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Mechanism on Sustainable Agricultural Plastic Waste Management in China-- Based on Cost-benefit Analysis and Public Participation

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Mécanisme de gestion durable des déchets plastiques agricoles en Chine -- Basé sur l'analyse coûts-avantages et la participation du public

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Abstract

Agricultural plastics are indispensable in agricultural production. Of them, mulch film plays a particularly crucial role. The application of mulch film has significantly improved agricultural operation conditions and increased crop yields by 20-50%, making substantial contributions to ensuring food security and enhancing farmers' incomes. However, due to the difficulties in recovery and high recycling costs, agricultural white pollution has become a significant issue. This adversely affects crop yield and quality and results in environmental, economic, and social problems such as landscape pollution and microplastic contamination, posing severe threats to the environment, food safety, and human health. As a great agricultural country, China consumes the largest amount of agricultural plastics globally. Simultaneously, China faces the most severe agricultural white pollution in the world. To promote sustainable agriculture development, the Chinese government has increasingly prioritized the issue of agricultural plastic waste (APW). In recent years, agricultural plastic waste management (APWM) has been designated an essential task in agriculture and rural development. Nonetheless, the current management is still plagued by issues such as undetermined about the cost-effectiveness of different APWM measures, unreliable management funds, and the uncertain of the multi-stakeholder cooperation mechanism.

In response, the research follows the logical framework of "problem diagnosis-comprehensive performance evaluation-sustainable management mechanism design" to explore the sustainable mechanism for APWM in China. Specifically, the research primarily focuses on two research topics and three research objectives, addressing four research questions. The first topic emphasizes the comprehensive performance evaluation of mulch film management. Applying the cost-benefit analysis, the study focuses on the first research objective, comprehensive performance analysis of two environmentally friendly mulch film management measures currently promoted in China: the applications of thicker mulch film and biodegradable mulch film. By defining the boundaries of mulch film procurement, utilization, and treatment, the model thoroughly calculates the costs and benefits incurred during the management process, thereby addressing the question, "What is the comprehensive performance of APWM?" The second topic lies in developing a sustainable APWM mechanism from the public participation perspective. By incorporating the principles of multi-entity corporations in environmental pollution control, the study integrates the public, a crucial stakeholder, into the management and constructs a sustainable management mechanism. In this regard, the sustainable APWM scheme based on public participation perspective was explored firstly. Initially, respondents' payment willingness for APWM was statistically described to answer the question, "Is it feasible of the public payment scheme for APWM?" Further, the extended theory of planned behavior (TPB) model was applied to clarify respondents' payment decision pathways and answer the question, "What are the psychological decision-making pathways of the public's payment decision?" Secondly, a randomized controlled trial (RCT) was designed to investigate the effectiveness of the informational intervention in enhancing the

public payment scheme. Difference-in-difference (DID) model was applied to examine the changes in respondents' willingness to pay (WTP) before and after the intervention to answer the question of "How to promote the public payment scheme for APWM evolve from idea to reality?"

The following conclusions have been drawn through the above research: Firstly, the current government policy to promote environmentally friendly mulch film management measures are lack of rationality. For thicker mulch film, it is cost-effective and has great potential to be promoted. However, it could have been adopted spontaneously even without financial support and the current government subsidy standard for it results in a certain degree of inefficient allocation of government financial resources. Besides, the inadequacy of its promotion rests in the policy makers' lack of recognition for waste treatment, which is a weak point but not adequately supported by the current subsidies. For biodegradable mulch film, its further development requires continuous external funding support to maintain its application due to its economic inefficiency. Nevertheless, the current subsidy standard exceeds what it requires. In addition, deficiencies in the product's performance restrict its universal application. Secondly, the public payment scheme for APWM is feasible to be a promising supplement to the existing APWM scheme. More than 2/5 of the respondents are willing to pay for APWM, and the average WTP is CNY 482.6 per household year. Further, the driving pathways of their payment decisions are clarified under the extended TPB model. Attitude (AT), subjective norm (SN), perceived behavior control (PBC), environmental cognition (EC), and environmental emotion (EE) have significant positive influences on payment intention (INT) towards APWM, with AT exerting the greatest impact, followed by SN and PBC, and EC and EE showing minimal direct effects. Thirdly, information intervention strategy effectively enhances the public payment scheme for APWM. The public's WTP for APWM is generally malleable, providing information targeting normative beliefs and control beliefs can significantly increase the WTP by CNY 307.2 and CNY 400.5, respectively.

On this basis, the research proposes the following recommendations to promote APWM in China: Firstly, the government should optimize the subsidy standards and dimensions for different environmentally friendly mulch film management measures according to their comprehensive cost-benefit performance. Besides, it is imperative to raise farmers' comprehensive knowledge of APWM and stimulate enterprises to reduce the costs and increase the efficiency of different mulch films to promote the management more effectively. Secondly, it is feasible to enhance APWM by initiating the public payment scheme. A multi-pronged initiatives including strengthening the public's comprehensive evaluation of APWM and environmental cognition, reinforcing subjective norms of paying for APWM, establishing the payment platform to open up channels for the public to pay, and nurturing the public's environmental emotions are beneficial for the public payment scheme. Thirdly, information strategy could be leveraged policymakers to promote the public payment scheme. It is imperative to prioritize strengthening relevant norm and constructing public payment mechanism. Information regarding reinforcing norm and control beliefs should be highlighted to enable the information strategy to have a better effect in enhancing the public payment scheme for APWM.

Résumé

Les plastiques agricoles sont indispensables à la production agricole. Parmi eux, le film de paillage joue un rôle particulièrement crucial. L'application du film de paillage a considérablement amélioré les conditions d'exploitation agricole et augmenté les rendements des cultures de 20 à 50 %, contribuant de manière significative à assurer la sécurité alimentaire et à améliorer les revenus des agriculteurs. Cependant, en raison des difficultés de récupération et des coûts de recyclage élevés, les déchets de film de paillage sont devenus un problème important. Cela affecte négativement le rendement et la qualité des cultures et entraîne des problèmes environnementaux, économiques et sociaux tels que la pollution des paysages et la contamination par les microplastiques, ce qui constitue de graves menaces pour l'environnement, la sécurité alimentaire et la santé humaine. En tant que grand pays agricole, la Chine consomme la plus grande quantité de plastiques agricoles au monde. Parallèlement, la Chine est confrontée à la pollution blanche agricole la plus sévère au monde. Pour promouvoir un développement agricole durable, le gouvernement chinois a de plus en plus priorisé la question des déchets plastiques agricoles (DPA). Ces dernières années, la gestion des déchets plastiques agricoles (GDPA) a été désignée comme une tâche essentielle dans l'agriculture et le développement rural. Néanmoins, la direction actuelle est en proie à des problèmes tels que l'incertitude quant à la rentabilité des différentes mesures de gestion, le manque de fiabilité des fonds de gestion et l'absence de mécanismes de gestion durables.

En réponse, La recherche suit le cadre logique de « diagnostic du problème - évaluation de la performance globale - conception de mécanismes de gestion durable » pour explorer les mécanismes durables de la GDPA en Chine. Plus précisément, la recherche se concentre principalement sur deux thèmes de recherche et trois objectifs de recherche, abordant quatre questions de recherche. Le premier thème met l'accent sur l'évaluation de la performance globale de la gestion du film de paillage. En utilisant le modèle d'analyse coût-bénéfice, l'étude se concentre sur le premier objectif de recherche, à savoir l'analyse de la performance globale de deux mesures de gestion du film de paillage respectueuses de l'environnement actuellement promues en Chine : les applications de films de paillage plus épais et de films de paillage biodégradables. En définissant les limites de l'achat, de l'utilisation et du traitement du film de paillage, le modèle calcule minutieusement les coûts et les avantages encourus lors du processus de gestion, répondant ainsi à la question : « Quelle est la performance économique de la GDPA ? ». Le deuxième thème concerne le développement d'un mécanisme de GDPA durable sous l'angle de la participation publique. En considérant l'ensemble des parties prenantes selon une approche multi acteurs, l'étude intègre les agriculteurs en tant qu'acteurs clés et construit un mécanisme de gestion durable. À cet égard, le schéma de GDPA durable basé sur la perspective de la participation publique a d'abord été exploré. Tout d'abord, la volonté de paiement des répondants pour la GDPA a été décrite statistiquement pour répondre à la question : « Le schéma de paiement public pour la GDPA est-il faisable ? » Ensuite, , la théorie du comportement planifié étendue a été

appliquée pour clarifier les trajectoires décisionnelles des répondants en matière de paiement et répondre à la question : « Quelles sont les trajectoires psychologiques des décisions de paiement du public ? ». Deuxièmement, un essai aléatoire contrôlé a été conçu pour étudier l'efficacité de l'intervention informative dans l'amélioration du schéma de paiement public. Le modèle des doubles différences a été utilisé pour examiner les changements dans la volonté de payer des répondants avant et après l'intervention, afin de répondre à la question : « Comment promouvoir le schéma de paiement public pour la GDPA, de l'idée à la réalité ? »

Les conclusions suivantes ont été tirées de cette recherche : Premièrement, la politique gouvernementale actuelle visant à promouvoir les mesures de gestion du film de paillage respectueuses de l'environnement manque de rationalité. Pour le film de paillage plus épais, il est rentable et présente un grand potentiel de promotion. Il pourrait donc être adopté spontanément même sanssoutien financier. Le taux de subvention gouvernementale actuel entraîne une certaine inefficacité dans l'allocation des ressources financières de l'État. De plus, l'insuffisance de sa promotion réside dans le manque de reconnaissance du traitement des déchets, qui est un point faible mais non suffisamment soutenu par les subventions actuelles. Quant au film de paillage biodégradable, son développement futur nécessite un soutien financier externe stabilisé en raison de son inefficacité économique. Néanmoins, la norme de subvention actuelle dépasse ses besoins. En outre, les lacunes dans la performance du produit limitent son application universelle. Deuxièmement, le schéma de paiement public pour la GDPA est faisable et pourrait constituer un complément prometteur au schéma de GDPA existant. Plus de 2/5 des répondants sont prêts à payer pour la GDPA, et le consentement à payer moyen est de 482,6 CNY par foyer et par an. En outre, les trajectoires décisionnelles de leur paiement ont été clarifiées dans le cadre du modèle de la théorie élargie du comportement planifié. L'attitude (AT), la norme subjective (SN), le contrôle perçu du comportement (CPC), la connaissance environnementale (EC) et l'émotion environnementale (EE) ont des influences positives significatives sur l'intention de paiement (INT) envers la GDPA, AT exerçant le plus grand impact, suivi de SN et CPC, tandis que EC et EE montrent des effets directs minimes. Troisièmement, la stratégie d'intervention informative améliore efficacement le schéma de paiement public pour la GDPA. Le consentement à payer du public pour la GDPA est généralement malléable ; fournir des informations ciblant les croyances normatives et les croyances de contrôle peut augmenter significativement la volonté de payer de 307,2 CNY et de 400,5 CNY, respectivement.

Sur cette base, la recherche propose les recommandations suivantes pour promouvoir la GDPA en Chine : Premièrement, le gouvernement devrait optimiser les normes et le dimensionnement des subventions pour les différentes mesures de gestion du film de paillage respectueuses de l'environnement en fonction de leur performance globale coût-bénéfice. En outre, il est impératif d'accroître les connaissances des agriculteurs sur la GDPA et d'explorer des stratégies visant à réduire les coûts et à augmenter l'efficacité des différents films de paillage pour promouvoir la gestion plus efficacement. Deuxièmement, il est faisable d'améliorer la GDPA en lançant le schéma de paiement public. Les initiatives à volets multiples visant à renforcer l'évaluation globale de la GDPA et la connaissance environnementale du public, à renforcer les normes subjectives de paiement pour la GDPA, à établir une plateforme de paiement pour ouvrir des canaux permettant au public de payer, et à cultiver les émotions environnementales du public, sont bénéfiques pour le schéma de paiement public. Troisièmement, une stratégie d'information pourrait être utilisée pour promouvoir le schéma de paiement public. Il est impératif de donner la priorité au renforcement des normes pertinentes et à la construction de mécanismes de paiement public. Les informations concernant le renforcement des croyances normatives et des croyances de contrôle devraient être mises en avant pour permettre à la stratégie d'avoir un meilleur effet sur l'amélioration du schéma de paiement public pour la GDPA.

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Time has flown by peacefully. The four-year journey as a Ph.D. student has not only been a pivotal experience for academic pursuit but also a profound period of personal growth and discovery. As I bring this dissertation to completion, I wish to express my deepest gratitude to everyone who has supported and encouraged me throughout this journey.

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Aibo HAO

11/2024 in Gembloux, Belgium

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List of abbreviations

APW: agricultural plastic waste
APWM: agricultural plastic pollution management
TPB: theory of planned behavior
DID: difference-in-difference
EPR: extended producer responsibility
ToC: theory of change
WTP: willingness to pay
AT: attitude
SN: subjective norm
PBC: perceived behavior control
EC: environmental cognition
EE: environmental emotion
INT: intention
SEM: structural equation model
CR: composition reliability
AVE: average variance extracted
HTMT: Heterotrait-Monotrait Ratio
CMV: common method variance
VIF: variance inflation factor
NPV: net present value
BCR: benefit-cost ratio
PV: present value
SDGs: Sustainable Development Goals
COM-B: Capability-Opportunity-Motivation-Behavior
BBBF: Behavioral Barrier-Based Framework
KAP: knowledge-attitude-practice
EKC: Environmental Kuznets Curve
RCT: randomized controlled trial
NPV: net present value
BCR: benefit-cost ratio
GHG: greenhouse gas
VAT: value added tax
LLDPE: linear low-density polyethylene
DCF: donation-based crowdfunding
LCA: life cycle assessment

1

Chapter I: Status of mulch film application, pollution and management in China

Adapt from:

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1. Status of mulch film utilization in China

In the 1950s, concurrent with the advent of the plastics industry, plastic films first emerged within the realm of scientific research. By the early 1960s, mulch films began to be utilized in vegetable production, and subsequently, the film mulching technology gradually proliferated across countries such as Japan and those in Europe and North America (Lv et al. 2007). It is estimated that currently, the annual production of agricultural plastics is at least 12.5 million tons globally (FAO 2021). The application of plastics in agriculture encompasses a variety of materials and uses, including mulch films for soil, tunnels and greenhouses, nets for crop protection and shading, silage films, plastic irrigation systems, and containers for packaging (Table 1-1). Among the diversified application scenarios, mulch film stands out as one of the most critical applications, accounting for 28.8% of the total agricultural plastic usage (Orzolek 2017).

Table 1-1 Main agricultural plastics application

protected films	nets	packaging
greenhouses	anti-hail	fertilizer sacks
mulch film	anti-bird	ago-chemical cans/bottles
nursery films	wind-breaking	containers
directive covering	shading	tanks for liquid storage
covering vineyards/orchards	nets for olives/nuts harvesting	crates
tunnels		
piping, irrigation/drainage	**others**	
water reservoir	silage films	
channel lining	fumigation films	
irrigation tapes and pipes	bale twines and wraps	
micro-irrigation	nursery pots	
drippers	strings and ropes	

Source: Summarized by the author.

As a major agricultural country, China currently stands as the world's largest producer and consumer of agricultural plastics, particularly mulch film. Since the 1970s, China has experimented with the application of mulch film on crops such as vegetables and cotton in selected regions. Following small-scale cultivation trials, China imported a set of film mulching technologies from Japan in 1978, which included operational methods, mulch film products, and mulching machinery. Subsequently, the significance of film mulching technology in agricultural production has been increasingly recognized, leading to its progressively widespread adoption across vast farmland (Gao et al. 2019). Different from the practice in developed countries where mulch film is mainly adopted for high-value crops such as vegetables and fruits, it is extensively applied to a wide range of cash and field crops in China. In addition, due to differences in its application scenarios, the thickness of widely used mulch film in China is much thinner than that in developed countries. In sum, China has developed a mulch film cultivation system with distinct Chinese characteristics.

Over the past fifty years, film mulching technology has been vigorously promoted in China, with both the mulching area and the usage amount showing a sustained growth and then stabilized trend (Figure 1-1). In 1996, the film mulching area reached 7.4 million ha. By 2006, the usage amount of mulch film had further increased and surpassed 1 million tons. In 2016, the film mulching area had expanded to 18.4 million ha, more than three times that in 1993. And the usage amount of mulch film reached 1.3 million tons, about four times that in 1992. The film mulching area accounts for 10.8% of the total sown area in China (NBSC 2022). Since 2016, the application of mulch film has largely stabilized. This trend primarily reflects the saturation of mulch film use across the country. Additionally, with the escalating challenges posed by agricultural plastics residuals, the Chinese government has placed greater emphasis on mulch film waste control, introducing a series of regulatory measures. These policies encourage farmers to adopt scientific application practices and reduce unnecessary mulch film coverage. Consequently, the growth trend of both the usage amount and the mulching area has plateaued, with even a modest decline observed. Nevertheless, the usage amount of mulch film in China constitutes three-quarters of the global total currently, and the film mulching area in China makes up more than 90% of the total mulching area in the world (FAO 2021).

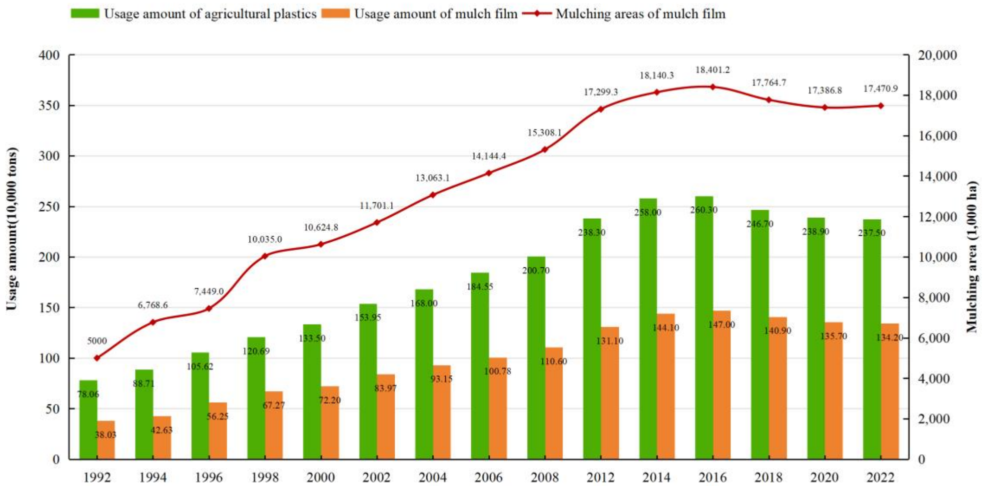

Figure 1-1 Agricultural plastics utilization in China: 1992-2022. Data source: China Rural Statistical Yearbook.

Regarding the regional characteristics of mulch film application, it is most prevalent in the corn and cotton planting areas of Northwest China, the peanut planting areas of Northeast China, the peanut and cotton planting areas of North China, the tobacco planting areas of Southwest China, and all major vegetable planting areas throughout the country (Figure 1-2, Figure 1-3). Specifically, Shandong and Xinjiang, as primary vegetable and cotton planting bases respectively, are the two leading provinces in terms of mulch film application. In terms of mulch film usage from 2000 to 2022, Xinjiang and Shandong stand out with significantly higher usage amount and mulching areas compared to other provinces, collectively accounting for approximately 30% of the national total. In the northern inland areas, including Xinjiang, Gansu, and Inner Mongolia, represents the areas with the highest intensity of mulch film application in China. The proportion of film mulching farmland here exceeds 20%, with some areas reaching as high as 57.7%, far surpassing the national average of 10.3%. Additionally, provinces such as Henan, Hebei, Sichuan, and Yunnan also exhibit substantial mulch film usage amount and mulching areas.

