancement of RDST is a critical aspect of improving the rural living environment and plays a pivotal role in the development of aesthetically pleasing rural communities. RDST projects not only improve environmental conditions but also reduce pollution levels. However, the inherently public welfare-oriented nature of RDST projects, combined with their low direct economic returns, results in limited financing capacity. This financing challenge is exacerbated by the reliance on government financial resources, with insufficient social participation, which places considerable fiscal pressure on government budgets. In light of these challenges, this study employs LCC analysis of PPP projects in RDST to expand the multi-stakeholders' participation mechanism from the perspective of rural residents. It provides an expanded and in-depth framework for improving institutional and policy effectiveness by promoting collaboration among multiple stakeholders. Such collaboration is essential for balancing the dual objectives of enhancing efficiency and protecting the environment in RDST projects.

In Chapter 4, this thesis employs the LCCA method and utilizes a case analysis to conduct a comprehensive cost assessment of PPP projects in RDST. The analysis reveals significant cost distributions, with pipe construction accounting for a substantial 72% of the total construction expenditure, and electricity expenses comprising 51% of the operation and maintenance costs. Furthermore, the study employs scenario simulations to explore the factors influencing LCC of PPP projects in RDST. The results identify operational lifespan as a critical determinant of cost. Specifically, when other variables are held constant, a ten-year operational lifespan results in an ATC approximately 4.5 times higher than that of a fifty-year operational lifespan. Additionally, population changes significantly impact the LCC of PPP projects in RDST. Rapid population growth drastically reduces the operational lifespan of these projects, often leading to project failure, while rapid population decline increases the ATC, resulting in resource wastage. These findings highlight the necessity of considering both operational lifespan and population changes in the planning and implementation of PPP projects in RDST to ensure their long-term viability and cost-effectiveness.

In Chapter 5, this thesis investigates the probability of rural residents' WTPP and WTP for CMP of RDST, along with identifying key influencing factors. The results indicate that over 79% of surveyed rural residents are willing to participate in the CMP of RDST. The expected WTP for CMP among all respondents is 47.46 CNY/year, while for those with a positive WTPP, it is 63.13 CNY/year. Given a service life of 20 years for RDST facilities, these contributions could cover 16.28% and 21.65% of construction costs, respectively. The study further explores the factors affecting rural residents ' WTPP and WTP, including perceptions of RDST, government propaganda, and individual and household characteristics. Findings reveal that rural residents' perception of RDST necessity significantly and positively influences their WTPP and WTP. Additionally, exposure to government propaganda about RDST is associated with higher WTPP and WTP levels. Significant determinants of WTPP include age, education, village cadre, income, and access to centralized water supply, while age, education, and income significantly affect WTP. These findings highlight the critical role of raising awareness and targeted government propaganda in enhancing financial participation in RDST projects.

In Chapter 6, this thesis investigates the effects of three environmental regulations on rural residents' WTPP and WTP for sustainable RDST. The research also examines the heterogeneous and interaction effects of these regulations, with a focus on the mediating role of rural residents' cognition. Firstly, 83.5% of rural residents in the study area demonstrate a positive WTPP for sustainable RDST, indicating substantial support. In addition, the rural residents’ WTP ranges from 8.14 CNY/month to 9.75 CNY/month, which has been calculated to cover at least 47.55% of RDST maintenance costs. Secondly, the three environmental regulations exhibit heterogeneous effects on WTPP and WTP among rural residents. Thirdly, rural residents' cognition significantly enhances their WTPP and WTP for sustainable RDST, acting as a crucial mediating variable. Furthermore, while the pairwise interactions between the environmental regulations significantly impact WTPP and WTP, the combined interaction of all three regulations does not show a significant effect. These findings highlight the importance of understanding cognitive factors and the differential impacts of environmental regulations in shaping rural residents' financial support for sustainable RDST. By incorporating these insights, policymakers can design more effective regulations and policies that encourage greater financial participation.

In conclusion, this thesis significantly advances the development of a multi-stakeholders' participation mechanism involving government, rural residents, and public or private sectors in RDST. By examining government guiding and incentive mechanisms, rural residents' payment systems, and the cost analysis of public or private sectors, this research provides crucial insights for addressing funding challenges in RDST projects. These findings can guide policy optimization to enhance public participation in rural environmental management in developing countries. As technology and the economy progress, successful RDST implementation in China will be pivotal in achieving rural revitalization and beautiful countryside construction.