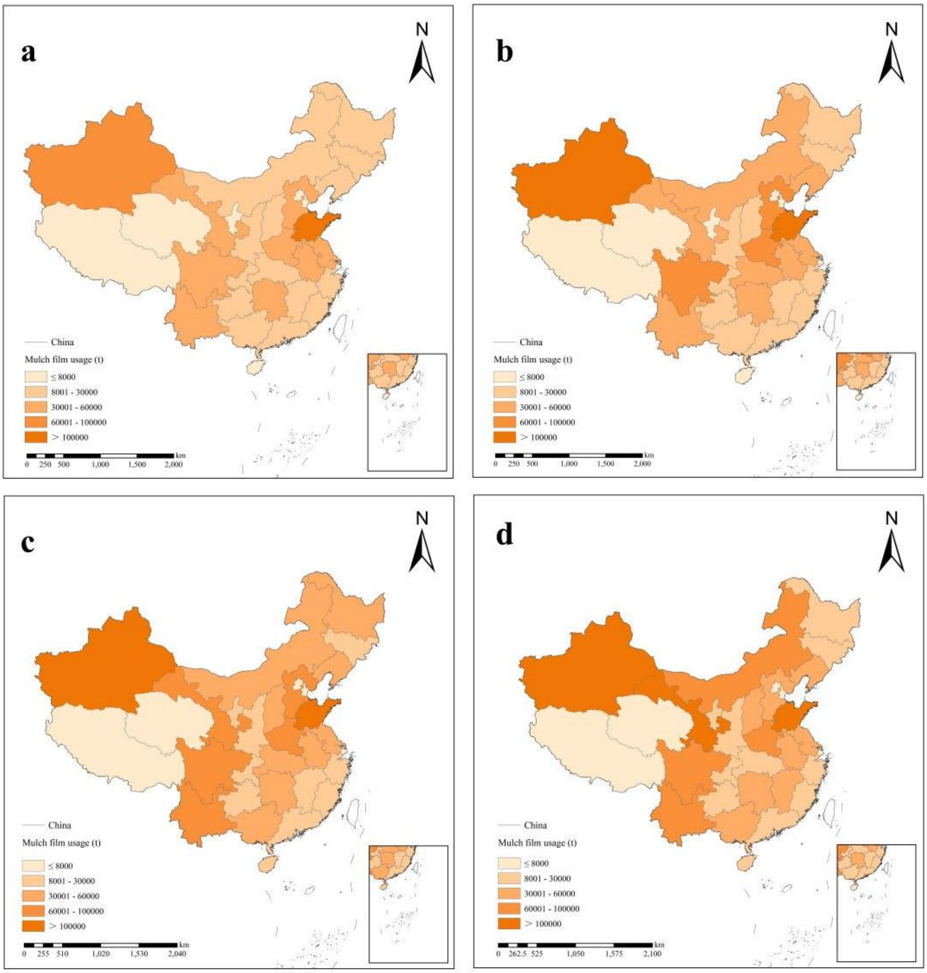

Figure 1-2 The average usage of mulch film in different provinces: 2001-2005 (a), 2006-2010 (b), 2011-2015 (c), 2016-2022 (d). Data source: Statistics of China Rural Statistical Yearbook.

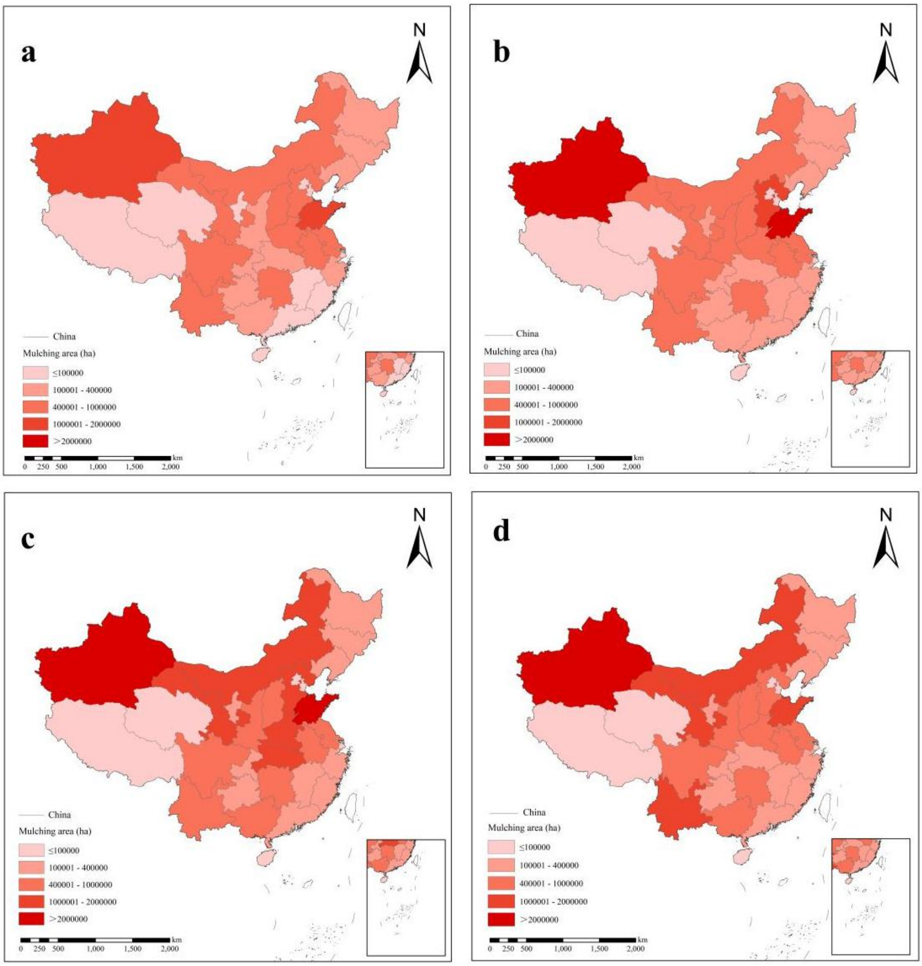

Figure 1-3 The average mulching area in different provinces: 2001-2005 (a), 2006-2010 (b), 2011-2015 (c), 2016-2022 (d). Data source: Statistics of China Rural Statistical Yearbook.

The types of mulching crops have undergone considerable changes in the past fifty years since the introduction of film mulching technology. Initially, mulch film cultivation technology was primarily applied to high-value crops such as vegetables and flowers. With extensive theoretical research and practical application, the technology has rapidly advanced and expanded to a diverse array of cash crops, including peanuts, tobacco, and cotton, as well as staple crops such as corn, wheat, and rice. In regions characterized by cold climates, aridity and semi-aridity, such as Xinjiang, Shandong, Shanxi, Inner Mongolia, Shaanxi, and Gansu, film mulching technology has been widely adopted across most crops and continues to exhibit a growth trend (Figure 1-4).

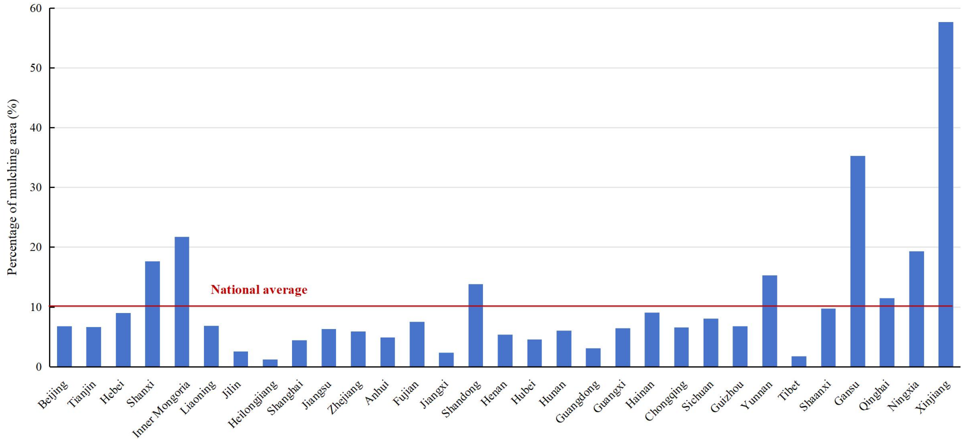

Figure 1-4 Percentage of mulching area by Provinces in China: 2022. Data source: Statistics of China Rural Statistical Yearbook.

2. The roles of mulch film application and its impacts

The contributions of mulch film to agricultural production are primarily manifested in thermal insulation and water conservation, herbicide reduction, crop yield and quality enhancement, and cultivation area expansion. Firstly, mulch film significantly mitigates the constraints of low temperatures and water scarcity on agricultural production. By reducing soil surface evaporation, impeding heat exchange, and increasing net radiation, mulch film effectively enhances soil warming and insulation (John and Jifon 2004; Jiang et al. 2018). Its impermeable nature allows rainwater to collect on the ridges and be distributed into the furrows, thereby converting the rainwater into effective precipitation (Fan et al. 2016; Zhang et al. 2022). Additionally, mulch film can block water vapor, thus effectively reducing soil moisture evaporation and achieving superior moisture retention(Li et al. 2014; Lin et al. 2015). Secondly, due to its mechanical barrier and light transmission reduction properties, mulch film can effectively suppress weed growth, thereby reducing the need for herbicides. This is especially true for black mulch film, which has a light transmittance of less than 10%, greatly inhibiting the photosynthesis of weeds beneath the mulch and thus providing optimal weed control (Zhang et al. 2017). Thirdly, the benefits of soil warming, moisture retention, and weed suppression provided by mulch film greatly improve the micro-ecological environment for crop growth. The barrier effect of mulch film also prevents nutrient volatilization and leaching caused by rainfall or irrigation, thereby maintaining soil fertility (Subedi et al. 1998; Chakraborty et al. 2008; Vial et al. 2015). These improvements create a more favorable environment for crops, leading to enhanced yield and quality (Shi et al. 2001; Zhu et al. 2015; Lu et al. 2016). Fourthly, mulch film alleviates the limitations imposed by insufficient accumulated temperature and short frost-free periods on agricultural production, particularly expanding the planting range of thermophilic crops such as grains and vegetables (Liu et al. 2005). Film mulching can extend the suitable planting zones for some thermophilic crops northward by 2-5 degrees of latitude and increase the planting altitude by 500-1,000 meters (Yan et al. 2014).

Owing to the aforementioned positive impacts of mulch film on agricultural production, the technology has significantly enhanced crop yield by 45.5% averagely (Sun et al. 2020). The resultant economic benefits from this increased yield amount to an impressive CNY 120 - 140 billion annually in China (Yan et al. 2021). Mulch film has substantially contributed to securing food supply and boosting farmers' incomes, leading to the mulch film application being hailed as "white revolution."

However, every coin has two sides. With the large-scale promotion and application of mulch film in China, a large amount of mulch film residues inevitably remain in the farmland. Notably, the continuous application and the practice of "emphasizing the utilization while neglecting management" deteriorate the status. In the vast rural areas of China, loose mulch film residues are randomly abandoned in farmland and natural environment, which causes severe "white pollution". What is worse, due to the characteristics of long degradation cycle, airtight and watertight, mulch film residues will make a great negative effect on soil once the amount of residues in the farmland exceeds natural capacity (Li et al. 2019). It is no doubt to affect the normal crop growth. In addition, mulch film residues may enter the breeding system along with the straw and feed, which will kill livestock if eaten by mistake in severe cases (Yan et al. 2014). Proper disposal of the mulch film waste has become a realistic and urgent issue.

According to the survey conducted by the former Ministry of Agriculture in the early 1990s across 17 provinces and municipalities, all film mulching farmland exhibited varying degrees of mulch film residues, with the residual amount accumulating over the years of application (He et al. 2009). The First National Pollution Source Census (2007) indicated that mulch film residues in planting areas was 121,000 tons (MOEE et al. 2010), accounting for 11.5% of the total mulch film application in the current year (NBSC 2023). The Second National Pollution Source Census (2017) revealed that the average mulch film residues in surveyed farmlands reached 63.5 kg/ha (MOEE et al. 2020). The most severe residual area was the cotton-planting farmlands of the northwestern inland area, where the average mulch film residues was up to 200 kg/ha (Yan et al. 2014a). The regional characteristics of mulch film residues are consistent with the application, namely, a decreasing trend from north to south and from west to east (Yan et al. 2014).

Due to their characteristics of being non-degradable, impermeable to air and water, and containing unavoidable additives, mulch film residues accumulate in the soil, leading to a series of environmental, economic, and social issues. These issues include visual pollution, agricultural ecosystem degradation, soil and water contamination, harmful substances release, farmland degradation, and crop yield and quality reductions (Kong et al. 2012; Briassoulis et al. 2013; Magdouli et al. 2013; Wang et al. 2013; Zhai et al. 2024). Additionally, mulch film residues could release microplastics into the soil through mechanical abrasion and photodegradation (Zhou et al. 2021). Due to their diminutive size, microplastics can be ingested by animals and bioaccumulate within their bodies, subsequently entering biological systems through the food chain. This poses potential threats to human health and well-being (Li et al. 2016; Horton et al. 2017; de Souza Machado et al. 2018; Prata et al. 2020; Ya et al. 2021; Leslie et al. 2022; Barceló et al. 2023). Increasing evidence indicates that agricultural plastic waste (APW) is damaging ecosystems and, in the long term, adversely affecting agricultural production, food security, food safety, and nutrition. Thus, the challenge of how to utilize mulch film scientifically and reasonably, to maximize their benefits in agricultural production while preventing soil pollution, has become a pressing issue that requires urgent resolution.

While agricultural plastic waste management (APWM) is indeed a global issue, China confronts unique challenges. To begin with, the extensive and widespread application of mulch film in China complicate APWM efforts. China is the largest consumer of agricultural plastics in the world, accounting for nearly 50% of global consumption annually (FAO 2021). Specifically, mulch film, which constitutes half of the total agricultural plastic usage in China and almost three-quarters of mulch film usage globally (FAO 2021), presents more significant recycling challenges than other kinds of agricultural plastics due to its non-point characteristics. This complexity is exacerbated in the vast northwestern, northeastern, and northern areas of China, where mulch film is extensively utilized not only for economic crops and vegetables but also for field crops, thereby greatly increasing the complexity of mulch film recycling. Second, Chinese farmers commonly use thin mulch films with low mechanical strength for their low price, making it difficult to collect after use. Since 1992, China has adhered to a national standard of 0.008 mm thickness for mulch film. In 2017, China introduced a new national standard requiring the mulch film's thickness to be no less than 0.010 mm (GB 13735-2017 2021). Nevertheless, this thickness is still significantly lower than the minimum thickness of 0.020-0.025 mm in other major mulch film application countries such as the United States, the European Union, and Japan (Hu et al. 2019). Generally, after a usage period of several months to a year, the mechanical strength of mulch film deteriorates significantly, complicating its collection and processing. The thickness of mulch film has a substantial impact on the recyclability of mulch film, with greater thickness resulting in better collectability and processability (Xiong et al. 2023).

3. Overview of mulch film management

3.1 Mulch film management in developed countries

3.1.1 Mulch film management in Europe countries

In Europe, the annual consumption of agricultural plastics reaches approximately 722,000 tons, predominantly silage films and greenhouse films, with mulch films constituting a smaller share of around 12.2% (EU 2021). The annual mulching area in Europe spans approximately 373,000 ha, primarily across Spain, Italy, Germany, and France, where it is mainly applied to vegetable and fruit cultivation (EU 2021). The standard for mulch film of European Union is the Thermoplastic Recyclable Film for Use in Agriculture and Horticulture (EN 13655-2018), which is a non-mandatory guideline (European Committee for Standardization 2018). This standard specifies a minimum thickness of 0.025 mm for mulch films.

European countries have implemented APWM systems primarily based on the extended producer responsibility (EPR) framework (Yan et al. 2024), effectively establishing a market-driven and economically efficient recycling system for APW. The EPR approach manifests in several distinct forms: producer-funded schemes, whereby producers either contribute to a designated fund or pay a treatment fee; consumer-oriented models in which users bear end-of-life treatment costs, such as through deposit-refund systems; and trade-in schemes that encourage the exchange of old products for new ones (Yan et al. 2024). While the EPR mechanism for APWM vary slightly among European countries, the core principles remain similar across different national implementations.

France

The French organization A.D.I.VALOR (**A**griculteurs, **D**istributeurs, **I**ndustriels pour la **Valor**isation des Dechets Agricoles), initiated in 2001, is a voluntary nationwide alliance focused on agricultural waste recycling, setting a benchmark in agricultural waste management across Europe (Figure 1-5, Figure 1-6) (https://www.adivalor.fr/). Jointly operated by ten associations representing industrial enterprises, distributors, and farmers, A.D.I.VALOR is grounded in the principles of shared responsibility and voluntary commitment. It ensures the safe disposal and efficient recycling of different crop protection products at the end of their lifecycle. Its scope encompasses over twenty types of agricultural waste, including categories such as used packaging, obsolete crop protection products, agricultural films, and ropes and nets.

Producers and importers fulfill their lifecycle responsibility for products by paying the eco-contribution fee or tax, which funds A.D.I.VALOR's recycling and processing system. Producers may also label their products with the A.D.I.VALOR logo or the Agricultural Plastics Environment (APE) certification, enhancing product visibility and appeal. Farmers are responsible for sorting, cleaning, and storing agricultural waste according to recycling guidelines and transporting it to designated collection points on dates specified by collection station operators. Regional agricultural chambers and other organizations provide farmers with support and guidance in these efforts. Over 90% of collection stations are operated by agricultural cooperatives or distributors, all of whom must register with A.D.I.VALOR to obtain the operational license. These operators supervise and manage recycling activities, including the sorting and storing of agricultural waste at collection stations, before transporting it to recycling factories for further processing. Currently, A.D.I.VALOR's recycling system includes over 350 producers and importers, 1,200 collection operators, more than 7,000 collection points, and 300,000 farmers. In 2020, over 79,000 tons of APW were collected, achieving a collection rate of 78% and a recycling rate of 74%. For mulch film specifically, the collection rate reached 85%, with 99% of the collected mulch film waste being recycled.

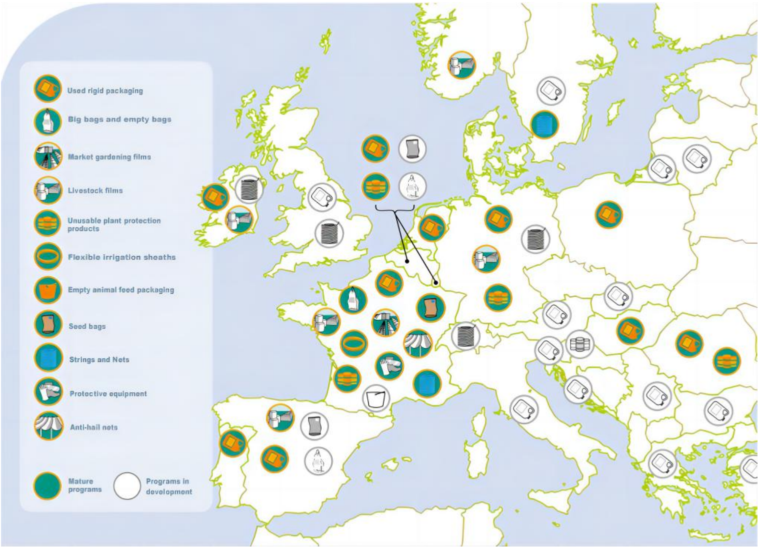

Figure 1-5 Type and coverage area of agricultural waste recycling by A.D.I.VALOR. Resource: © A.D.I.VALOR.

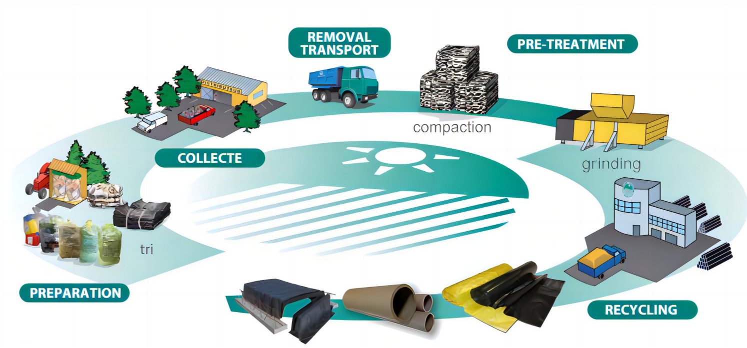

Figure 1-6 A.D.I.VALOR agricultural waste recycling system. Resource: © A.D.I.VALOR.

Germany

Initiated by the German Association for Plastics Packaging, the Agricultural Plastics Recycling System in Germany (Entsorgungssystem für Agrarfolien Deutschland – ERDE), established in 2013, remains the sole recycling system dedicated to APW in Germany (https://www.erde-recycling.de/en/). ERDE focuses primarily on silage films, stretch films, bale nets, baling twine, and mulch films (Figure 1-7). Producers and distributors voluntarily join ERDE as members, providing financial support for APWM and thus assuming responsibility for their products' entire lifecycle. Consumers, including contractors and farmers, are required to follow ERDE's guidelines by sorting, bundling, and cleaning APW before delivering them to ERDE collection points and paying treatment fees. Compared to alternative disposal methods in Germany, such as incineration, ERDE's recycling system offers a significantly reduced fee and issues a carbon reduction certificate, effectively incentivizing participation. ERDE's collection stations are established, managed, and expanded by its system operators, with trade organizations, farm groups, contractors, and recycling companies eligible to join as operators, receiving support as needed. By 2020, the ERDE system comprised 531 permanent collection stations and 1,936 mobile collection points, collectively recycling 28,011 tons of APW, representing 51% of the agricultural plastics consumption in Germany.

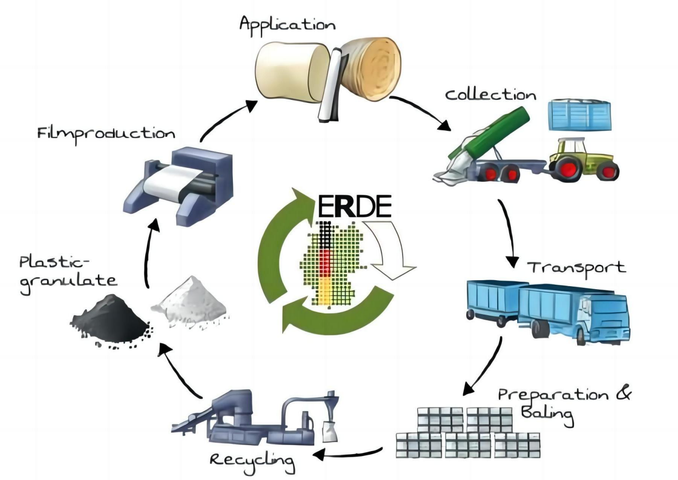

Figure 1-7 ERDE APW recycling system. Source: © ERDE-recycling.

Ireland

Ireland is among the few European countries with specific legislation designed to promote APWM. The Agricultural Plastics Regulations mandate that agricultural plastics producers bear legal responsibility for recycling APW. Enterprises that sell agricultural plastic products must either engage directly in the recycling process through a deposit-return scheme or participate in a government-approved APW recycling program like the Irish Farm Film Producers Group (IFFPG). IFFPG stands as Ireland's sole compliant organization for APW recycling and represents the most economical and efficient option for APWM (https://farmplastics.ie/).

IFFPG focuses on recycling agricultural plastics such as silage films, netting, fertilizer and feed packages, drums, and mulch films. Producers support the IFFPG by paying a recycling tax of €140/ton, thereby fulfilling the financial responsibility for the lifecycle of their products. Farmers transport their APW to IFFPG collection centers or schedule an on-farm collection service on designated collection days. They are required to sort, clean, dry, and bundle the APW and pay processing fees based on the type and weight of the waste. Compared to landfill, which costs €150/ton, IFFPG provides a more economical APWM solution. Additionally, when farmers purchase agricultural plastics with the recycling tax paid, they can receive a label code with a six-digit identifier from the distributor, which entitles them to substantial discounts on processing fees. For example, in 2022, the processing fee for silage film was significantly reduced through this incentive (Table 1-2).

Table 1-2 Processing fee for silage film of IFFPG in 2022

Service	With Label Code (1 ton)	Without Label Code (1 ton)
Bring-centres	€100	€200
farmyards	€200	€400

Source: © IFFPG

Collection operators are responsible for transporting the gathered APW to recycling factories for further processing. Currently, 40 manufacturing enterprises have joined IFFPG as members, providing financial support to the program. Nationwide, Ireland has established 235 collection centers, annually recycling more than 35,000 tons of APW, constituting 90% of the total APW collected nationwide.

Furthermore, Spain, particularly the Andalusia region, is the highest contributor to APW in Southern Europe, with an annual output of approximately 324,000 tons (Hachem et al. 2024). The high demand for APWM has fostered the growth of Green World Compounding (GWC), a global leader in APW recycling and circular economy solutions. GWC provides recycling services to numerous European countries (Figure 1-8). Additionally, Belgium organizations, Plastics Recyclers Europe and Plastics Europe, represent significant organizations in the European plastics waste recycling sector, dedicated to advancing innovation and development in APWM. Similar to the ones above, these enterprises are committed to offering comprehensive services to agricultural associations, cooperatives, and municipal authorities to APWM.

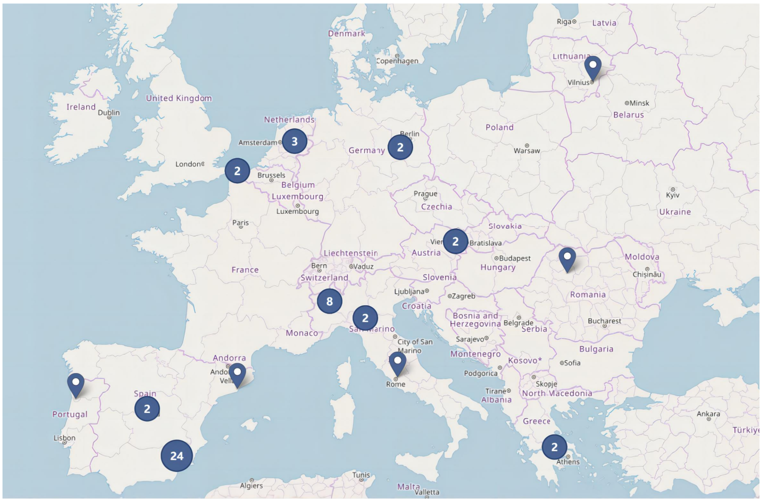

Figure 1-8 Coverage area of agricultural waste recycling by GWC. Source: © Green World Compounding

3.1.2 Mulch film management in Japan

Japan commenced research and application of agricultural plastics in 1948, establishing itself as one of the earliest applicators of plastics in agriculture (Hu et al. 2019). Currently, the annual application of mulch films is approximately 40,000 tons, covering around 167,000 ha (e-Stat 2020). Notably, the application of biodegradable mulch films has expanded steadily, reaching 12,000 ha by 2020 (Yan et al. 2024). Mulch film standards in Japan are primarily informed by the voluntary standards for polyethylene mulch film issued by the Japanese Industrial Standards Committee (JIS-K-6781:1994) (Japan Industrial Standard 1994), with a recommended thickness of 0.02mm to 0.03mm.

As one of the early adopters in addressing solid waste management and resource recovery, Japan has developed a comprehensive APWM system. APW recycling operates within a legal framework, with the Association for the Promotion of Film Recycling for Agricultural Use serving as the principal entity for APWM coordination and enforcement (http://www.noubi-rc.jp/). The Waste Disposal and Public Cleansing Act mandates that APW generators, including farmers and other entities, bear primary responsibility for the proper disposal of APW. Non-compliance can result in substantial fines or imprisonment. The Association outlines detailed roles and obligations for agricultural plastics manufacturers, distributors, and recycling enterprises, creating a collaborative system between the government, farmers, manufacturers, and recycling organizations. In practice, mulch film waste is collected primarily through two modes. First, farmers may individually collect and clean the mulch film waste before delivering it to specialized recycling facilities, where they pay a recycling fee of J¥ 30-50/kg (1 J¥ = 0.0065 USD). Alternatively, the Association collaborates with distributors to embed treatment costs into the purchase price of mulch films, with subsequent unified management efforts by the Association post-consumed. Local governments and agricultural cooperatives are tasked with formulating recycling plans, coordinating the recycling process, and providing subsidies for recycling costs, typically ranging from J¥ 10-30/kg. Recycling entities, including collection centers, recycling enterprises, and transport services, must obtain approval from relevant government authorities. The operational framework for mulch film recycling is depicted in Figure 1-9.

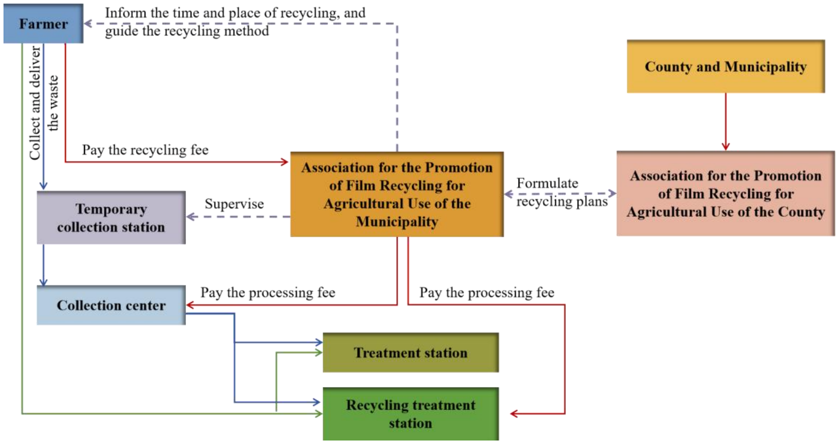

Figure 1-9 Mulch film waste recycling and charging system in Japan. Source: © Association for the Promotion of Film Recycling for Agricultural Use.

In Japan, disposal methods for mulch film waste primarily include recycling, landfilling, and incineration. In 1989, 43% of mulch film waste was incinerated, 22% were landfilled, and the recycling rate stood at a mere 23%. With advancements in the Waste Disposal and Public Cleansing Act, improvements in APW processing capacity, and heightened awareness and capabilities among stakeholders, the APW recycling rate in Japan has increased significantly. By 2023, the recycling rate for mulch film waste reached 70%, while only 11% were incinerated and 10% landfilled (Figure 1-10).

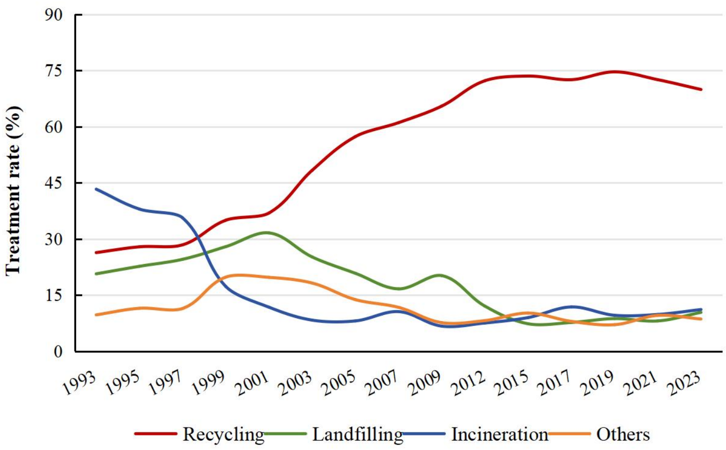

Figure 1-10 Status of Mulch film waste treatment in Japan. Source: © Association for the Promotion of Film Recycling for Agricultural Use.

Leveraging insights from other countries can offer valuable guidance for improving APWM in China. In developed nations, agricultural plastic recycling systems are typically grounded in strict regulatory frameworks or substantial financial support from large producer alliances. In the collection phase, farmers bear the main behavioral responsibility. Meanwhile, agricultural plastic collectors receive effective incentives throughout the collection process, including relatively low disposal fees, discounted recycling costs, carbon reduction certificates, and stringent penalties, which significantly enhance farmers' willingness to participate in recycling activities. The success of this model is rooted in the shared responsibility principle under the EPR framework. Here, government agencies lead efforts to connect manufacturers, distributors, farmers, collectors, and recycling companies, ensuring that each stakeholder understands their responsibilities, acts proactively, and collaborates effectively. This coordination is essential for establishing a functional recycling chain for agricultural plastics.

In China, however, APWM primarily relies on government intervention. The government has provided substantial direct and indirect subsidies to incentivize farmers to collect residual film, adopt environmentally friendly film, and support enterprises in recycling APW into reusable resources. Although recent years have seen increased efforts to raise awareness among farmers and foster a recycling market for APW, China's APWM remains highly dependent on government funding. Whether internationally practiced models, such as user-pays systems, stringent punitive measures, and a heavily market-driven recycling approach, are fully applicable to China's unique context remains a matter of debate. Considering the complexities of practical circumstances and multiple influencing factors, a prudent approach might involve policy pilot trials to identify a contextually suitable accountability framework, followed by legislative action to formalize it.

3.2 Policy evolution of mulch film management in China

The policy of APWM in China has gone through a development process. Based on the crucial documents release and policy priority (Table 1-3), the policy can be roughly divided into three period: pollution awareness formation - waste comprehensive prevention and control - waste recycling utilization. Simultaneously, the governance entity has also developed through the evolution of "farmers - government - government & market".

Pollution awareness formation period based on farmers' spontaneous cleaning (1995-2005): Before 1995, policies related to agricultural plastics focused on securing production supplies to improve agricultural production. With the popularization of mulch film application, the negative environmental impacts of APW initially emerged. In 1995, the Law of Solid Waste Prevention and Control was released, which legally imposed requirements on the prevention and control of mulch film waste for the first time, initiating the prelude to APWM. In this period, policymakers are beginning to recognize the adverse effects of APW; however, this issue has yet to attract sufficient concern from the government and society. APWM is mainly performed by some farmers' spontaneous cleaning for mitigating the hindrance of agricultural practices and pollution of farmland.

Waste comprehensive prevention and control mainly led by the government (2006-2011): During this period, the negative externalities caused by APW accumulation became increasingly severe, and administrative forces began to intervene in APWM. The government introduced a series of policies to promote the "decontamination" of farmland agricultural mulch film residues. For example, binding regulations that strictly limit the production and utilization of ultra-thin mulch film; incentives such as investing in research and development of mulch film collection machinery, incorporating mulch film recycling machines within the scope of the subsidy programs, and price discounts for the standard mulch film; and guiding policies such as education and publicity to call on cleaning up the plastic waste on the farmland and encourage to produce and utilize the mulch film no thinner than 0.008mm.

Resource utilization of APW with "government subsidy & market operation" model (2012 to present): The government further intensifies APW recycling during this period, and APWM enters an accelerating period. From 2012 to 2015, the central government invested CNY 901 million in agriculture cleaner production pilot demonstrations, primarily supporting APW recycling. In 2016, the central government further invested CNY 1 billion to promote drought farming technology, focusing on the life-cycle management of film mulching technology. During the period, the government included mulch film recycling in " One Control, Two Reductions, Three Basics" (The "One Control" initiative aims to regulate the total volume of agricultural water usage by establishing strict thresholds for both overall consumption and utilization efficiency. The "Two Reductions" strategy seeks to decrease the aggregate application of fertilizers and pesticides. The "Three Fundamentals" seeks to fundamentally resolve the issues of livestock waste, mulch film waste, and straw waste through resource-based utilization methods.) and " Five Major Actions for Agriculture Green Development, (action for the resource utilization of livestock and poultry manure, action to replace chemical fertilizers with organic fertilizers for fruits, vegetables and tea, action for straw treatment in northeast region, action for agricultural films recycling, and action for aquatic life protection in the Yangtze River)" fully subsidized mulch film recycling machines and innovated "trade-in" and "cash subsidy" models to motivate farmers to collect and deliver mulch film waste to recycling plants. In 2017, the Action Plan for Agricultural Films Recycling made detailed planning and practical arrangements for the objectives, practices and models of APW recycling. In the same year, the national standard for mulch film was updated, raising the lower limit of mulch film thickness from 0.008 mm to 0.010 mm. Further, the 0.015 mm thicker mulch film is promoted in 2022. In 2021, the VAT policy on comprehensive resources utilization was adjusted to include mulch film in the "Catalogue of Preferential VAT on Products and Services for Comprehensive Resources Utilization (2022 version)".

Two significant changes in APWM policy occurred during this period: First, the policy priority shifted from decontamination to resource utilization, turning APW into "resource." The central government started to conduct pilot demonstrations for APW resource utilization. 100 counties in Gansu, Xinjiang and Inner Mongolia were chosen as pilots, aiming to develop repeatable mechanism and model for APW resource utilization. Meanwhile, policies made detailed requirements for technical specifications, utilization rate and so on. In addition, policies of subsidizing mulch film collection machines, promoting farmers to hand over mulch film to recycling enterprises, and increasing mulch film thickness to improve its collectability and processability promote the resource utilization of mulch film waste indirectly. Second, the policy further emphasizes the role of the market. Utilizing the above-mentioned special projects and local government finances, supporting processing enterprises through awards, subsidies after construction, subsidies after utilization, subsidized loans, and VAT refunds, and support recycling outlets through in-kind and financial subsidies to reduce pressure on resource utilization enterprises and foster a resource utilization market system. Supporting enterprises by awards, subsidies, discounted loans, VAT refunds, and supporting recycling stations through in-kind subsidies and cash subsidies, to reduce the financial burden on relevant enterprises and cultivate the resource utilization market. Further, in 2017, four counties in Gansu and Xinjiang established a pilot EPR system of “who produces, who recycles,” compacting the recycling and utilization responsibilities to the agricultural plastics producers.

Under the policy and financial support of the Chinese government, significant progress has been made in addressing agricultural white pollution. The monitoring system for mulch film waste has been continuously improved, efforts to develop recycling machinery and biodegradable mulch film have been intensified, and the policy framework supporting APW recycling and resource utilization has been initially constructed. In key regions for agricultural plastics application, the worsening trend of agricultural white pollution has been effectively curbed. For instance, the mulch film recovery rate in Gansu increased from 57% in 2011 to 85% in 2020. By 2019, over 80% of the 40 key film mulching counties in Xinjiang had achieved a recovery rate above 80%, while in Inner Mongolia, 14 counties hosting mulch film recycling demonstration projects reported recovery rates exceeding 82%. In these regions, initiatives such as agricultural clean production, mulch film recycling pilot demonstration counties, and mulch film scientific utilization and recycling have facilitated sustained recycling actions. Regarding the recycling systems, a comprehensive and multi-tiered framework has been established, featuring village-level recycling points, township-level collection stations, county-level processing facilities, and the active participation of specialized service organizations. Furthermore, substantial progress has been made in broadening resource reutilization pathways, advancing the harmless treatment of APW, innovating recycling mechanisms, and enforcing producer responsibility in the management process. However, the overall APWM situation remains challenging. Achieving the national target of an 85% recovery rate for mulch film faces significant obstacles, particularly in areas outside pilot project regions, where the issue of APW persists. Several critical problems undermine the effectiveness of the recycling system: incomplete recycling infrastructure, low farmer perception and participation in APW collection, limited economic value of recycled APW products, financial pressures on recycling enterprises, inadequate adaptability of recycling machinery, and technical and cost-related challenges associated with biodegradable agricultural products. Additionally, the implementation of APWM policies remains overly reliant on government subsidies. As the profound transformations of agricultural development in China, the primary challenges facing agriculture sector have undergone profound transformations, and advancing green development of the agricultural sector has become a broadly recognized priority. Against this backdrop, APWM has entered a new phase of development opportunities. To further enhance the effectiveness of management, it is imperative to leverage the current policy window period and adopt a multifaceted approach to promote sustainable APWM development.

Table 1-3 Main APWM-related policies in China.