2. General discussion

2.1 The potential influencing factors of LCC

In Chapter 4, as the most common model for public participation in RDST in China, the PPP model was costed for a case analysis by employing the LCCA method. Notably, a considerable portion of overall expenditures pertains to the construction of pipeline infrastructure. Thus, capitalizing on pre-existing drainage channels and other existing infrastructure within the locality for pipeline installation could markedly mitigate construction and labor costs associated with pipeline deployment. Concerning operation and maintenance expenses, electricity consumption emerges as the most significant component, constituting 51% of total operational expenditures. Consequently, expediting the research and development efforts aimed at enhancing the energy efficiency of sewage treatment processes and equipment, while concurrently ensuring treatment efficacy, holds considerable potential for reducing LCC and improving funds utilization efficiency.

The operational lifespan serves as a crucial determinant of the LCC in PPP initiatives within the domain of RDST. A prolonged operational lifespan tends to correlate with elevated LCC but diminished ATC. Diverse factors, including deficient engineering design and suboptimal maintenance practices, can precipitate impairments or non-functionality of RDST facilities in certain locales, thereby precipitating a sharp rise in ATC and subsequent financial inefficiencies. Furthermore, population changes exert notable influence on the LCC of PPP endeavors in RDST. Particularly, rural population migrations can alter the effective operational lifespan of treatment facilities. In regions experiencing rapid population growth, the resultant upsurge in sewage discharge may lead to facility overutilization and hastened depreciation. Conversely, in areas witnessing swift population decline, diminished sewage discharge rates could elevate ATC and potentially compromise the efficacy of RDST projects employing microbiological treatment methodologies.

2.2 The potential of rural residents' WTP for the construction on RDST

In light of the estimation results by the Tobit model in Chapter 5, the expected WTP for CMP of RDST with total respondents and truncated respondents was 47.46 CNY/year and 63.13 CNY/year, respectively. Thereby, the aggregate value would be estimated at 1.1 billion CNY and 1.2 billion CNY for the total households and the households excluded the negative WTP proportion (18.13%) per year. Based on MOHURD (2020), the provincial governments of Shandong, Jilin and Gansu invested 947.75 million CNY, 159.71 million CNY and 185.37 million CNY in RDST of 2019, respectively. It is obvious that farmers can also be potential contributors to financial access in RDST. However, depending on the estimation of the construction cost of existing CM of RDST, the average construction cost is roughly calculated of 5832 CNY per household with a 20-year service life of the RDST facility. According to our results on farmers' WTP, the expected payments from households account for 16.28% and 21.65% of the total cost. This conclusion may be referred to policies formulating regarding RDST payment mechanism. In addition, it also reflects the fact that the contributions of farmers or government neither can not cover the cost of CMP of RDST, and there is a significant funding deficit. Accordingly, in view of the actual situation, it is suggested that the financial investment at the national level should be effectively increased and establish relevant special funds. Since the expected value of farmers' WTP in three provinces varied significantly, it is also recommended that government should take into account the socio-economic factors and demographic factors of different regions to formulate relevant policies according to local conditions. Recently, a multitude of studies focused on influencing factors analysis of farm households' WTPP of RDST (Fu et al., 2018a; Liu and Feng, 2019; Su et al., 2020), as well as concentrating on farmers' WTP analysis of RDST without separating the provision phase and maintenance phase (Chen et al., 2017; Xie et al., 2018), but virtually few studies have measured WTP for CMP of RDST by applying econometric models in China.

The descriptive statistics analysis of this study revealed that only 40% of the farmers in the study area are currently accessing CM of RDST, while nearly 80% of the investigated farmers tend to adopt CM of RDST. This indicates that a minimum of 40% of the farmers in the study area expect to avail themselves of CM of RDST, which implies that in order to meet the requires of this portion of rural residents, about 55 billion CNY will need to be invested. In consideration of the fact that rural households may only be willing to pay for their own households, the total value (for 20 consecutive years) for this proportion of farmers is about 8.96 billion CNY. However, the governments of these three provinces invested a total of about 1.3 billion CNY in RDST in 2019 (MOHURD, 2020), which obviously reflects an enormous funding deficiency and intense pressure on government finances. If we assume that the annual investment amount of the government remains stable and rural households contribute at a rate of 16.28%, it will take 35.4 years to raise 55 billion CNY which is required for the demand of CMP of RDST in the three provinces. According to Ledyard (1995), if rural households were possible to contribute between 40% to 60%, the corresponding time for raising funds would be reduced to 16.9 to 25.4 years. Undoubtedly, farmers contribute significantly to CMP of RDST, while the government remains the tremendous source of funding. However, in reality, the process of improving rural living environment, especially RDST, will be relatively delayed if it only relies on the investments by government and farmers. Therefore, it is suggested that various funding sources should be introduced, especially for social organizations and enterprises.