Date	Document name	Main content
2006		
2006.3	"No. 1 central document" for 2006	Develop and promote biodegradable mulch and establish an extended producer responsibility system to promote recycling of waste mulch.
2009		
2009.9	"Opinions on Strengthening the Recycling and Utilization of mulch Film waste and Promoting Agricultural Non-point Pollution Control" of Gansu Province.	
2011		
2011.3	The 12th Five-Year Plan	Manage non-point pollution of pesticides, fertilizers and agricultural film, promote breeding pollution prevention.
2011.12	Agricultural Cleaner Production Demonstration Project	Select ten provinces where mulch film is used extensively to demonstrate the scientific use and strengthen the agricultural clean production capacity.
2013		
2013.11	"Notice on Concentrated Management of mulch film waste" of Gansu Province. "Regulations on mulch film waste recycling" of Gansu Province.	
2014		
2014.1	"No. 1 central document" for 2014	Increase efforts to prevent and control agricultural non-point pollution, promote high standard mulch film, and carry out mulch film waste recycling pilot.
2015		
2015.2	"No. 1 central document" for 2015	Strengthen agricultural non-point pollution control and carry out regional demonstration of mulch film recycling.
2015.4	"Implementation Opinions on the Prevention and Control of Agricultural Non-point Pollution" of Ministry of Agriculture and Rural Affairs	Realize the recycling, resource utilization, and pollution-free treatment of mulch film. In 2017, five significant actions for green agriculture development, including mulch film waste pollution control, were carried out, and the extended producer responsibility of "who produces, who recycles" was proposed.
2016		
2016.1	"No. 1 central document" for 2016	Strengthen the prevention and control of agricultural non-point pollution, implement zero-growth action of fertilizers and pesticides, and implement waste resource utilization

Date	Document name	Main content
		demonstration pilots.
2016.3	The 13th Five-Year Plan	Develop eco-friendly agriculture. Implement agricultural recycling demonstration project, and promote the resource utilization of breeding waste. Carry out comprehensive prevention and control of agricultural non-point pollution.
2016.5	"Soil Pollution Prevention and Control Action Plan" of State Council	Strengthen the recycling and utilization of mulch film waste, crack down on the illegal production and sale of substandard mulch film, establish and improve the recycling, storage, transportation and comprehensive utilization network of mulch film waste, and carry out pilot projects for the recycling and utilization of mulch film waste.
2017		
2017.1	The national standard GB 13735-2017	"Polyethylene Blow Molding Agricultural Mulching Film" was issued. The scope of application, thickness and deviation, tensile properties, weather resistance and other indicators of mulch film have been revised.
2017.2	"No. 1 central document" for 2017	Promote agricultural waste utilization pilot and explore to establish sustainable operation and management mechanisms. Carry out pilot demonstrations of clean production of mulch film. Promote the creation of the national demonstrated pilot for sustainable agricultural development.
2017.5	"Mulch Film Recycling Action Plan" of Ministry of Agriculture and Rural Affairs	Formulate four critical tasks to promote the reduction of mulch film coverage, product standardization, collection mechanization, and recycling specialization, build 100 recycling demonstration counties, and establish pilot counties of the extended producer responsibility in Gansu and Xinjiang.
2018		
2018.2	"No. 1 central document" for 2018	Strengthen the prevention and control of agricultural non-point pollution, and carry out the agricultural green development action. Promote actions of organic fertilizer substitution for chemical fertilizers, livestock and poultry manure treatment, comprehensive utilization of crop straw, recycling of mulch film waste, and green pest prevention and control.
2018.7	The national standard GB/T 35795-2017 "Biodegradable Mulch Film" was implemented	It stipulates some important performance technical requirements for fully biodegradable agricultural mulch film including mechanical properties, water vapor transmission rate, heavy metal content, biodegradation performance, artificial weathering performance, etc.
2018.11	"Agricultural and Rural Pollution	Focusing on the soil cleaning project, implementing mulch film recycling, promoting the

Date	Document name	Main content
	Control Action Plan" of The Ministry of Agriculture and Rural Affairs and the Ministry of Ecology and Environment	technology of mulch film reducing and the efficiency increasing, building 100 demonstration counties of mulch film recycling, and putting forward the goal of achieving a national agricultural film recycling rate more than 80% by 2020.
2019		
2019.1	Implementation of "The Law of the People's Republic of China on the Soil Pollution Prevention and Control"	It marks that the recycling of mulch film waste has a formal legal binding force, and the unreasonable disposal of mulch film waste will be fined.
2019.2	"No. 1 central document" for 2019	Develop ecological recycling agriculture, promote agricultural waste utilization of livestock and poultry manure, straw and mulch film, realize the governance of animal manure, and make great efforts on white pollution control.
2019.6	"Opinions on Accelerating the Prevention and Control of Mulch Film Waste Pollution" of The Ministry of Agriculture and Rural Affairs, the Ministry of Industry and Information Technology	By 2020, the mulch film waste recycling mechanism will be established, the primary responsibilities will be clarified, the recycling system will be basically established, the mulch film waste recovery rate will be more than 80%, and the mulched area will no longer increase. By 2025, the mulch film waste will be fully recycled, the national mulch film residues will achieve negative growth, and the white pollution will be effectively prevented and controlled.
2020		
2020.1	"Opinions on Further Strengthening Plastic Pollution Control" jointly issued by the Ministry of ecological environment and the national development and Reform Commission	Put forward several opinions on strengthening the supervision and management of mulch film production and sales, standardizing the recycling and disposal of waste plastic film, and developing and promoting degradable plastic film.
2020.2	"No. 1 central document" for 2020	Carry out in-depth action to reduce pesticides and fertilizers, strengthen the treatment of mulch film waste pollution, and promote the comprehensive use of straw.
2020.7	"Notice on Solidly Promoting Plastic Pollution Control" of the National	Organize the exchange of old films for new ones, handover by business entities, and recycling by special organizations, promote the pilot of the extended producer responsibility

Date	Document name	Main content
	Development and Reform Commission, the Ministry of Ecology and Environment and other 9 ministries and commissions	system for mulch film and the construction of mulch film waste recycling demonstration, improve the recycling system of mulch film waste, and standardize the collection and disposal of plastic wastes.
2020.9	"Work plan for supply and market cooperatives to actively participate in promoting agricultural film treatment" of All China Federation of Supply and Marketing Cooperatives	Give full play to the advantages of industry and organization of the supply and marketing cooperatives to help mulch film waste pollution control.
2021		
2021.2	"No. 1 central document" for 2021	Promote the green development of agriculture. Fully implement the comprehensive use of straw and mulch film waste, pesticide packaging recycling action. Promote the research and development of degradable mulch film.
2021.2	"Guidance on Accelerating the Establishment of a Sound Green Low-Carbon Circular Development Economic System" of the State Council	Put forward the governance of mulch film waste pollution, and establish a green and low-carbon cycle development production system..
2021.3	The 14th Five-Year Plan	Promote the green transformation of agriculture, strengthen the governance of production areas, develop water-saving agriculture and dry farming, implement pesticide and chemical fertilizer reduction actions, manage mulch film waste pollution, and improve the recycling rate of mulch film waste.
2021.6	"Regulations on the Management of Farmland Mulch in the Xinjiang Uygur Autonomous Region" of Xinjiang Uygur Autonomous Region.	
2021.9	"Notice on the issue of the Action Plan for Plastic Pollution Control during the 14th Five-Year Plan" of The Ministry of Ecology and	Clear the goal that by 2025, the recycling rate of mulch film should reach 85%, and the national mulch film residue will achieve the goal of zero growth.

Date	Document name	Main content
	Environment of the National Development and Reform Commission	
2021.11	"The 14th Five-Year Plan for Industrial Green Development" of the Ministry of Industry and Information Technology of the People's Republic of China	Promote rural energy-saving and environmental protection equipment such as mulch film waste pollution control.
2021.12	"Announcement on improving the value added tax policy for resource comprehensive utilization" of Ministry of Finance of the People's Republic of China	Adjust the preferential VAT policy on comprehensive resource utilization. The VAT of recycling utilization enterprises is levied at a fixed rate of 3%, the VAT refund ratio of agricultural plastics waste reproduction is adjusted from the original 50% to 70%, and the VAT refund of re-produced granulates of mulch film waste is added to 100%.
2022		
2022.2	"No. 1 central document" for 2022	Strengthen the comprehensive management of agricultural non-point pollution, further promote the reduction of agricultural inputs, strengthen the resource utilization of livestock and poultry manure, promote the scientific use and recycling of mulch film waste, and support the comprehensive utilization of straw.
2022.3	Notice on the Pilot Project on Scientific Use and Recycling of Mulch Film of the Ministry of Agriculture and Rural Affairs and the Ministry of Finance	Carry out pilot projects on scientific use and recycling of mulch film, focusing on critical areas to carry out the pilot projects to systematically solve the difficulties in recycling and replacing traditional mulch film.
2023		
2023.1	"No. 1 central document" for 2023	Establish and improve the system for the collection, utilization and treatment of agricultural waste such as straw, mulch film, pesticide packaging waste and manure.

Source: Obtained from Ministry of Agriculture and Rural Affairs of China and summarized by the author.

3.3 Key measures for mulch film management in the current stage

To address the persistent challenges associated with the mulch film residues and effectively mitigate agricultural white pollution, the Ministry of Agriculture and Rural Affairs, in conjunction with the Ministry of Finance, initiated a pilot demonstration in 2022 focused on the mulch film scientific utilization and recycling. The initiative prioritizes the promotion of thicker mulch films to enhance recycling and biodegradable mulch films to eliminate the plastic residues at the source.

This pilot policy delineates the objectives of promoting these two kinds of environmentally friendly mulch films in Hebei, Inner Mongolia, Liaoning, Shandong, Henan, Sichuan, Yunnan, Gansu, and Xinjiang, Xinjiang Production and Construction Corps and the Beidahuang Group Co., Ltd. The focus is on crops and areas with preliminary trials have been conducted, with a measured and orderly increase in expanded application areas. In 2022, the initiative successfully promoted the application of thicker mulch films across 3.3 million ha and biodegradable mulch films across 0.3 million ha (Table 1-4), with the pilot areas encompassing 2.9% of the total farmland in China. By 2025, the goal is to extend the application of thicker mulch films to 13 million ha and biodegradable mulch films to 2 million ha, thereby expanding the pilot areas to cover 12.0% of the total farmland nationwide.

Table 1-4 Mission on mulch film scientific utilization and recycling in 2022 (1 ha=15 mu)

No.	District	Area of thicker mulch film application ($10^{\wedge 4}$ mu)	Area of biodegradable mulch film application ($10^{\wedge 4}$ mu)
1	Hebei	300	50
2	Inner Mongolia	800	130
3	Liaoning	100	50
4	Shandong	600	120
5	Henan	300	50
6	Sichuan	300	-
7	Gansu	900	-
8	Yunnan	300	50
9	Xinjiang	1000	-
10	Xinjiang Production and Construction Corps	350	30
11	Beidahuang Group Co., Ltd	50	20
	Sum	5000	500

Data source: Notice of the General Office of the Ministry of Agriculture and Rural Affairs and the General Office of the Ministry of Finance on the pilot program for the mulch film scientific utilization and recycling

The pilot encompasses two primary tasks: first, the scientific promotion of thicker mulch films. For major film mulching crops such as cotton, corn, and vegetables, the pilot advocates the application of mulch films with a thickness of no less than 0.015mm. This approach aims to improve the recyclability of mulch film waste.

Second, the orderly promotion of biodegradable mulch films. For suitable crops such as potatoes, peanuts, and garlic, the pilot supports the systematic promotion of biodegradable mulch film application that meet the national standard “Biodegradable Agricultural Ground Covering Film” (GB/T 35795-2017). This promotion is based on the evaluation of the effectiveness of biodegradable mulch film applications.

The government has allocated subsidy funds to support the implementation of the mulch film scientific utilization and recycling pilot demonstration across different pilot provinces and areas. Regarding thicker mulch films, the government will provide subsidies considering factors such as actual agricultural production conditions and the costs of procurement and recycling. Subsidies may take the form of direct and indirect ways, and trade-in programs. This subsidy follows a phased approach: one year of support, two years of consolidation, and three years of establishing mechanism establishment. Supporting policies will be phased out as the market-driven operating model gradually develop. For biodegradable mulch films, subsidies will be determined based on factors such as farmers’ acceptance and the comprehensive benefits of their application, with adjustments made to the subsidy standards based on the implementation progress. Subsidy follows the “purchase first, subsidise later” model. As the market matures and product competitiveness strengthens, the government will gradually reduce subsidy standards, fostering a virtuous cycle of development where farmers actively participate, enterprises benefit, and the environment improves.

3.4 Mulch film management practices in pilot area

3.4.1 Mulch film management in corn planting area represented by Horqin Right Wing Front Banner in Inner Mongolia

Horqin Right Wing Front Banner (hereinafter referred to as Banner), located in northeast of Inner Mongolia Autonomous (Figure 1-11), stands out as one of the most distinctive and typical integrated farming and animal husbandry areas in China. Situated in the center of the spring corn planting belt, Banner boasts an annual grain output exceeding 1.5 billion kg, making it the major grain producing county in China. In 2022, the total crop planting area in Banner reached 277.3 thousand ha, predominantly dedicated to corn with 201.3 thousand ha, soybeans covering 31.3 thousand ha, and rice occupying 8.7 thousand ha. Banner has maintained a stable film mulching area of 20 thousand ha, accounting for approximately 10% of the total farmland, with an annual mulch film usage of about 1.5 thousand tons. Film mulching crops are predominantly corn, with notable proportion of rice and vegetables also mulched.

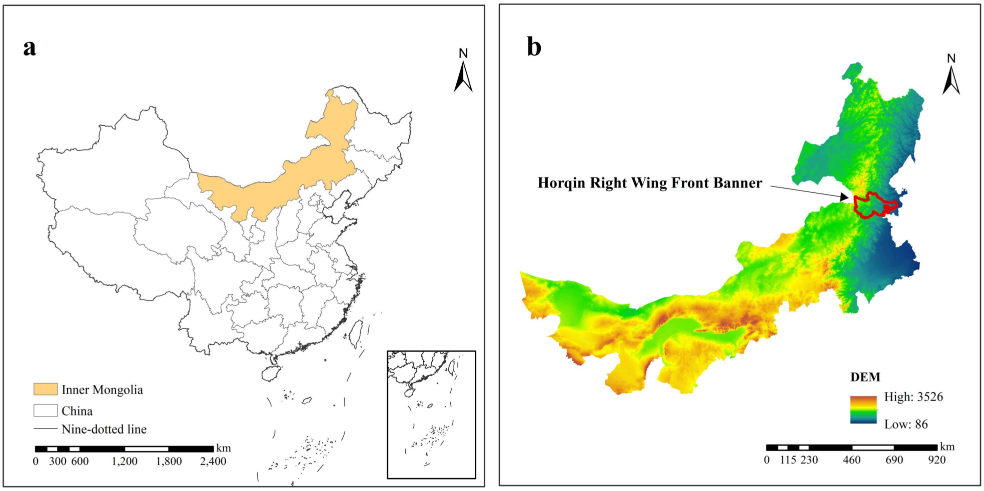

Figure 1-11 Horqin Right Wing Front Banner of Inner Mongolia. Source: Data from Geospatial Data Cloud (https://www.gscloud.cn/) and diagrammed by the author.

In Banner, the pilot project for mulch film scientific utilization and recycling has been comprehensively advanced across the region. From controlling at the source, mulch film waste recycling, to treatment, residues monitoring, records establishing, and supported program, meticulous implementation plans have been devised for each stage. Since 2022, all initiatives have been strictly adhered to the plans, yielding initial successes. By the end of 2022, Banner achieved a 100% rate of mulch film residues collection and an exceeding 82% waste removal rate from farmland.

In Banner, efforts in mulch film management have been initiated comprehensively, including controlling at the source, overseeing procurement and sales, enhancing recycling networks, refining disposal methods, and monitoring mulch film residues. Concurrently, robust financial support and extensive promotional guidance have been provided, resulting in initial achievements in mulch film management in the region.

1.Promoting the utilization of thicker and biodegradable mulch film to control plastic waste at the source

Banner is characterized by a continental monsoon climate and situated in a semi-arid area. Film mulching effectively retains soil moisture, increases farmland temperature, and suppresses weed growth. Since 2017, Banner has extensively promoted the national standard mulch film with the thickness of 0.010 mm, while also moderately promoting the thicker mulch film with the thickness of 0.012 mm. Although the national standard mulch film is of relatively good quality, the film-mulching scenario for the corn is particularly unique. Corn’s aerial roots can penetrate through the soil surface and then anchor into the ground, tightly securing the mulch film, making it difficult to collect the mulch film residues. Specifically, in Banner, where is of single planting systems, mulch film residues are typically recovered during land preparation before the following spring planting period, presenting challenges due to its high degree of weathering and fragmentation.

Therefore, Banner places great emphasis on the widespread adoption of thicker and biodegradable mulch films. Since being included in the pilot project for mulch film scientific utilization and recycling in 2022, the area successfully expanded thicker mulch film to 8 ha and biodegradable mulch film to 58.7 ha within the same year. In 2023, Banner further advanced this initiative, completing the pilot tasks as scheduled, mulching 10 thousand ha with thicker mulch film and 7.2 thousand ha with biodegradable mulch film.

2.Supervision of mulch film purchase and sales to ensure traceability of its utilization and recycling

Establishing purchase and sales records for mulch film. When purchasing, vendors need accurately record the name, specifications, quantity, and supplier contact information of the mulch film. When selling, vendors need accurately document the identity of the users, the details of mulching farmland, specifications and quantities of the mulch film. Farmers purchasing mulch film are required to submit their purchase and sales lists to the village administration for registration at the village. For mulch film purchased from outside Banner, farmers must request certificates of conformity, inspection reports, invoices, etc., and report to village. Corresponding documents and samples of mulch film should be submitted to village for registration. Village is responsible for filing and keeping records of relevant documents, retaining the samples submitted by farmers for joint sampling and testing by agricultural departments and the market supervision departments of the Banner.

3.Promoting mulch film recycling through subsidies and enhanced recycling networks

Firstly, linking farmland conservation subsidies with mulch film recycling. According to the regulations on mulch film management, adhering to the principle of "who uses who recovers and who pollutes who manages," farmers are required to collect mulch film residues from farmland. These residues must be deposited at designated points in village. To ensure the effectiveness of mulch film removal from farmland, adjustments in the distribution method and timing of farmland conservation subsidies are made. Funds are reserved for mulch film applying farmers, overseen by three-tier verification teams composed of banner, township, and village, with timely subsidies issued to compliant farmers. Subsidies are withheld or temporarily suspended for those who fail to recover mulch film residues, mandating immediate corrective action. Failure to rectify promptly or thoroughly may result in penalties under the Law of the People's Republic of China on Prevention and Control of Soil Pollution.

Secondly, enhancing the three-tier recycling system spanning villages, township, and banners. Leveraging the existing foundation for mulch film recycling, efforts in 2023 secured local government funding of CNY 800,000 to further refine the three-tier recycling system of "village collection, township transfer, banner disposal". Coordinating funds from local financial subsidies, village collective funds, and contributions from villagers, each village is equipped with at least one temporary point to deposit mulch film waste recovery uniformly. Villages equipped with transport vehicles handle delivery of mulch film waste recovered by farmers to township transfer stations. Alternatively, township collect from villages and transport the mulch film waste to Banner for centralized processing. As of June 2023, more than 20 specialized recovery points have been established across the banner, complemented by over 200 simple recovery points in villages.

Thirdly, establishing the three-tier monitoring ledger for mulch film recycling across the banner, township, and villages. Each village is required to establish a village-level mulch film recycling ledger. According to the usage records reported by farmers, entries in the mulch film usage ledger must be completed, including the name, ID number, contact information of the mulch film depositor, film mulching area, plot location, the methods of recovery and disposal, and the quantity involved. Township establish township-level management ledgers for mulch film recycling, recording film mulching crops and areas, the area and weight of recycling, and disposal methods. These details are scheduled daily and reported weekly. The banner establishes a comprehensive mulch film management ledger, scheduling weekly assessments of recycling progress across all township centers and issuing monthly reports. This ledger ensures timely updates on mulch film recycling progress across the banner, enabling dynamic monitoring and proactive resolution of potential issues during the recycling phase.

4.Detailed classification and refinement of mulch film waste disposal methods

The collected mulch film waste is categorized for final disposal. Firstly, resource utilization through recycling. Mulch film waste that is relatively intact low impurity rate is classified for resource utilization. Local mulch film production enterprises are encouraged to engage in recycling and utilization operations. These enterprises process mulch film waste to enhance its added value. A minimum price of CNY 2,000/ton is mandated for purchasing mulch film waste. If the market price exceeds CNY 2,000/ton, the market price prevails. Secondly, energy utilization. mulch film waste highly mixed with crop residues, such as those extensively intertwined with crop root residues, is categorized for energy utilization alongside straw. This approach involves compressing and processing them together for energy utilization. Thirdly, harmless treatment. Mulch film waste that lacks recycling value or fails to meet recycling standards is incorporated into rural domestic waste collection and disposal systems. This integrates into tasks such as rural settlement environment improvement, urban-rural sanitation integration, and waste sorting. Villages, townships, and banner collect, transport, and ultimately treat abandoned mulch film waste through sanitary landfilling or controlled incineration to achieve harmless treatment.

5.Long-term monitoring of mulch film residues

Since 2018, Banner has initiated long-term monitoring of mulch film residues in farmlands, currently establishing two monitoring points. These points correspond to farmlands where mulch film has been continuously applied for several years, thus offering strong representativeness. Annually, prior to spring plowing, working group members conduct residue monitoring at designated sampling locations, collecting mulch film residues from sample plots and documenting their weights according to the prescribed protocol.

6.Safeguard measures

Firstly, financial supports. The central government provides subsidies for the pilot projects at rates of CNY 375/ha for thicker mulch film and CNY 1,800/ha for biodegradable mulch film. Banner government has received a total of CNY 16.2 million in special central funds, primarily allocated for the subsidies of purchasing mulch films. Additionally, local fiscal funds are supplemented with an allocation of CNY 5.6 million, with CNY 4.8 million designated for mulch film price subsidies and CNY 0.8 million to support the operation of mulch film waste recycling.

Secondly, promotional efforts. Utilizing television, newspapers, the internet, and other media platforms, targeted promotional campaigns are organized during critical periods for the recovery of mulch film residues in spring and autumn. These campaigns focus on intensifying the dissemination of relevant laws, regulations, and policies concerning the management of mulch film waste. Over 300 copies of the pilot project manual have been distributed to all stakeholders involved in the production, operation, utilization, recovery, and recycling of mulch film. Furthermore, more than 50 large-scale promotional signs, wall slogans, and banners have been created. During both spring and autumn seasons, technical personnel are dispatched to project areas to provide technical service guidance, conduct demonstration and observation session on biodegradable mulch film, and convene mobilization meetings on mulch film recycling. A total of 150,000 text messages have been sent within Banner via China Mobile and China Unicom (the leading communications providers in China). These efforts effectively mobilize enthusiasm among farmers to adopt thicker and biodegradable mulch films and actively engage in the collection and recovery of mulch film, as well as enhancing public awareness of mulch film scientific utilization and recycling practices.

3.4.2 Mulch film management in cotton planting area represented by Changji Hui Autonomous Prefecture in Xinjiang

In Xinjiang, characterized by the paradigm of “desert oases and irrigated agriculture,” mulch film has become an indispensable agricultural input, particularly prevalent in cotton fields where nearly 100% film mulching is achieved. In 2022, Xinjiang accounts for 21.4% of the national film mulching area and 19.4% of the total national utilization, ranking first nationwide in both metrics (Figure 1-12).

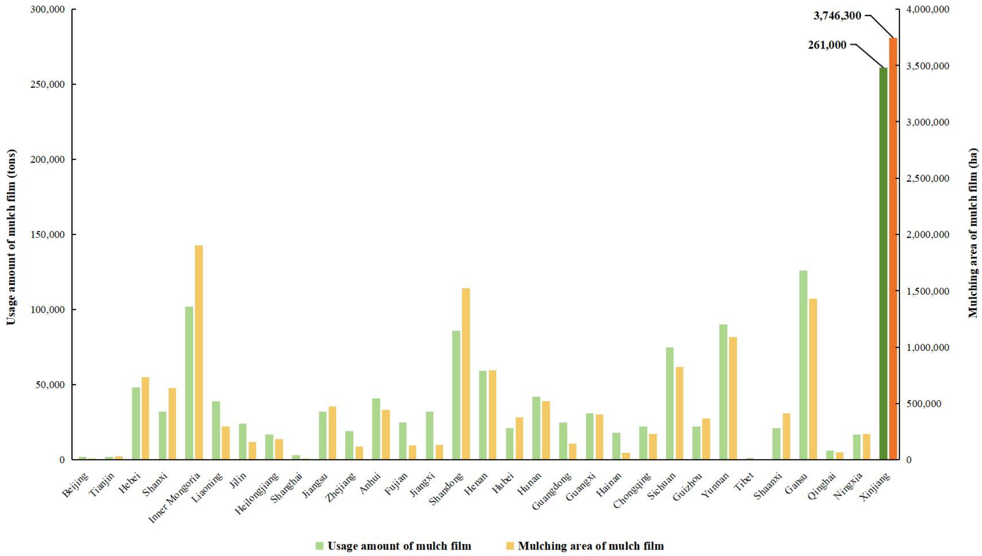

Figure 1-12 Mulch film application in Xinjiang. Data source: China Rural Statistical Yearbook.

After nearly three decades of continuous intensive mulch film application, plastic residue has emerged as a significant pollution issue in cotton planting areas of Xinjiang. According to the Second National Pollution Source Census Bulletin, the average mulch film residue intensity in China stands at 67.5 kg/ha. In Xinjiang, particularly in cotton fields, the average mulch film residue intensity is notably higher at 259 kg/ha (Yan et al. 2014b). Comprehensive analysis of mulch film residue surveys across different regions of Xinjiang reveals that plastic residue levels ranging from 42 to 540 kg/ha (Yan et al. 2008; He et al. 2009), far exceeding the 75 kg/ha national limit stipulated by GB/T 25413-2010.

As the region with the longest history of mulch film application, highest usage amount and intensity, most severe mulch film residue, and the most urgent demand for mulch film waste management in China, the cotton planting areas of Xinjiang underscore the critical importance and urgency of mulch film management. In response, a comprehensive investigation into mulch film management has been initiated in Changji Hui Autonomous Prefecture (hereinafter referred to as Changji Prefecture), Xinjiang.

Changji Prefecture, situated at the northern foot of the Tianshan Mountains and on the southeastern edge of the Junggar Basin (Figure 1-13), falls within the temperate zone and experiences a typical continental arid climate. In 2023, the crop planting area in Changji Prefecture reached 0.5 million ha, with film mulching area of 287,000 ha and a total usage of 19,300 tons of mulch film. Different types of crops are cultivated under mulch film, primarily cotton, corn, tomatoes, and sweet melons. In 2023, Changji Prefecture initiated the pilot demonstration of mulch film scientific utilization and recycling (Table 1-5). By the end of the year, 56,000 ha had been mulched with thicker mulch film, meeting annual deployment targets. Plans for 2024 aim to expand film mulching area to 173,000 ha by thicker mulch film and 20,000 ha of biodegradable mulch film.

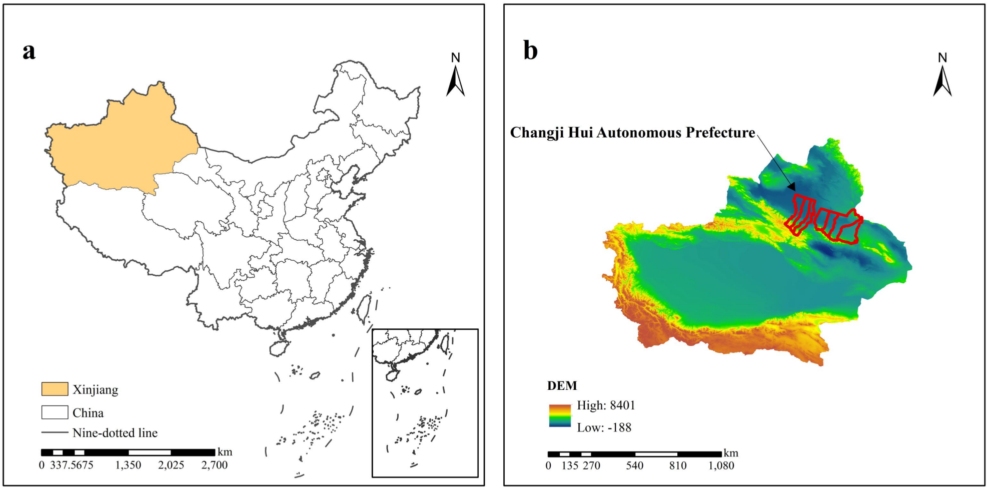

Figure 1-13 Changji Hui Autonomous Prefecture of Xinjiang. Source: Data from Geospatial Data Cloud (https://www.gscloud.cn/) and diagrammed by the author.

Table 1-5 Mission of the mulch film scientific utilization and recycling pilot demonstration in Changji Prefecture. (1 ha=15 mu)

No.	City/County	Area for thicker mulch film			Pilot area for thicker mulch film in 2024 (10^4 mu)	Area for biodegradable mulch film in 2024 (10^4 mu)
		Area be completed in 2023 (10^4 mu)	Area will be completed in 2024 (10^4 mu)	Sum (10^4 mu)		
1	Changji Hui Autonomous Prefecture	84	241	325	15	0.3
2	Manasi County	0	50	50	15	
3	Hutubi County	21	59	50		
4	Changji City	25	35	60		
5	Fukang City	10	20	30		0.05
6	Jimusaer County	11	19	30		
7	Qitai County	7	43	50		
8	Mulei Kazakh Autonomous County	5	5	10		0.25
9	Agricultural district	5	10	15		

Source: Notice of the Bureau of Agriculture and Rural Affairs of Changji Hui Autonomous Prefecture on the Implementation Plan for the Mulch Film Scientific Utilization and Recycling in 2023.

Changji Prefecture has implemented a comprehensive mulch film management system aimed at controlling mulch film waste encompassing five stages: production, sales, utilization, recovery, and treatment.

1.Production

Strict adherence to the "Autonomous Region Mulch Film Management Regulations" ensures standardized production and sales of mulch film in Changji Prefecture. Registration of mulch film production enterprises within the region is mandatory, accompanied by the establishment of production and sales registration logs. Specifically for manufacturers of thicker mulch film, the Autonomous Region mandates the inclusion of identifiable company markings on each roll of mulch film. This initiative establishes a system for traceable mulch film quality, facilitating product traceability and market oversight.

2.Sales

To further prevent substandard mulch film from entering the agricultural supply market and discourage reverse selection by farmers, Changji Prefecture has formulated the "Recommendation List of Thicker Mulch Film Production Enterprises for the Mulch Film Scientific Utilization and Recycling Pilot Project in 2022-2023." Counties and cities are required to prioritize purchasing thicker mulch film from enterprises listed on this recommendation.

Furthermore, Changji Prefecture government mandates that enterprises producing thicker mulch film establish separate logs for factory output and sales. The factory output log must record details such as products' name, specifications, quantity, production date, batch number, quality inspection information, purchaser's name, and contact details. These records are required to be retained for a minimum of two years. The sales log should include information on product name, specifications, quantity, producer, production date, supplier's name, contact information, purchase date, and should also be kept for at least two years.

Simultaneously, rigorous quality supervision and random inspections of mulch film products are intensified in the market. Authorities crack down on production and sale activities that fail to meet national standards. Enterprises found in violation of laws and regulations are subject to penalties under the "Product Quality Law of China" and the "Management Measures for Mulch Films," potentially leading to inclusion in lists of dishonest entities and the revocation of relevant preferential policies.

3.Utilization

In the practical implementation, governments allocate pilot project areas incrementally based on actual film mulching area, as well as feasibility and necessity assessments. Upholding the principle of voluntary participation among farmers, they progressively promote the application of thicker and biodegradable mulch films.

The central government provides a subsidy of CNY 450/ha for the application of thicker mulch film. The autonomous region has detailed and consolidated the use of special funds, specifying that farmers applying thicker mulch film receive a subsidy not exceeding 80% of the national subsidy standard, which amounts to CNY 360/ha. This subsidy is disbursed in installments: CNY 180/ha is provided when farmers purchase the thicker mulch film. The rest will be provided after the recycling.The remaining 20% of the subsidy funds are allocated for mulch film waste recovery activities, recycling system development, and mulch film residues monitoring. Specific subsidy standards are clarified by counties and cities based on local conditions, with any shortfall in funds supplemented by the counties and cities. Farmers benefiting from subsidies are required to report to the village collective usage logs, providing proof of film mulching areas by thicker mulch film. This includes details such as usage dates, locations, recipients, product names, quantities, and other relevant information.

4.Recycling

This phase primarily applies economic measures such as recycling subsidies and deposit refund schemes, enhances mulch film recycling, constructs and enhances recycling points, and strengthens mulch film residues monitoring.

(1)Economic measures

Subsidies for recycling. Following crop harvesting, farmers are obligated to recover mulch film residues as required. Upon inspection and verification, farmers receive the remaining 50% of the utilization stage subsidy (CNY 180/ha) and an additional recycling stage subsidy (CNY 75/ha), totaling CNY 255/ha. Requirements for the distribution of recycling stage subsidies stipulate that thicker mulch film must achieve a recovery rate exceeding 85% and a transport rate of 100%.

Deposit refund scheme. According to regional regulations, clauses regarding the deposits related to mulch film management are added to farmland leasing contracts. Village collectives collect deposits from lessees at a rate of CNY 600/ha. Upon lease expiration, if the mulch film recovery requirements are met, the entire deposit is refunded. Otherwise, the deposit is retained by the village collective and used as the funds to recover mulch film residues from the leased land.

(2)Management mechanism

On one hand, Xinjiang benefits from favorable conditions for mechanization, while on the other, government policies in promoting mechanized mulch film recovery are robust, particularly evident in Changji Prefecture where mechanized mulch film recovery rates are fairly high. In 2022, Xinjiang initiated extensive subsidies for the procurement and application of mulch film recovery machinery, covering 1/3 to 1/2 of the machine's sales price. Furthermore, over the past two years, Changji Prefecture has strategically allocated funds from rural revitalization and local bond sources to purchase efficient mulch film recovery machines. These machines are distributed free of charge to townships, servicing rural areas for mulch film recovery. When needed, farmers can apply through their townships, only needing to bear labor and fuel costs. Each machine can recover mulch film from 13.3 ha per day, equivalent to the daily recovery volume of approximately 40-50 workers.

(3)Recycling points

Utilizing surplus funds from the mulch film scientific utilization and recycling pilot project, the Changji Prefecture government subsidizes the establishment of mulch film recovery points in townships, granting each township a subsidy of CNY 30,000. Townships are encouraged to coordinate these subsidies according to their specific needs, covering transportation subsidies from recovery points to mulch processing and utilization sites, subsidies for purchasing necessary equipment at recovery points, and essential management subsidies for these sites.

(4)Mulch film residues monitoring

The formulation of the “Plan of regional mulch film residues monitoring” involves continuous monitoring of mulch film residues post-autumn crop harvests. Across different townships, a network of 20 long-term, designated monitoring sites for mulch film residues has been established. Following a standardized operation protocol, specific enterprises are commissioned to conduct comprehensive farmland mulch film residues assessments and recovery rate calculations, adhering to a uniform procedure. This initiative aims to enhance surveys on mulch film application and mulch film residues monitoring effectively, scientifically evaluating regional plastic waste residues and the efficacy of mitigation measures.

5.Treatment

(1)Mechanical recycling - granulation

Relying on local mulch recycling enterprises like Qinyuan Plastics, Changji Prefecture promotes the resource utilization of mulch film waste. Qinyuan Plastics primarily engages in the processing and recycling of mulch film and drip irrigation tapes. With 8 sets of initial mulch film waste cleaning equipment and 3 production lines for granulation, their annual capacity for mulch film waste treatment exceeds 47,000 tons, with an annual processing capacity of recycled plastic granules reaching 2,100 tons.

(2)Energy utilization - household waste incineration for electricity generation

Changji Prefecture collaborates with City Environmental Energy (Changji) Ltd. to initiate the project of agricultural waste incineration for electricity generation. This company specializes in the harmless disposal and resource utilization of different low-value wastes such as household garbage, kitchen waste, and urban sludge. Under an agreement with the Urban Construction Department of Changji City, waste is transported to the power plant, where it undergoes incineration for electricity generation. The department compensates the company at a standard of CNY 69/ton for these services.

(3)Sanitary landfill

Mulch film waste constitutes industrial waste in agriculture. Overemphasis on resource utilization without effective management not only yields poor results but also leads to significant resource wastage. Particularly for mulch film residues accumulated at historical dumping sites in some rural areas, which are unsuitable for energy utilization and cannot be recycled, Changji Prefecture mandates that such mulch film waste be uniformly transported to local landfill sites at village, township, and county levels for sanitary landfill.

Horqin Right Wing Front Banner and Changji Hui Autonomous Prefecture are typical regions characterized by intensive mulch film application, severe mulch film residual issues, and an urgent need for mulch film waste control. These regions have established regulatory systems covering the entire industrial chain of mulch film production, sales, application, recycling, and disposal, thereby facilitating waste control efforts. Since 2022, with solid support from pilot policies promoting much film scientific utilization and recycling, both regions have widely adopted environmentally friendly alternatives, which including thicker and biodegradable mulch films. These initiatives have effectively increased the recyclability of mulch films and mitigated plastic residuals at the source, achieving substantial environmental, economic, and social benefits alongside effective mulch film management.

Nevertheless, the positive outcomes of APWM in these pilot regions are highly reliant on government subsidies. When supported by such subsidies, mulch film management measures can be effectively implemented. However, the inherent uncertainty of government policies, such as fluctuations, reductions, or even the complete elimination of subsidies, can significantly and profoundly affect the sustainability and effectiveness of APWM. To promote more sustainable and resilient APWM, it is essential to conduct a comprehensive analysis of the stakeholder's interests and responsibilities along the APWM chain. Each stakeholder's role and responsibilities should be clarified from the perspectives of capital, technology, service markets, and product markets. Additionally, it is crucial to explore mechanisms for orderly cost-sharing, value-added creation, and benefit-sharing from the standpoint of responsibility extension, benefit-sharing, and incentive compatibility, thereby establishing an effective APWM system.

4. Key issues of agricultural plastic waste management in China

4.1 The integrated cost-effectiveness of APWM is undetermined

The Chinese government has shown a significant commitment for APWM in the past decade. China's No. 1 Central Document has emphasized addressing agricultural plastic pollution for eleven consecutive years. Between 2012 and 2015, the central government allocated over CNY 900 million to APWM. Local governments, in turn, have provided special funding based on fiscal capacity and local APWM needs. In 2022, China launched a pilot program in nine major agricultural provinces, focusing on "mulch film scientific utilization and recycling" to promote two environmentally friendly options: thicker and biodegradable mulch films. This pilot policy is one of the principal measures of APWM in China.

However, implementing APWM initiatives necessitates substantial external funding. Taking the "mulch film scientific utilization and recycling" pilot project as an example, the cost of environmentally friendly mulch films is significantly higher than conventional ones. Research indicates that the usage cost for thicker mulch film is approximately CNY 1,242/ha, and biodegradable mulch film costs about CNY 3,276/ha-notably surpassing CNY 828/ha for conventional mulch film. To incentivize farmers to adopt these environmentally friendly alternatives, the government provides price subsidies of CNY 450/ha for thicker mulch film and CNY 1,800/ha for biodegradable mulch film, offsetting the additional costs associated with these alternatives. Chinese government has set ambitious targets for mulch film management. In 2022, the pilot area under the pilot initiative covered

366,700 ha, with plans to expand the area to 1.5 million ha by 2025, encompassing over 85% of mulching crops nationwide. Under current subsidy standards, this expansion would require a government expenditure of hundreds of billions of CNY, representing approximately 3.0% of the nation's agricultural budget.

Nonetheless, the integrated effectiveness of current mulch film management measures remains to be determined. Government subsidies for thicker and biodegradable mulch films are primarily calibrated to offset the additional economic costs borne by farmers for these alternatives. Setting appropriate subsidy standards is crucial for ensuring the effectiveness and sustainability of management efforts. If subsidies are set too low, farmers' motivation to adopt environmentally friendly mulch films may wane, undermining policy goals; conversely, excessively high subsidies may strain government finances and compromise the efficient allocation of fiscal resources. Optimal external investment in mulch film management should be anchored to the comprehensive economic performance of different mulch film type, which also serves as a critical criterion for evaluating and refining current subsidy policies. The absence of information on the integrated effectiveness of different mulch film management measures could lead to biased government subsidy decisions.

4.2 APWM fund is lacking of reliability

Currently, APWM operates on the model combining government subsidies with market-based operations. Taking the "mulch film scientific utilization and recycling" pilot project as an example, the government provides subsidies that fully cover the additional costs associated with adopting environmentally friendly mulch films based on the cost differentials across mulch film types, thereby encouraging farmers' adoption. In the recycling phase, mulch film recycling enterprises are primarily responsible for treatment, addressing the disposal of mulch film waste. Farmers, as critical stakeholders, primarily bear responsibilities related to the on-site collection of mulch film residuals.

The "government subsidy & enterprise operation" model for APWM presents substantial challenges regarding the sustainability of funding. First, if the government bears the total management cost alone, it will create a significant fiscal strain. Specifically, achieving the target for the "mulch film scientific utilization and recycling" pilot demonstration in 2022 and 2025 would require an investment of CNY 2.1 billion and CNY 9.6 billion, respectively. Moreover, over the long term, as the pilot projects conclude and government subsidies taper, funding gaps for APWM are likely to emerge. Additionally, the APW recycling sector operates on slim profit margins, making it challenging to incentivize enterprises to maintain ongoing mulch film recycling activities; in practice, these operations are primarily dependent on government subsidies. Attaining a sustainable framework for mulch film management remains a distant goal, and innovative solutions are urgently needed to establish a reliable and stable funding stream for enduring management practices.

4.3 The mechanism for multi-stakeholder cooperation remains uncertain

Currently, the sustainability of APWM faces significant challenges, mainly due to an incomplete engagement mechanism among stakeholders.

Presently, APWM is driven by three primary stakeholders, government, farmers, and enterprises-who each have direct ties to the system. The government plays a central role in guiding, supervising, and supporting APWM, gradually building and refining the macro-level framework. Through establishing regulatory measures, the government curtails improper practices, such as farmers' burning or burying of mulch film residues and enterprises' neglecting of recycling responsibilities. Additionally, the government provides financial and policy incentives, supporting farmers in purchasing environmentally friendly mulch films and facilitating the establishment and improvement of recycling networks while also assisting enterprises in maintaining recycling activities. Under this regulatory and supportive framework, farmers apply government-recommended mulch film products, including thicker and biodegradable mulch films, and conduct post-harvest recovery of mulch film residues. Meanwhile, enterprises, under governmental supervision and support, engage in the recycling and utilization of mulch film waste, effectively transforming waste into resources.

The agricultural environment is inherently linked to the well-being of all individuals. The mitigation of environmental pollution, food safety risks, and health threats achieved through APWM offers widespread societal benefits. The general public, embodying the roles of recipients of agricultural plastic service, victims of APW pollution, and beneficiaries of APWM, represents an important stakeholder group beyond government, enterprises, and farmers; thus, they should not be regarded as mere bystanders in APWM. However, the current APWM model does not account for potential public collaboration. This may be mainly attributed to the lack of mechanisms to promote public participation in real life, preventing widespread public involvement in APWM. Moreover, the externalities inherent in the agricultural environment allow individuals to enjoy the benefits of APWM regardless of their involvement, which may also contribute to a weak awareness and social atmosphere for public engagement in APWM.

Given the challenges facing APWM, no one can remain unaffected from the perspective of a shared future for humankind. Advancing toward sustainable and resilient governance requires exploring broader possibilities. This entails raising awareness of collective responsibility among all stakeholders, establishing inclusive channels for diverse participation, and designing incentives to encourage active engagement from different parties. Such efforts are essential to fostering a more sustainable and resilient model for the management of agricultural white pollution.

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2

Chapter II: Theoretical foundation, thesis framework, research objectives, methodology, and survey and data

1. Theoretical foundation

(1) Externality theory

Externalities refer to situations where the actions of one economic entity affect other entities without corresponding costs being borne or benefits being received by the entity responsible for those actions (Marshall 1890). Externalities can be classified into positive and negative externalities (Pigou 1920). Positive externalities refer to situations where the production or consumption activities of an economic entity confer benefits on other economic entities without compensation. Conversely, negative externalities arise when the actions of an economic entity impose additional costs on others without corresponding compensation. Externalities can lead to market failure, making it impossible to rely on free competition to reach Pareto optimality (Pigou 1920).