2.3 Feasibility, contribution and influencing mechanism of rural residents' payment

Chapter 6 provided foundations for establishing a payment mechanism for rural residents regarding sustainable RDST. Currently, the average household size in rural China is 2.7 persons (National Bureau of Statistics of China, 2021), assuming that the per capita domestic sewage production is 70 L/day (Liu and Shen, 2014), the average household domestic sewage discharge is about 5.67 m3/month. Actually, the RDST maintenance cost in China is approximately 1.38 CNY/m3 to 3.02 CNY/m3 (Cheng and Jin, 2022; Guan and Li, 2020). Therefore, the payment level of rural residents in the study area may cover at least 47.55% of the domestic sewage treatment maintenance cost, and even could achieve full cost coverage and be profitable in some areas. This also firmly demonstrates the feasibility of establishing the payment mechanism for rural residents of sustainable RDST.

It is evident that the mediating effect of rural residents' cognition on diverse environmental regulations was verified. This also indicated that the partial impact of environmental regulations on rural residents' WTPP and WTP was achieved by influencing their cognition. In addition, it was further revealed that the existence of the influence mechanism of "environmental regulation - rural residents' cognition - WTPP and WTP" in rural residents' participation in RDST. Furthermore, based on the above analysis of the interaction effects of different environmental regulations, the existence of both substitutional and complementary relationships between them was identified. According to the results of this study, the combination of two environmental regulations is more effective and complementary or substitutive to each other, which further enhances rural residents' WTPP and WTP for sustainable RDST. However, excessive implementation of different types of environmental regulation may expose rural residents to stricter supervision, which may inhibit their WTPP and WTP in rural environmental management.

2.4 The contribution and effects of rural residents' WTP on LCC

Rural residents WTP plays an important role in the impact of CMP of RDST costs. In Chapter 5, the expected WTP proportion of rural residents for CMP of RDST with total respondents and truncated respondents was 16.28% (for 20 consecutive years), respectively. In Village W, for instance, the WTP for rural residents could be up to 1.17 million CNY, which might reduce the construction costs for the governments and public or private sectors. Simultaneously, the loan interest could be reduced accordingly by 101.23 thousand CNY, which could effectively reduce the cost of the construction phase of Village W RDST's PPP project, alleviate the financial pressure on both the government and the project company, and thus improve the efficiency of funding utilization.

In addition, in Chapter 6, the average payment levels for the total respondents were 8.14 CNY/month. Therefore, the following formula was applied to calculate the aggregate amount of rural residents' WTP for the entire life cycle.

$$AWTP = \sum_{n=1}^{N}(WTP * \frac{1}{(1+r)^n} * HN * 12) \quad (7\text{-}1)$$

where $AWTP$ represents the aggregate rural residents WTP for the entire life cycle (unit: CNY), where n denotes the nth year, WTP represents the average WTP of rural residents (unit: CNY/month), r denotes the discount rate, and HN represents the number of RDST project-served rural households.

Table 7-1 demonstrates the aggregate WTP of rural residents for different operational lifespan. As the contract term of the PPP project of RDST in Village W is 30 years, the project company may acquire additional revenue 729.77 thousand CNY for 30 years. In addition, the project company will hand over the RDST project to the government after 30 years of operation. If the project is properly operated and maintained and continues to operate for a further 20 years (50 years in total), the government will receive a revenue of 136.88 thousand CNY, which to a certain extent compensates for the government's financial investment.

Table 7-1 Aggregate WTP under different operational lifespan.