The internalization of external costs is of paramount importance. In this regard, Pigou introduced the concept of the "Pigovian tax," positing that externalities could be internalized through the imposition of taxes and subsidies (Pigou 1920). Specifically, polluters must account not only for their conventional production costs but also for the additional social costs engendered by their activities. The government should impose taxes or fines on goods with negative externalities to align the marginal private cost with the marginal social cost. Conversely, it should subsidize or reward goods with positive externalities to elevate the private benefit to the level of the social benefit (Baumol 1972).

Regarding agricultural plastics application, in the situation where the market price of mulch films is low, their adoption can enhance crop yield and quality, thereby improving the private benefits to farmers' agricultural production. However, the plastic residuals left in the farmland from the mulch film application leads to soil contamination, crop growth restriction, crop yield decrease, and microplastic contamination, all of which contribute to external costs that society must bear. APWM presents a similar issue. If farmers were to adopt environmentally friendly alternatives, such as thicker or biodegradable mulch films, instead of conventional mulch films, it would reduce plastic residues in the farmland and mitigate the external costs imposed on society. Yet, the adoption of such environmentally friendly alternatives increases the production costs, thus diminishing farmers' private profits and discouraging their use. According to the principles of externalities and the Pigovian tax solution, the government could theoretically internalize the externalities associated with APWM through the imposition of taxes on conventional mulch films or the provision of subsidies for environmentally friendly alternatives. In the current agricultural context in China, however, prohibiting the application of conventional mulch films or imposing heavy taxes on them would be economically burdensome for farmers unless economically attractive alternatives are available to secure their income levels. Such alternatives include appropriate subsidies for environmentally friendly mulch films to safeguard farmers' economic interests, alongside providing farmers with information about the environmental and economic advantages of these alternatives. This would improve the farmers' economic welfare and enhance their image of responsible producers among consumers and society as a whole.

(2) Public goods theory

According to classical economic theory, societal goods can be categorized into private goods and public goods (Mill 1848; Samuelson 1954). Private goods are characterized by exclusivity, rivalry, and divisibility, being owned and utilized by individuals. In contrast, public goods are those owned and utilized collectively by an indeterminate multitude, marked by non-rivalrous consumption, non-excludability of benefits, and indivisibility of utility. The consumption of a public good by any individual does not impede its consumption by others. The utilization of public goods is susceptible to the tragedy of the commons (Hardin 1968) and the free-rider problem (Olson 1971). The tragedy of the commons refers to a scenario wherein individuals, acting rationally in their own self-interest, overexploit and rapidly deplete an open-access and unregulated resource, consequently compromising collective welfare. The free-rider problem arises when individuals, recognizing the non-rivalrous and non-excludable nature of a public good, opt to benefit from it without contributing to its cost, thereby engaging in opportunistic behavior. As the number of free riders increases, the overall efficiency diminishes, ultimately undermining collective interests.

Agricultural resources and environments exhibit the quintessential characteristics of non-rivalry and non-excludability, thus classifying them as public goods. The occurrence of agricultural white pollution epitomizes the tragedy of the commons. Initially, limited awareness of ecosystem services led farmers to prioritize economic gains, resulting in extensive utilization and inadequate recycling of agricultural plastics. Over time, the accumulation of APW in farmlands has surpassed the carrying capacity of the ecosystem, precipitating a series of environmental pollution issues. APWM is also prone to the free-rider problem. Each farmer may hope that others will clear the APW from the soil, thereby benefiting from a clean agricultural environment without expending personal effort. Consequently, they become free riders. Similarly, the public, which are significant stakeholders in APWM, benefit from a more secure food supply and a cleaner living environment resulting from effective management. In practice, they often contribute nothing to the management efforts, relying instead on the endeavors of farmers, enterprises, and government agencies to provide the services of agricultural resources and environments for free. However, if everyone adopts a free-rider mentality, no one will be incentivized to provide public goods or engage in APWM activities. Ultimately, this would result in the inability of any societal member to enjoy the benefits of agricultural resources and environments.

The market mechanism under conditions of imperfect competition fails to effectively incentivize farmers and enterprises to mitigate agricultural non-point pollution caused by APW. Moreover, it cannot adequately motivate the beneficiary group, the general public, to contribute financially to the provision of public goods. Consequently, relying solely on market mechanisms is insufficient for achieving optimal resource allocation and can lead to market failure. As the representative of public interests, the government must employ external intervention strategies to internalize external costs.

(3) Stakeholder theory

Stakeholder refers to any individual or group who can affect or is affected by the achievement of the organization's objectives (Freeman 1984). Stakeholder theory posits that the actions and management processes of any organization or social system do not exist in isolation within a social environment (Mitchell et al. 1997). Instead, an organization's objectives are achieved through the comprehensive integration and optimal allocation of resources, grounded in the coordination of various stakeholders' interests to maximize utility and benefits. At its core, stakeholder theory focuses on attaining organizational goals by reasonably coordinating and managing the distribution of interests among multiple stakeholders.

APWM involves various economic entities, such as APW recycling enterprises and farmers. These stakeholders often encounter conflicts as they pursue their respective objectives and strive to maximize their own benefits. Stakeholder theory is well-suited to address these conflicts and align the interests of different parties. It facilitates the equitable distribution of the positive externalities associated with pollution control and the sharing of the negative externalities and associated costs of environmental pollution among all the stakeholders. Based on key criteria such as legitimacy, power, and urgency, the primary stakeholders identified in APWM are the government, APW recycling enterprises, farmers, and the public.

In the process of APWM, the government serves as the principal stakeholder representing public interests and holds significant influence over achieving targeted objectives. On one hand, the government formulates regulations to restrain behaviors such as the utilization of ultra-thin mulch films, arbitrary disposal, and open-air burning by farmers. On the other hand, through fiscal subsidies, public awareness campaigns, and educational initiatives, the government guides APW recycling enterprises and farmers in adopting measures for the resourceful utilization of APW. Farmers constitute the most direct and pivotal participants in APWM. Historically, due to limited environmental consciousness and pursuit of economic interests, farmers' tendencies towards emphasizing utilization while ignoring recycling directly result in severe plastic residues in farmland, hindering agricultural production and reducing agricultural income. With government guidance and support, farmers adopting environmentally friendly practices in APWM can effectively alleviate non-point pollution issues and mitigate associated environmental and economic challenges. APW recycling enterprises are indispensable entities in APWM process. By facilitating the recycling and resourceful utilization of APW, these enterprises resolve the dilemma of plastic waste disposal and enable the closure of the APW recycling chain. Simultaneously, enterprises can generate profits through the recycling process, thereby achieving their economic objectives. The participation of numerous APW recycling enterprises in establishing and refining market mechanisms contributes to more efficient resource allocation and fosters the sustainable development of APWM initiatives. The public serves as an indirect stakeholder in APWM. Plastic production and consumption are integral to human origins, offering clean, abundant, and high-quality products and services that benefit humanity as a whole. Nevertheless, mismanagement of agricultural plastics can lead to widespread environmental pollution, food security threats, and human health hazards, affecting both rural farmers and urban citizens alike. Moreover, the public is the beneficiary APWM practices. Social organizations play a crucial role as intermediaries in environmental protection efforts, advocating for environmentalist groups, conveying public sentiments, and securing additional social resources to promote agricultural white pollution control. They also disseminate environmental policies, concepts, and knowledge related to APWM to educate and inform the public effectively.

(4) Behavioral economics

As one of the outstanding achievements in the development of modern economics, behavioral economics integrates the principles of economics and psychology, and is known as the "economics of psychology" (Xue et al. 2003). The analytical methodologies of behavioral economics is rooted in psychology, employing experimental analysis of human psychological characteristics to examine variations in economic behavior and decision-making.

Within the classical economics framework, participants in economic activities are assumed to be perfectly rational and self-interested. When costs exceed benefits, the optimal behavioral decision for economic agents is "not to act". According to the logic of bounded rationality, while economic agents may not always pursue the absolute minimization of costs or maximization of benefits, their fundamental decision-making logic still aims to maximize utility. However, an increasing number of research reveals that human activities are not solely driven by economic gain but may also be motivated by other objectives such as justice, reciprocity, and altruism (Kahneman and Tversky 1979; Seaton 2013). Particularly in the realm of public goods, studies have shown that individuals may choose to contribute even in the absence of direct benefits or when the actions are costly. In this context, behavioral economists have incorporated psychological factors such as behavioral attitudes, emotions, irrationality, and uncertainty into economic analysis, blending the maximization of utility in economics with the maximization of satisfaction in psychology (Smith 1976; Kahneman and Frederick 2002).

Based on the aforementioned discussion concerning the stakeholder theory, the general public is not a direct stakeholder in APWM. Over the past decade, the public's attitudes towards APWM have evolved from "unawareness" to "awareness," from "indifference" to "intense concern," and from "outsider" to "active participant." Public engagement in APWM is driven by the indirect benefits of ensuring food safety and environmental improvement, as well as fulfilling psychological needs for social responsibility and reciprocity. Therefore, behavioral economics can effectively elucidate and interpret public cognition, attitudes, expectations, motivations, and behaviors regarding the public's collaborative participation in agricultural white pollution control.

Throughout the development of behavioral economics, several key theories have emerged, including prospect theory (Kahneman and Tversky 1979), framing effects (Kahneman and Tversky 2000), social cognitive theory (Bandura 1986), and the theory of planned behavior (TPB) (Ajzen 1991). Among them, TPB is valuable and influential in individual behavior research for considering the interaction between individual, social, and environmental factors (Yuriev et al. 2020). The theory has generally been favoured over other models and been the most widely used because of its structural simplicity and general applicability across domains and cultures (Klöckner 2015).

(5) Theory of change

The theory of change (ToC) is “a theory of how and why an initiative works” (Weiss 1997) which “can be empirically tested by measuring indicators for every expected step on the hypothesized causal pathway to impact” (De Silva et al. 2014). ToC typically begins with the desired impact, mapping backward from this goal to identify the necessary preconditions through an analysis of the intervention's context and stakeholder consultations (Dyson and Todd 2010). It establishes pathways of change, articulates intermediate objectives, formulates testable hypotheses, and is documented through visual diagrams, narrative summaries, or other forms of presentation (Belcher et al. 2024). Over time, ToC has evolved into a strategic tool widely utilized in philanthropy, international development, social enterprises, and other fields committed to driving societal transformation. It serves as a foundation for planning, monitoring, and evaluation efforts (Brest 2010).

Under the APWM framework, which predominantly operates through the government subsidy & enterprise operation model, significant challenges have emerged. These include an overreliance on government subsidies and the inherent uncertainty surrounding funding sources. APWM represents a public good characterized by positive externalities—it contributes to a cleaner environment, safer food supplies, and improved public health. Given its intrinsic connection to agricultural ecosystems as a type of public good, APWM concerns all members of society. To enhance the sustainability and resilience of APWM, it is imperative to integrate the broader public as key stakeholders into the management framework. Such effort can mitigate the current situation in which the public remains largely “outsiders” to the APWM system. Behavioral economics provides a theoretical foundation for designing interventions aimed at improving public engagement. These interventions could elevate societal awareness of APWM, strengthen social norms around active participation, and enhance individuals’ perceived behavioral control over contributing economically to the management. Harnessing the latent potential of the public in this way could significantly advance more effective environmental governance. Furthermore, as a comprehensive systems-based endeavor, sustainable APWM necessitates the collaboration of all stakeholders—governments, enterprises, farmers, and the public. Such a framework, rooted in symbiotic interests, shared rights, and collective responsibilities, fosters a more resilient approach to environmental governance. This collaborative model aligns closely with the United Nations' Sustainable Development Goals (SDGs), particularly SDG-2: Zero Hunger, SDG-3: Good Health and Well-being, and SDG-13: Climate Action (UN 2015). Theory of Change for APWM is shown in Figure 2-1.

Situation	Operating on the government subsidy & enterprise operation model, APWM lacks sustainability.
Intended outcome	Increase APWM sustainability and resilience.
Outcome pathway	Short-term outcome: Public participation in APWM to alleviate the uncertainty caused by the funding gap of APWM. Long-term outcome: Stakeholders of APWM including governments, enterprise, farmers and the public collaborate in APWM.
Intervention activity	Provide information to intervene with the public to strengthen their comprehensive knowledge of APWM, reinforce their social norms and their sense of behavioral control to participate in APWM.
Assumption	The public's perception of APWM, social norms for contributing to APWM, and sense of behavioral control can be effective in promoting their participation in APWM.
Impact	Sustainable APWM practices contribute to the SDGs.

Figure 2-1 Theory of Change for APWM. Source: Diagrammed by the author.

The theoretical foundation is summarized as Figure 2-2.

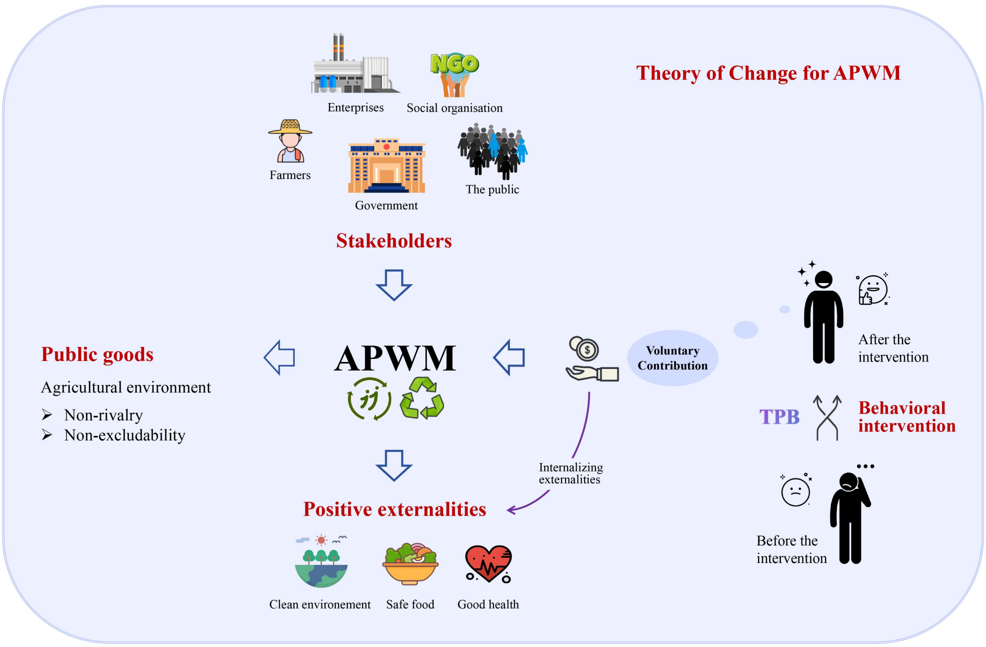

Figure 2-2 Theoretical foundation. Source: Diagrammed by the author.

2. Thesis framework and research objectives

2.1 General framework and outline

The research applies a logical framework of “problem diagnosis - comprehensive performance evaluation - sustainable management mechanism design” to enhance the APWM through cost-benefit analysis and public participation. Specifically, the research progresses as follows: Firstly, taking mulch film as the example, the current application, pollution, and management status of agricultural plastics are thoroughly reviewed, practical and scientific issues in their application and management are diagnosed. Secondly, by integrating statistical data with field surveys, representative regions for the study of APWM are identified, and specific study regions for in-depth investigation are determined. Thirdly, a comprehensive performance analysis of two environmentally friendly mulch film management measures - thicker mulch film application and biodegradable mulch film application - is conducted. The evaluation provides scientific references for subsequent policy assessment and optimization of APWM strategies. Fourthly, from the multi-entity participation perspective, the feasibility of public payment scheme for the sustainable APWM is investigated. Fifthly, leveraging information intervention strategies, the initiatives that can evolve the APWM public payment scheme from idea to reality are examined. Finally, a general discussion is conducted, and directions for upcoming research are proposed. The structure and analytical outline of the thesis are as follows in Figure 2-3.

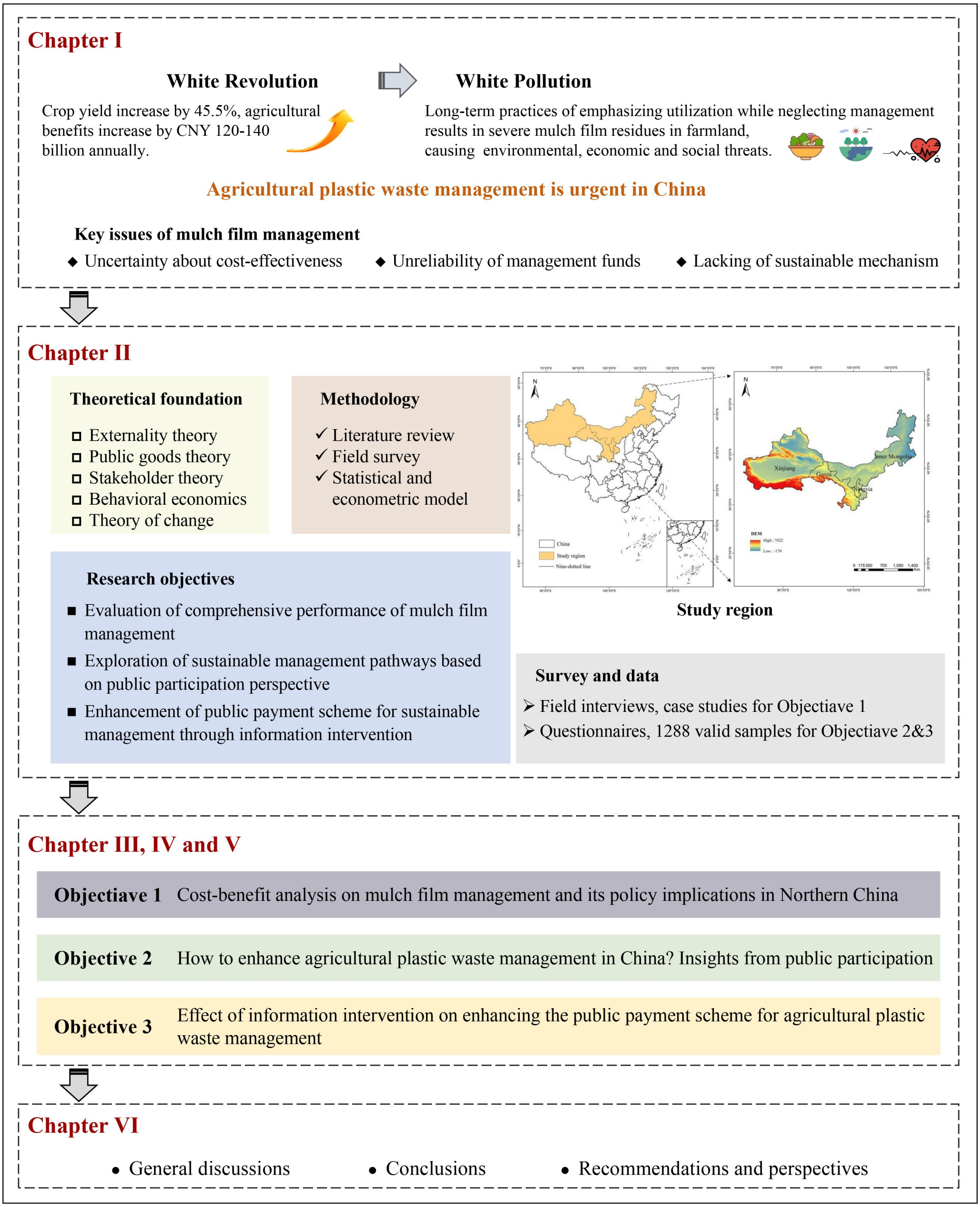

Figure 2-3 Thesis framework. Source: Diagrammed by the author.

2.2 Research objectives

In order to better explain research objectives of the thesis, a schematic diagram for elaborating the system of sustainable APWM has been drawn (Figure 2-1). Based on the aforementioned discussion of the initiative as well as problematic issues of APWM, the objectives of this thesis can be split into three directions:

Objectives 1: Comprehensive performance analysis of mulch film management (Chapter III)

The goal of the study to establish an economic decision-making model by applying the cost-benefit analysis to systematically assess the economic performance of mulch film management and furnish detailed information on the cost-benefit correlation of different management measures. Evaluating the economic feasibility of different mulch film management strategies can provide scientific reference for the current mulch film policies and bring insights for restructuring regulatory frameworks and modifying incentives to allocate fiscal resources more efficiently, hence enhancing support for agricultural white pollution control. This is of significant theoretical and practical implications for improving the agricultural ecological environment and facilitating integrated economic, social, and environmental development.