	Operational lifespan				
	10 years	20 years	30 years	40 years	50 years
AWTP (thousand CNY)	366.57	591.61	729.77	814.58	866.65

2.5 Mechanism expansion of multi-stakeholders' participation in RDST

RDST possesses a strong public interest and has low direct economic benefits, resulting in a weak financing capacity. Its financing channels are dominated by government funds, with insufficient participation by public or private sectors, and a single financing channel undoubtedly puts enormous pressure on the government payment. There has been a lot of literature conducted relevant research from the perspective of government and public or private sectors respectively, but most focused on aspects such as risk and responsibility sharing in PPP projects (El-Kholy and Akal, 2020; Lv et al., 2021; Chen et al., 2023). Although Li et al. (2020) evaluated public satisfaction with PPP wastewater treatment projects from a public perspective, they did not focus on the impact of public participation on government and public or private sectors participation. Previous research on co-operation frameworks for PPP projects have tended to exclude the public and only focused on government and public or private sectors. Yang et al. (2016) summarized the operational mechanism of urban wastewater treatment PPP projects, but this mechanism excluded urban residents. Although Zhang (2016) constructed a project implementation framework of government-public or private sectors-farmers' participation in the study of PPP model for agricultural infrastructure investment, the position of farmers as the main stakeholders was not reflected in this study, and they were only in the role of expressing the demand for the government and public or private sectors. Therefore, on the basis of analyzing the LCC of PPP projects for RDST, this study includes rural residents in the multi-stakeholder participation mechanism to fundamentally solve the problems of funding shortage and inefficient utilization. Firstly, redirect the current governments' funding for RDST facilities to develop a shared-funding scheme with public or private sectors, that is, implementing PPP projects, and clarifying the position of rural residents as stakeholders in PPP projects of RDST. Secondly, in the initial stage of the PPP project, rural residents pay for the construction and operation and maintenance costs according to their willingness, and gradually pay for the operation and maintenance costs according to the actual water consumption of rural residents in the subsequent stage. Finally, the relationship between governments and rural residents is explored, that is, governments should adopt guiding and incentive approaches towards rural residents. This study clarifies the payment path for rural residents based on the existing operational framework of the PPP model of RDST. This allows for enhanced profitability and risk mitigation, thereby attracting public or private sectors to participate in the RDST projects. The specific mechanism flowchart is shown in **Figure 7-1**.

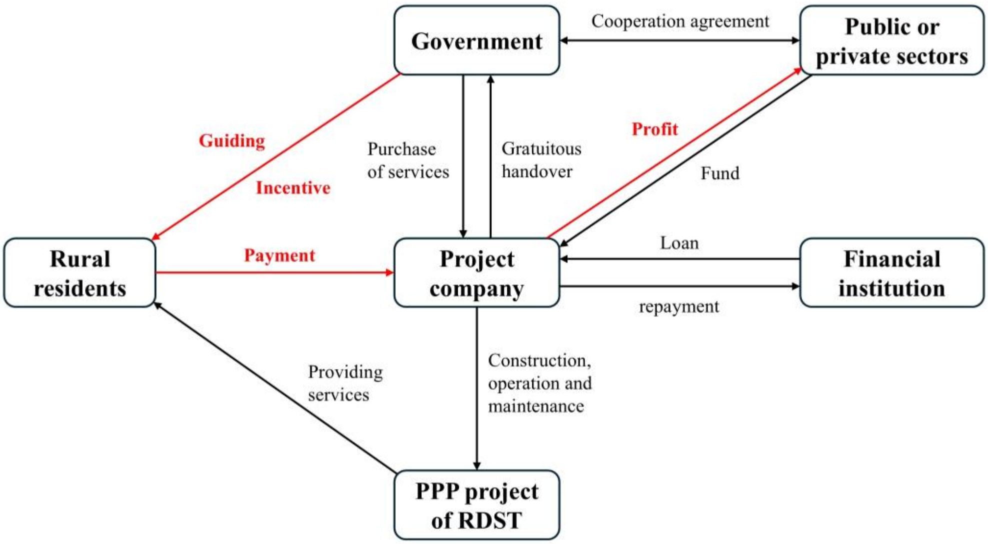

Figure 7-1 Mechanism expansion of multi-stakeholders' participation in RDST.

3. Policy implications

3.1 Enhance dissemination and increase rural residents' WTPP for RDST

Firstly, it is necessary to strengthen the external restraint mechanism, such as legislation and village regulations and other "hard constraints" to reduce farmers' pollution behavior. Secondly, it is recommend further raising the health awareness of rural residents, which would make them aware of the dangers of pollution to human health and contribute to the participation and willingness in environmental management. Thirdly, the propaganda approaches should also be broadened, a variety of propaganda methods should be promoted for various regions with heterogeneous rural residents. Besides traditional posters and brochures, new media platforms should also be promoted and introduced to diversify the propaganda about environmental protection and RDST.

3.2 Promote environmental regulation system to enhance the rural residents' WTP for sustainable RDST

Firstly, a payment mechanism for sustainable RDST should be gradually established for rural residents. If the payment is based on the actual consumption volume of water, it may exceed the affordability of rural residents and thus reduce their willingness, so it is suggested that in the initial stage, it should be based on the results of this study, which ranged from 8.14 CNY/month to 9.75 CNY/month as a reference standard. In the later stage, the charges could be raised gradually on the basis of the improvement of rural residents' cognition and increase of their income, until it is changed from monthly payment to charging according to the consumption volume of water. Secondly, the environmental regulation system for rural areas requires further improvement. In comparison with cities and towns, rural environmental management is relatively backward, the establishment of environmental regulations is still relatively imperfect, which might reduce the capacity and effectiveness of rural environmental management. Therefore, it is necessary to establish and improve rural environmental regulations based on the characteristics of rural areas. Thirdly, the government should emphasize the differences between various environmental regulations when formulating relevant policies and avoid the single implementation of binding regulation. Moreover, the combinations of diverse environmental regulations may contribute to improving rural residents' WTP and payment level for sustainable environmental management, but it should be noted that excessive environmental regulations may lead to the phenomenon of "policy failure".

3.3 Improve multi-stakeholders' participation mechanisms to fully realize RDST

Firstly, the responsibilities and obligations of the government, rural residents and public or private sectors in RDST should be clarified. Secondly, government departments should dominate the RDST and establish a comprehensive guiding and incentive mechanism for rural residents and public or private sectors. Thirdly, rural residents should actively participate in RDST, completing the transition from "want me to treat" to "I want to treat". Finally, the PPP model for RDST should be optimized to guarantee the profitability and risk mitigation ability of public or private sectors, thereby attracting and guiding public or private sectors institutions to assume social responsibility and jointly participate in RDST.

4. Limitations

This thesis has several inevitable limitations. Firstly, this thesis exclusively employs the LCCA method to evaluate the economic viability of PPP projects in RDST, without incorporating the consideration of environmental benefits. To achieve a more comprehensive understanding of the multifaceted impacts of RDST projects, it is recommended that future research adopts an integrated approach that combines LCA with LCCA. This dual-method approach would not only provide a thorough economic assessment but also account for environmental impacts, thereby facilitating a more holistic evaluation of RDST projects. Such an integrated framework would ensure that both economic and environmental dimensions are adequately addressed, leading to more informed decision-making and sustainable project outcomes.

Secondly, there is inevitably bias in adopting CVM, because respondents may, for some reason, deliberately exaggerate or underestimate their WTP. In this study, respondents might have a psychological tendency to ‘free-riding’, thus underestimating their WTP. Mitchell and Carson (1989) pointed out that due to the bias of the CVM, the sample size should be larger than the normal statistical threshold. They believe that a minimum sample size of 600 would ensure that the estimated WTP is within 15% error of the true WTP. Therefore, in future studies, it is recommended that a larger sample size should be selected to reduce errors.

Thirdly, utilizing open-ended questions to elicit rural residents’ WTP is typically not the most appropriate methodological approach. However, due to the paucity of literature on rural residents’ WTP for RDST, and considering the variations in economic development levels and geographic locations across different regions, this study employs open-ended questions as an initial exploratory tool in the study area. Consequently, it is recommended that future research incorporates a broader range of elicitation methods to enhance the robustness and reliability of the findings. Employing diverse elicitation techniques in subsequent studies will provide a more nuanced understanding of rural residents’ WTP and ensure the generalizability of results across different contexts and regions.