Objectives 2: Exploration of sustainable APWM pathways based on public participation perspective (Chapter IV)

The study attempts to explore whether public payment can be a promising solution to mitigate the APWM funding gap. Specifically, the study offers some new insights in the following two aspects. Foremost, the public's payment willingness towards APWM is innovatively investigated to determine the possibility of raising APWM funding through public payment. Subsequently, applying the extended TPB, the driving pathways of the public's payment decision are clarified to guide initiatives for promoting public payment. The findings are conducive to understanding the public's decision-making of participating in APWM and thus provide a theoretical basis for developing a sustainable and resilient agricultural non-point waste management scheme.

Objectives 3: Enhancement of public payment scheme for sustainable APWM through information intervention (Chapter V)

The aim of the study is to verify the effect of information intervention on the public's payment for APWM. Specifically, the study applied a randomized controlled trial (RCT) to explore whether the information strategy is effective in influencing respondents' WTP for APWM, and if so, how does information take effect in this matter. The findings can help accurately identify the outstanding issues hindering public participation in APWM and clarify the motivated mechanism of promoting the public to contribute. The insights gained from the study would provide theoretical evidence that can guide policymakers in developing targeted policies and promoting widespread social support to facilitate the public payment scheme for APWM evolving from idea to reality.

To clarify, as previously mentioned, agricultural plastics encompass a wide variety of types, with mulch film being one such category. In this research, the analysis for Objective 1, which pertains to cost-benefit analysis, is conducted using mulch film as a case study. In contrast, Objectives 2 and 3, which focus on public participation, are based on agricultural plastics more broadly.

There are three reasons why the study regarding the cost-benefit analysis of APWM is conducted taking the mulch film as example. Firstly, mulch films are the most typical application scenario for agricultural plastics in China. China consumes approximately 2.4 million tons of agricultural plastics annually, with over 50% attributed to mulch film. The mulching area of mulch films is approximately 17 million ha. In comparison, the second largest category of agricultural plastic is greenhouse film, with an annual mulching area of 4.1 million ha. Among various agricultural plastics, mulch film waste contributes the most to white pollution, making research on APWM represented by mulch film waste management in Chapter III highly representative. Secondly, mulch film management poses significant challenges and urgent needs among all agricultural plastics. Mulch film waste is very thin and more difficult to collect than other agricultural plastics. Mulch films are typically applied on the soil surface, and their residuals often include plant roots and soil, making the cleaning challenge and preprocessing difficult and complex. Thirdly, conducting a cost-benefit analysis of APWM using mulch film as a case study helps avoid unnecessary complexity and ensures the feasibility of the research. Agricultural plastics encompass a wide array of products and usage scenarios. Including all agricultural plastics in the analysis would render the study overly lengthy and intricate, and introduce significant data collection and analysis challenges. Therefore, to enhance the feasibility and effectiveness of the research, this study focuses specifically on mulch film, thereby streamlining the analytical framework and enabling a more in-depth examination of its management costs and benefits. Regarding the studies for the public payment scheme for APWM in Chapter IV and Chapter V, they aim to explore a more sustainable and resilient management mechanism for APWM by incorporating the public in. The public's awareness of agricultural white pollution is general, without distinguishing whether the pollution originates from mulch films or other agricultural plastics. Those willing to pay for APWM expect that agricultural white pollution's threat to the environment, food, and health can be broadly mitigated through collaborative efforts with society and government. Therefore, the waste from agricultural plastics is regarded as the research object in Chapter IV and Chapter V.

3. Methodology

The research integrates normative and empirical analysis, as well as qualitative and quantitative methods, emphasizing a comprehensive application of literature review, field survey, and statistical and econometric model analysis.

(1) Literature review

By systematically searching, reviewing, and analyzing the literature in the fields of agricultural waste management, comprehensive performance analysis, individual behavior science, and public environmental governance, a thorough understanding of the research edge on APWM is gained. The insights and methodologies derived from the literature provide both theoretical support and a methodological reference for the current research.

(2) Research survey

In alignment with the research objectives and questions, and based on a proficient grasp of survey methodologies, the research designs and refines survey questionnaires, conducts field interviews, and implements both online and face-to-face questionnaire surveys. Field interviews are conducted primarily in Lanzhou, Wuwei, and Jinchang in Gansu, Hinggan League in Inner Mongolia, and Changji Hui Autonomous Prefecture in Xinjiang. Interviewees include government officials, mulch film manufacturer, managers and employees of mulch film recycling enterprises, and farmers. The field interviews aim to understand the mulch film management practices in the study region, the challenges faced by different stakeholders, and the application and management of different kinds of mulch films. The questionnaire survey targets the general public in Xinjiang, Gansu, Ningxia, and Inner Mongolia, via the largest online survey platform in China, Questionnaire Star (https://www.wjx.cn/). The survey focuses on respondents' demographic characteristics, awareness of APWM, and WTP for the management initiatives. Additionally, a RCT examining the effect of information intervention on individuals' payments for APWM was designed in this questionnaire.

(3) Statistical and econometric model

Initially, descriptive statistics are applied to depict the demographic characteristics of respondents in the study region, understanding their environmental cognition, APW awareness, willingness to participate in environmental initiatives, and WTP for APWM. This analysis thoroughly characterizes the sampled individuals and lays the analytical foundation for subsequent research on public participation in APWM. Subsequently, different econometric models are applied based on the varying research content and objectives. Specifically, cost-benefit analysis is utilized to calculate the comprehensive performance of different mulch film management measures over their lifecycle. Structural equation model (SEM) clarifies the psychological decision-making pathways behind the public's payment willingness for APWM, and Difference-in-Difference (DID) model tests the effect of information interventions on individuals' payment for the management.

4. Study region, survey and data

The study region of the research encompasses four provinces (autonomous regions) in the north of China: Xinjiang, Gansu, Ningxia, and Inner Mongolia (Figure 2-4). The region is the largest cotton planting area and a significant corn and potato planting area in China, representing remarkably typical and representative scenarios of mulch film application (Yan et al. 2014). Moreover, the frigid and arid climate here renders mulch films the essential agricultural inputs. Statistics reveal that approximately 30% of farmland in the region is covered by mulch film, far exceeding the national average of 10.3%. Annually, around 446,080 tons of mulch films are utilized in the region, making up over one-third of the total consumption in China (NBSC 2023) (Figure 2-5 - Figure 2-7). Correspondingly, the region faces severe mulch film waste and urgent agricultural white pollution control challenges

(Zhang et al. 2022). In 2022, the Chinese government has piloted 2.0 million ha of thicker mulch film and 106,667 ha of biodegradable mulch film across the four provinces (autonomous regions). The region accounts for nearly 60% of the overall pilot area despite comprising only 20% of the national farmland.

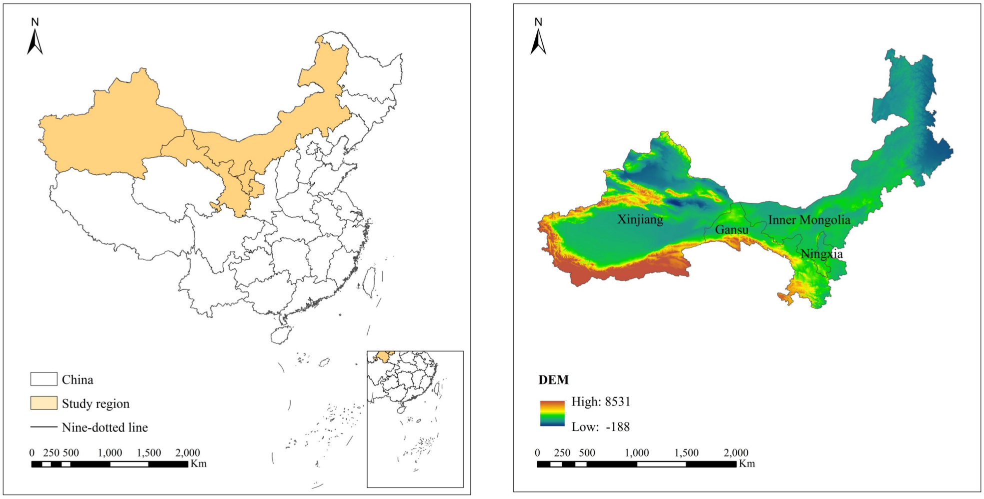

Figure 2-4 The study region. Source: Data from Geospatial Data Cloud (https://www.gscloud.cn/) and diagrammed by the author.

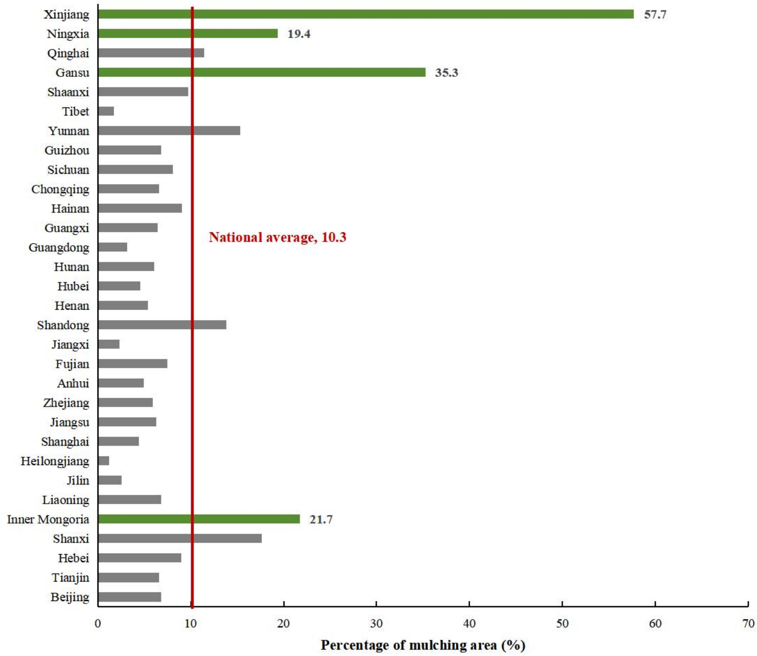

Figure 2-5 Percentage of mulching area in the study region. Data source: China Rural Statistical Yearbook 2023.

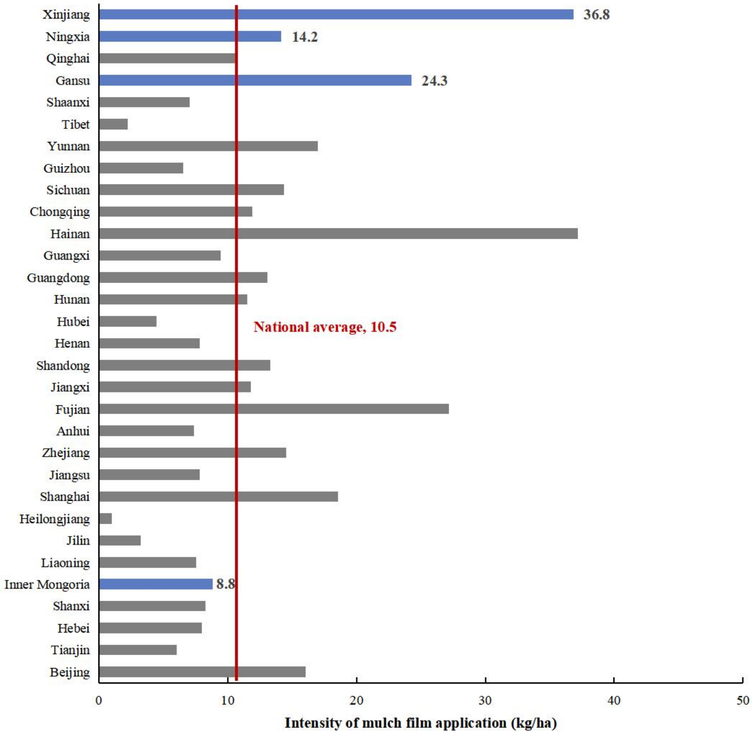

Figure 2-6 Intensity of mulch film application in the study region. Data source: China Rural Statistical Yearbook 2023.

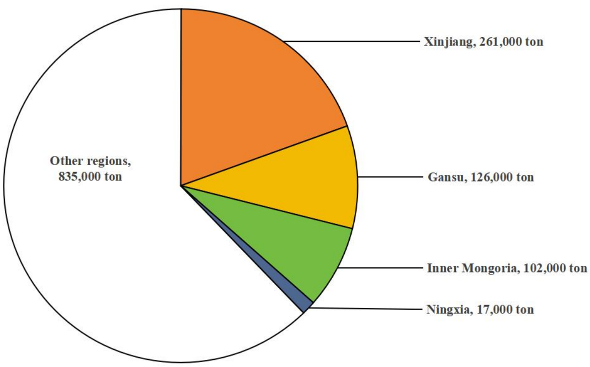

Figure 2-7 Percentage of mulch film usage in the study region. Data source: China Rural Statistical Yearbook 2023.

Additionally, samples within the same geographic location are relatively homogeneous, minimizing the interference of confounding factors. The four provinces (autonomous region) surveyed are in north of China and characterized by comparable demographic characteristics, such as the population's urban-rural ratio, education level, and household economic condition. Furthermore, the similarity in natural climatic conditions, the relatively uniform distribution of primary crops, and comparable levels of mulch film management result in minor differences in mulch film utilization, collection, and disposal practices. This homogeneity mitigates the impact of external conditions on the research outcomes.

The research survey incorporates both field interviews and questionnaires. The cases and associated data gathered through field interviews provide the basis for the cost-benefit analysis of mulch film management (Chapter III). Building upon the selection of four target provinces (autonomous regions), the sampling framework was designed to comprehensively consider factors such as geographical location, levels of socio-economic development, crop types, and the application and management practices of mulch film and other kinds of agricultural plastics. Using a typical sampling method, the study identified Lanzhou, Wuwei, and Jinchang in Gansu Province; Hinggan League in Inner Mongolia; and Changji Hui Autonomous Prefecture in Xinjiang as representative sample regions. These regions predominantly involve key film mulching crops, including corn, cotton, and potatoes. Guided by the research objectives and questions, the field interviews were conducted through semi-structured interviews targeting three primary respondent groups: government officials, mulch film recycling enterprises, and farmers.

Government officials. The study conducts focus group interviews with over 50 government personnel involved in mulch film management at the municipal (prefecture/league), county (banner), and township (sumu) administrative levels, as well as with village collective leaders. Through in-depth semi-structured interviews, the study primarily investigates the agricultural production conditions in the study region, the utilization of mulch film, the management practices for mulch film waste, the implementation plans for scientific utilization and recycling of mulch film at the provincial, municipal, and county levels, rural household waste treatment practices, and their perspectives on challenges and potential solutions in mulch film waste management from the viewpoint of government authorities. A memorandum summarizing the semi-structured interviews is provided in the Appendix.

Enterprises. The enterprise samples for the study are obtained through a typical sampling approach. A detailed list of the enterprises included in the interview survey is presented in Table 2-1.

Table 2-1 Details of enterprise samples.

Enterprise location		Enterprise name	Enterprise details
Gansu	Lanzhou City	Lanzhou Jintudi Plastic Products Co., Ltd.	http://www.lzjintudi.com/rece/AboutUs.asp?lanmu=3
		Gansu Jiyang Plastic Co., Ltd.	https://aiqicha.baidu.com/company_detail_16465174497117
		Lanzhou Xinyinhuan Rubber and Plastic Products Co., Ltd.	https://aiqicha.baidu.com/company_detail_16428181121813
	Wuwei City	Minqin County Weirui Environmental Protection Co., Ltd.	https://aiqicha.baidu.com/company_detail_83392327699286?t=0
		Gansu Bond Industrial Co., Ltd.	https://aiqicha.baidu.com/company_detail_16584042340711
	Jinchang City	Jinchang Xinji Water-Saving Technology Co., Ltd.	https://aiqicha.baidu.com/company_detail_16520762232428
		Jinchang Xinhengtai Manhole Cover Co., Ltd.	https://aiqicha.baidu.com/company_detail_89971866545159
Inner Mongolia	Hinggan League	Inner Mongolia Zhengrui Pipe Industry Co., Ltd.	https://aiqicha.baidu.com/company_detail_31235632011730
		Frontier Biomaterials Technology (Hinggan League) Co., Ltd.	https://aiqicha.baidu.com/company_detail_25667388396248
Xinjiang	Changji Hui Autonomous Prefecture	Qinyuan Plastic Products Factory, Beiwucha Town, Manas County	https://aiqicha.baidu.com/company_detail_99139935986289

Source: Summarized by the author.

For the enterprise samples, interviews are conducted with managers and employees of APW recycling enterprises to explore the operational characteristics of enterprises, the costs and benefits associated with APW recycling, the perceptions of enterprise managers regarding mulch film waste management, as well as the challenges faced in mulch film waste management and the proposed solutions, and enterprises' specific demands. Detailed information regarding the field interviews for enterprises is provided in Section 2.4 of Chapter III and further elaborated in the Appendix.

Farmers. Farmer samples are primarily obtained through simple random sampling within selected sample regions. In the Hinggan League of Inner Mongolia, 18 farmer samples are collected from five townships: Horqin, Dashizhai, Guiliuhe, Julihen, and Chaersen Towns(Horqin Right Wing Front Banner). In Changji Hui Autonomous Prefecture of Xinjiang, 12 farmer samples are gathered from Dianba Town (Changji City), Manas Town (Manas County), and Wutong Town (Wujiaqu City). And in Gansu Province, 12 farmer samples are obtained from Jinya Town (Yuzhong County, Lanzhou City), Suwu, Sanlei, and Daba Towns (Minqin County, Wuwei City), as well as Shuangwan and Ningyuanpu Towns (Jinchuan District, Jinchang City). The survey for farmers primarily focuses on the basic agricultural operational conditions, costs and benefits of crop cultivation, utilization and recycling of mulch film, and pilot demonstrations of scientific utilization and recycling of mulch film. Detailed information regarding the farmer interviews is provided in the Appendix.

In addition to the aforementioned survey subjects and content, supplementary field interviews are conducted to meet the research requirements. These include two APW recycling outlets in Lanzhou City; Chengdashunyuan Agricultural Machinery Manufacturing Co., Ltd. in Wuwei City; and Kangmu Breeding Cooperative in Jinchang City. In Changji Hui Autonomous Prefecture of Xinjiang, interviews are conducted at the landfill site, waste collection site, Chengfa Environmental Energy (Changji) Co., Ltd., Xuze Biotechnology Co., Ltd., and the Institute of Western Agriculture of Chinese Academy of Agricultural Sciences in Changji City.

Questionnaire surveys are conducted online, providing solid data support for the study regarding the public payment for APWM (Chapter IV and Chapter V). The questionnaire surveys are conducted across the entire research region, including Xinjiang, Gansu, Ningxia, and Inner Mongolia (Figure 2-2). The study primarily applies the online survey approach. Questionnaire Star (https://www.wjx.cn/), the most prominent online survey platform with over 300 million active users in China, is commissioned to survey in June and July 2022. Questionnaires are distributed on a large scale via online distribution to individuals residing in the study region. The feedback is administered via Cloud Research, which comes with the platform. Prior to the formal survey, two preliminary surveys with sample sizes of 97 and 487 are carried out for quality assurance. Based on the feedback received during two rounds of preliminary surveys, the final questionnaire is developed by eliminating irrelevant variables, supplementing missing items, addressing logical inconsistencies, and refining the phrasing of questions. This finalized questionnaire is then employed to conduct the formal survey. From the initial pool of 1,405 questionnaires obtained, 1,288 valid responses are finally identified after excluding low-quality submissions.

The questionnaire designed for the data required in Chapter IV comprises three primary parts. The first part includes the demographic characteristics of the respondents, which including the gender, age, place of residence, education level, marital status, number of households, teenagers, elderly, and household income. The second part is the respondents' payment willingness towards APWM. It begins with a Likert scale investigating respondents' payment intentions towards APWM, ranging from 1 (not at all) to 5 (very much), and then the maximum amount they are willing to pay (i.e., WTP) per household per year. The third part, aiming to assess the constructs of the extended TPB framework, contains six latent variables, totaling 32 observable variables (details in SM 2 of Chapter IV). In this part, respondents rate their degree of agreement or disagreement with each statement, using a Likert scale ranging from 1 (completely disagree) to 5 (completely agree). Similarly, the questionnaire tailored for the data required in Chapter V consists of three core components. After a brief introduction to the purpose of the questionnaire and obtaining consent, the first part concentrated on the demographic and household characteristics of the respondents, which is shared between the questionnaires for Chapter IV. The second part aimed at pretesting the respondents' WTP for APWM. WTP is quantified by the maximum amount respondents are willing to pay annually on a household basis. Afterward, participants were randomly assigned to different treatment or control groups, where corresponding information was provided for each group (details in 3.2 of Chapter V). In the third part, respondents were re-interviewed about their WTP in a post-test format.

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3

Chapter III: Cost-benefit analysis of mulch film management and its policy implications in Northern China

Adapt from:

Hao A, Yin C, Léonard A, Dogot T. 2024. Cost–benefit analysis of mulch film management and its policy implications in northern china. Agriculture, 14.