Fourthly, the occurrence of zero responses in questionnaire surveys is an inevitable phenomenon. However, the current questionnaire does not include items that probe the underlying reasons for zero payment responses when participants indicate a negative WTP for RDST. To address this limitation, future research should aim to investigate the factors contributing to zero payment responses. By incorporating questions that elucidate the motivations behind respondents' unwillingness to pay, subsequent studies can achieve a more comprehensive and in-depth understanding of the barriers to financial support for RDST projects. This approach will enhance the richness of the data collected and provide valuable insights for the development of more effective strategies to increase public investment in sustainable RDST projects.

Lastly, the data analyzed in this study are exclusively collected from China, which may limit the generalizability of the results to other developing countries. To address this limitation, it is recommended that future research be conducted in a variety of developing countries with diverse conditions and socio-economic characteristics.

Such comparative studies would enhance the robustness and applicability of the findings, providing a more comprehensive understanding of the factors influencing WTP for RDST projects across different contexts. Expanding the geographic scope of research will contribute to the development of more universally relevant insights and policies, thereby enriching the existing literature in this research field.

5. Perspectives of further research

This thesis initially explores an expanded participatory framework for multi-stakeholders in RDST from the perspective of rural residents' WTP. Despite the initial achievements of this thesis, future research could be conducted in the following three aspects to further enrich the achievements in RDST.

Firstly, this thesis preliminarily explores the WTP of rural residents, and the corresponding influencing factors. In light of the fact that most of the current worldwide sewage treatment fees are included in the tap water fees, the same approach applies to urban residents in China. In addition, rural residents in most parts of China still benefit from free tap water. Therefore, future research could further explore rural residents' WTP for tap water and their choice preferences for whether sewage treatment fees are included in the tap water fees.

Secondly, the implementation of policies usually leads to lagging effects. Therefore, future research could focus on the lagging effect of environmental regulation on rural residents and explore the most appropriate timing for environmental regulation implementation, thus further improving the research related to policy formulation.

Lastly, it is valuable to assess the economic and environmental value of rural domestic sewage reuse. Centralized treatment of rural domestic sewage for irrigation would create economic and environmental value, which could reduce financial pressure on governments and increase the profitability of the public or private sectors. In addition, rural domestic sewage reuse might also contribute to the reduction of carbon emissions, thus realizing its environmental value.

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Appendix

Field Survey Questionnaire for Rural Residents

1. Basic situation

1.1 Respondent’s gender (1=male, 0=female)

1.2 Respondent’s age

1.3 Respondent's education level (1=lower than primary school, 2=primary school, 3= junior school, 4=high school, 5=college and above)

1.4 Whether the respondent is the village cadre? (1=yes, 0=no)

1.5 How many members in respondent family?

1.6 What is the annual household income of the respondent?

1.7 Whether the respondent already use the centralized mode of rural domestic sewage treatment? (1=yes, 0=no)

1.8 Whether the respondent already have centralization of water supply? (1=yes, 0=no)

1.9 What is the distance from the respondent's living location to the town government?

2. Respondent’s perception

2.1 Do you think it is necessary to treat domestic sewage? (1=strongly disagree, 2=somewhat disagree, 3=neither agree nor disagree, 4=somewhat agree, 5=strongly agree)

2.2 Do you think the improperly treated domestic sewage affects the rural environment? (1=strongly disagree, 2=somewhat disagree, 3=neither agree nor disagree, 4=somewhat agree, 5=strongly agree)

2.3 Do you think the improper treatment of domestic sewage affects the health of villagers? (1=strongly disagree, 2=somewhat disagree, 3=neither agree nor disagree, 4=somewhat agree, 5=strongly agree)

3. Government Intervention and environmental regulation

3.1 Does the government ever propagate RDST? (1=yes, 0=no)

3.2 Does the government or village propagate the benefits of domestic sewage treatment? (1=yes, 0=no)

3.3 Does the government or village have material or verbal incentive measures to encourage rural residents to properly dispose of domestic sewage? (1=yes, 0=no)

3.4 Does the government or village have any material or verbal penalties for the arbitrary discharge of domestic sewage by rural residents? (1=yes, 0=no)

4. Respondent' willingness

4.1 Whether the respondent willing to participate in centralized mode provision of rural domestic sewage treatment? (1=yes, 0=no)

4.2 How much does the respondent willing to pay per year (for a total of 20 years)?

4.3 Whether the respondent willing to participate in sustainable RDST? (1=yes, 0=no)

4.4 How much does the respondent willing to pay per month?