Abstract

Agricultural white pollution is a pressing concern in China. However, the efficiency and rationality of the government's subsidies for mulch film management remain ambiguous. To formulate reasonable policies for mulch film management and optimize fiscal resource allocation, the study applies cost-benefit analysis to evaluate the economic performance of mulch film management. Two environmentally friendly measures being primarily proposed in China, namely the application of thicker mulch film and the substitution of biodegradable mulch film, are selected for analysis, with conventional mulch film serving as the benchmark for comparison. Primary data obtained through field surveys, supplemented by secondary data from national statistics, industry reports, and literature reviews, are used for the study. Results show that thicker mulch film application is cost-effective, with a net benefit of CNY 3,208.8/ha (1 CNY = 0.14 USD), which is CNY 253.8/ha higher than that of conventional mulch film. The net benefit for biodegradable mulch film application is lower than that for conventional mulch film, at CNY 2,244.6/ha. The results reveal the significant potential of promoting the use of thicker mulch film due to its recycling and economic advantages. Findings imply that the further promotion of its use lies in improving farmers' cognition and optimizing subsidy dimensions to allocate government financial resources more effectively. On the contrary, biodegradable mulch film utilization is unprofitable and relies on continuous subsidies. The government can optimize the subsidy standard based on the cost-benefit performance of different mulch films applied and provide incentives to promote cost reductions and efficiency increases. Further analysis indicates that sustainable mulch film management entails developing mechanism to internalize environmental benefits of management and innovating a new governance landscape.

Keywords

mulch film management; cost-benefit analysis; thicker mulch film; biodegradable mulch film; policy implication

1. Introduction

As a pivotal agricultural technique, mulch film application has revolutionized the conventional agricultural landscape, ushering in profound changes to agricultural production patterns and regional planting structures (Lobell and Field 2007; Kasirajan and Ngouajio 2012). Owing to its exceptional capabilities in soil warming, moisture conservation, and weed prevention, mulch film has the potential to elevate crop yields by 20-50% (Liu et al. 2014; Liu et al. 2014), thereby bestowing upon Chinese agriculture direct economic benefits ranging from CNY 120 to 140 billion annually (Yan et al. 2021). Nevertheless, over the span of more than forty years of utilization, insufficient environmental consciousness and disregard for recycling have precipitated the massive accumulation of residual plastics in farmland (Zhang et al. 2020), resulting in a litany of issues, including soil degradation, yield constraints, and microplastic contamination (Koskei et al. 2021). The “white revolution” is deteriorating into “white pollution”.

The Chinese government has progressively prioritized APWM in the past decade. Since 2022, authorities have initiated the pilot demonstration of “mulch film scientific utilization and recycling” in nine provinces (autonomous regions) where mulch film is intensively utilized, with the pilot area accounting for 2.9% of the nationwide farmland. The pilot emphasizes two main environmentally friendly mulch film management practices. These include, firstly, advocating for thicker mulch film application (Figure 3-1). Typically, the mechanical strength of mulch film declines after several months to one year of utilization, making it challenging to collect and reprocess, while increasing the thickness can significantly enhance its recyclability (Yu et al. 2021). The thickness of pilot-endorsed thicker mulch film measures 0.015 mm. This surpasses the conventional mulch film thickness of 0.010 mm, which is the current Chinese national standard (GB 13735-2017 2017). Evidence suggests that thicker mulch film has a recovery rate of over 90%, far exceeding that of conventional mulch film at 30% (Xiong et al. 2023). The other practice is promoting biodegradable mulch film application. Composed primarily of polysaccharides and polyesters, biodegradable materials theoretically have the potential to break down into H_2O, CO_2, and microbial biomass within a reasonable time frame (Sintim et al. 2020). After crop harvest, biodegradable mulch film is plowed into the soil and is expected to decompose over time, eliminating any need for recycling.

Thicker mulch film and biodegradable mulch film lead to discernibly higher utilization expenses compared with those of conventional mulch film owing to their elevated consumption volume and price per farmland area. Applying these two types of mulch film undoubtedly increases the economic strain on users, thereby dampening their enthusiasm for adoption. In order to incentivize farmers to use such mulch films, the government provides subsidies of CNY 450/ha for thicker mulch film and CNY 1,800/ha for biodegradable mulch film to offset the additional expenses. The Chinese government is ambitious in beating agricultural white pollution, aiming to scale up the pilot area to 15 million ha by 2025, covering over 85% of the national mulching farmland. Under the current subsidy standards, the government is required to allocate almost CNY 10 billion for mulch film management, which is more than 3.0% of its investment in environmental protection (MOF 2023). It should be acknowledged that mulch film management is only one aspect of environmental governance in China, and such significant financial expenses are obviously unsustainable. Especially given the current slowdown in economic growth and tight balance of financial circumstances, there is a growing emphasis on efficiently allocating fiscal resources.

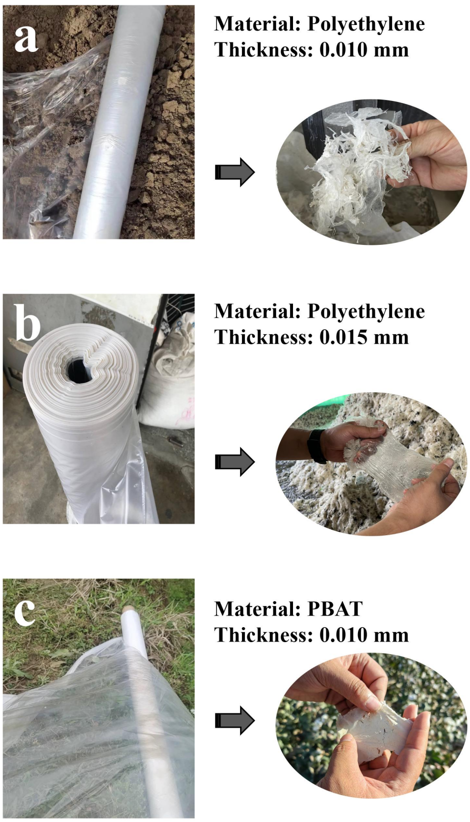

Figure 3-1 Comparison of three types of mulch film: (a) conventional mulch film, (b) thicker mulch film, and (c) biodegradable mulch film. Source: Photographed during the field survey by the author.

Reasonable subsidies constitute a pivotal aspect influencing the effectiveness of government policies (Li et al. 2022). An excessive subsidy for mulch film management may increase the financial burden on the government and impede the efficiency of fiscal resource allocation, while an insufficient subsidy could diminish the proactive engagement of farmers, obstructing the attainment of management objectives. It is essential to strike a balance between governments and other stakeholders in mulch film management expenditure. Thus, what is the economic performance of different environmentally friendly mulch film management practices? How reasonable are the current subsidy standards for mulch film management? Are the subsidies precisely targeted? Can the management mechanism be further refined to optimize government functions? Information on the cost-effectiveness of mulch film management can provide the foundation for addressing these inquiries (Chaianong et al. 2024). To this end, cost-benefit analysis is adopted to analyze the benefits and costs of mulch film management to improve the understanding of its economic performance (Brent 2006; Jeswani et al. 2010), to optimize mulch film management policies, and to formulate a sustainable management mechanism based on this information. The cost-benefit analysis is conducted in four provinces (autonomous regions) in the north of China: Xinjiang, Gansu, Ningxia, and Inner Mongolia. This region is the largest cotton planting area and a significant corn and potato planting area in China, representing remarkably typical and representative scenarios of mulch film application (Yan et al. 2014). Moreover, the frigid and arid climate here renders mulch film an essential agricultural input. Correspondingly, the region faces severe mulch film waste and urgent agricultural white pollution control challenges (Zhang et al. 2022). The Chinese government has piloted 2.0 million ha of thicker mulch film and 106,667 ha of biodegradable mulch film across the four provinces (autonomous regions). The region accounts for nearly 60% of the overall pilot area despite comprising only 20% of the national farmland.

In summary, the goal of this study is to establish an economic decision-making model by applying cost-benefit analysis to systematically assess the economic performance of mulch film management and provide detailed information on the cost-benefit correlation of different management measures. Evaluating the economic feasibility of different mulch film management strategies can provide a scientific reference for current mulch film management policies and provide insights for restructuring regulatory frameworks and modifying incentives to allocate fiscal resources more efficiently, hence enhancing support for agricultural white pollution control. This is of significant theoretical and practical importance for improving the agricultural ecological environment and facilitating integrated economic, social, and environmental development.

2. Methods

2.1. Cost-benefit model of mulch film management

This study conducts cost-benefit analysis of mulch film management, focusing on two specific environmentally friendly measures: the application of thicker mulch film (Option 1) and that of biodegradable mulch film (Option 2), with the application of conventional mulch film (Baseline) as the benchmark for comparison. The management process consists of three key stages: procurement, utilization, and treatment. Meanwhile, external costs that are not captured in financial expenditures are taken into account in the study. Drawing upon the methodologies applied previously regarding cost-benefit analysis (Djukic et al. 2016; Liu et al. 2020; Hsu 2021; Drenning et al. 2023), this study applies the net present value (NPV) and the benefit-cost ratio (BCR) to characterize the comprehensive performance associated with mulch film management. The equations for calculating NPV and BCR are as follows:

$$NPV = \sum_{t=0}^{X} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{X} \frac{C_t}{(1+r)^t} \quad (1)$$

$$BCR = \left(\sum_{t=0}^{X} \frac{B_t}{(1+r)^t}\right) / \left(\sum_{t=0}^{X} \frac{C_t}{(1+r)^t}\right) \quad (2)$$

where X represents the project's time span, t stands for time, and Bt and Ct denote the benefits and costs in year t, respectively. r is the social discount rate.

NPV is the summation of the present values (PVs) for future cash flows (Sinnott and Towler 2019). The most economically advantageous mulch film management measure is the one with the highest positive NPV. Similarly, if a project has a BCR greater than 1.0, it is expected to deliver a positive NPV to a firm and its investors (Ross and Westerfield 2021).

2.2. Costs of mulch film management

$C_{management}$ represents the costs of mulch film management. As stated above, $C_{management}$ mainly consists of the procurement cost ($C_{procurement}$), utilization cost ($C_{utilization}$), and treatment cost ($C_{treatment}$). $C_{management}$ is the sum of these three components:

$$C_{management} = C_{procurement} + C_{utilization} + C_{treatment} \quad (3)$$

2.2.1. Procurement costs

$C_{procurement}$ is the cost incurred during the purchase of mulch film by farmers. It depends on the unit price ($UP_{mulching}$) of the mulch film, the quantity of mulch film used per unit of farmland ($UQ_{mulching}$), and the mulching area ($S_{mulching}$). $C_{procurement}$ represents the multiplication of the three components:

$$C_{procurement} = UP_{mulch\,film} \times UQ_{mulching} \times S_{mulching} \quad (4)$$

2.2.2. Utilization costs

$C_{utilization}$ refers to the costs incurred during the mulching process. It mainly consists of two parts: Firstly, the transportation cost ($C_{transportation}$) incurred in transporting mulch film from manufacturer to farmland is referred to. $C_{transportation}$ is related to the quality of mulching per unit of farmland ($UQ_{mulching}$), the mulching area ($S_{mulching}$), the transportation distance from producer to farmland ($D_{transportation}$), and the unit transportation cost ($UC_{transportation}$). Secondly, the costs generated during the mulching process ($C_{mulching}$) are referred to, which include the fuel cost (C_{fuel}) and labor cost (C_{labor}). External costs incurred during the transportation and mulching processes are also accounted for, namely the monetization of greenhouse gas (GHG) emissions from fuel consumption (M_{GHG}). This is assessed using the unit price for CO_2 (UP_{GHG}), the quality of fuel consumed ($Q_{fuel\ consumption}$), and its carbon emission factor (EF_{fuel}).

$$\begin{aligned} C_{utilization} &= C_{transportation} + C_{mulching} \\ &= UQ_{mulching} \times S_{mulching} \times D_{transportation} \times UC_{transportation} + \left(C_{fuel} + C_{labor}\right) \times S_{mulching} + M_{GHG} \end{aligned} \quad (5)$$

2.2.3. Treatment costs

In the case of conventional mulch film, the collected residual film is transported to the fields or informal landfill sites around the farmland for landfilling. There are collection costs and transportation costs for the collected residual film, while the remaining film is left in the soil. Thicker mulch film has good collectability and processability. The residual film is collected, transported to a mulch film processing plant, and recycled through a series of processes such as crushing, washing, melting, extruding, and so on. $C_{treatment}$ primarily encompasses the costs of mulch film waste collection ($C_{collection}$), transportation ($C_{transportation}$), and mechanical recycling ($C_{mechanical\ recycling}$). Biodegradable mulch film is plowed into the soil after crop harvesting and decomposes completely without treatment.

$$C_{treatment} = C_{collection} + C_{transportation} + C_{mechanical\ recycling} \quad (6)$$

Similarly, the collection and transportation processes also entail economic and environmental costs. The economic costs are mainly labor and fuel costs. The environmental costs refers to the GHG emissions from fuel consumption.

$$C_{collection} = \theta \times UQ_{mulching} \times UC_{collection} \times S_{mulching} + M_{GHG} \quad (7)$$

$$C_{transportation} = (\theta \times UQ_{mulching} \times S_{mulching} \times D'_{transportation} \times UC_{transportation}) + M_{GHG} \quad (8)$$

where θ is the recovery rate of mulch film waste, $UC_{collection}$ is the unit price of mulch film collection, and $D'_{transportation}$ is the distance from the farmland to the treatment site.

In accordance with the project's financial analysis framework, $C_{mechanical\ recycling}$ comprises two main elements: capital costs and operating and maintenance costs (Jing *et al.* 2018; Ross and Westerfield 2021). Capital costs are the one-time expenditures derived from the land, plant, equipment and other fixed assets (Supplementary Material). In this study, capital costs are converted into annual costs by considering a 15-year depreciation period ($C_{depreciation}$). Operating and maintenance costs are annual ongoing expenditures, including equipment maintenance costs ($C_{equipment\ maintenance}$), labor costs ($C_{labor}$), enterprise management costs ($C_{enterprise\ management}$), procurement costs of materials like water, energy, and mulch film waste ($C_{material}$), mulch film waste storage costs ($C_{storage}$), sludge removal costs ($C_{sludge\ removal}$) and taxes (C_{tax}).

$$C_{mechanical\ recycling} = C_{depreciation} + C_{equipment\ maintenance} + C_{labor} + C_{enterprise\ management} + C_{material\ procurement} + C_{storage} + C_{sludge\ removal} + C_{tax} \quad (9)$$

(1) Depreciation costs

$C_{depreciation}$ is estimated by applying the straight line method. Under straight-line depreciation, a fixed amount of depreciation is charged for each period throughout the project's life cycle. The cumulative amount equals the original value of the asset (Panneerselvam 2013).

$$C_{depreciation} = (V_{initial} - V_{salvage})/n = \left[V_{initial} \times (1-\lambda)\right]/n \quad (10)$$

where $V_{initial}$ represents the initial value of the assets, $V_{salvage}$ represents the assets' salvage value, n is the lifespan of the assets, and λ is the salvage rate.

(2) Equipment maintenance costs

$C_{equipment\ maintenance}$ indicates the scheduled maintenance of the equipment. Maintenance costs are fixed throughout the lifespan. This value is calculated as a percentage, α, of $C_{depreciation}$:

$$C_{equipment\ maintenance} = C_{depreciation} \times \alpha \tag{11}$$

(3) Labor costs

C_{labor} is the cost incurred by employees. It is computed based on the average wages and the number of employees required. The number of employees depends on the enterprises' processing load and the working load of each employee.

$$C_{labor} = W_{local\ average} \times PC_{enterprise} \div L_{employee} \tag{12}$$

where $W_{local\ average}$ is the local average wage for the plastic recycling industry. $PC_{enterprise}$ is the enterprise's annual processing load, and $L_{employee}$ is the working load for each employee annually.

(4) Enterprise management costs

$C_{enterprise\ management}$ pertains to the daily expenses accrued by the administrative department of the enterprise in organizing production and operation activities. $C_{enterprise\ management}$ positively correlates with the number of employees. The study calculates it as a percentage, β, of C_{labor} (Li et al. 2016).

$$C_{enterprise\ management} = C_{labor} \times \beta \tag{13}$$

(5) Material costs

Different materials are required for the processing of mulch film waste. $C_{material}$ mainly includes electricity, fuel, and mulch film waste costs. It is calculated based on the quality of the treated plastic waste, the quantity of different materials required ($Q_{material}$), and the unit price of the material ($UP_{material}$):

$$C_{material} = \theta \times UQ_{mulching} \times S_{mulching} \times Q_{material} \times UP_{material} \tag{14}$$

where $Q_{material}$ is the quantity of material k required to treat each unit of mulch film waste, and $UP_{material}$ is the unit price of material k. k = 1, 2, 3 represents electricity, fuel, and mulch film waste, respectively.

(6) Mulch film waste storage costs

Generally, a certain amount of mulch film waste needs to be accumulated before it can be processed. Thus, storage costs are incurred. $C_{storage}$ is related to the volume of mulch film waste and the unit price for mulch film storage ($UC_{storage}$).

$$C_{storage} = \theta \times UQ_{mulching} \times S_{mulching} \times \eta \times UC_{storage} \tag{15}$$

where η is the conversion coefficient between mulch film waste's volume and weight.

(7) Sludge removal costs

The treatment of mulch film produces waste such as sludge. The removal of the waste incurs relevant costs. $C_{sludge\ removal}$ is a function of the sludge's weight and unit removal price ($UC_{sludge\ removal}$).

$$C_{sludge\ removal} = Q_{sludge} \times UC_{sludge\ removal} \tag{16}$$

(8) Tax

Mulch film recycling enterprises are responsible for paying the corresponding taxes as required. According to "Value Added Tax (VAT) Preferences Catalogue of Products and Services for Resources Comprehensive Utilization" (MOF and STA 2021), mulch film recycling is eligible for a 100% instant VAT refund policy. Therefore, C_{tax} only includes income tax in this study.

$$C_{tax} = PBT \times \tau \tag{17}$$

where *PBT* is the profit before tax, and τ is the rate of income tax.

2.3. Benefits of mulch film management

The benefits of mulch film management ($B_{management}$) encompass economic gains and environmental benefits (benefits from reduced environmental impacts compared with conventional mulch film application) (Haraguchi et al. 2019). Generally, the benefits consist of four main components.

Firstly, mulch film application leads to increased crop yields, resulting in economic benefits ($B_{increased\ yield}$). These are primarily associated with the potential increase in yield of different crops with different mulch films. The planting area within the study region is 20.3 million ha, with corn, potato, and cotton collectively accounting for 50.38% of the total (NBSC 2023a). These three crops are the predominant mulching crops in China. Hence, the three crops are considered target mulching crops for calculation.

$$B_{increased\ yield} = IY_{crop} \times S_{crop} \times UP_{crop} \tag{18}$$

where IY_{crop} represents the potential increase in yield of crop *i* after mulching with mulch film *j*, S_{crop} is the area of crop *i* with mulch film *j*, and UP_{crop} is the market price of crop *i*. *i* = 1, 2, 3 represents corn, potato, and cotton, respectively, and *j* = 1, 2, 3 represents conventional mulch film, thicker mulch film, and biodegradable mulch film, respectively.

Secondly, there are economic advantages introduced by selling generated byproducts ($B_{generated\ byproduct}$). These primarily refer to regenerated plastic pellets. $B_{generated\ byproduct}$ is related to the quantity of regenerated plastic pellets and their unit price ($UP_{generated\ byproduct}$).

$$B_{generated\ byproduct} = \theta \times UQ_{mulching} \times S_{mulching} \times \mu \times UP_{generated\ byproduct} \tag{19}$$

where μ is the conversion coefficient between mulch film waste and regenerated plastic pellets.

Thirdly, products regenerated through waste recycling offer environmental benefits. These products reduce raw material consumption and, correspondingly, prevent the release of GHG emissions from the manufacturing of products ($B_{products\ avoidance}$). This value is mainly calculated based on the quantity of regenerated plastic pellets and the GHG emissions ($GHG_{plastics}$) during their manufacture.

$$B_{products\ avoidance} = \theta \times UQ_{mulching} \times S_{mulching} \times \mu \times GHG_{plastics} \tag{20}$$

Lastly, there are environmental benefits of recycling and substitution ($B_{recycling\ and\ substitution}$). These refers to the reduction in GHG emissions resulting from avoiding improper disposal of plastic waste through the recycling of thicker mulch film and the substitution of this with biodegradable mulch film. $B_{recycling\ and\ substitution}$ is determined by the amount of plastics that are prevented from being inappropriately disposed and the difference in GHG emissions.

$$B_{recycling\ and\ substitution} = \theta \times UQ_{mulching} \times S_{mulching} \times \mu \times GHG_{emission\ gap} \tag{21}$$

Thus, $B_{management}$ can be expressed as follows:

$$B_{management} = B_{increased\ yield} + B_{generated\ product} + B_{product\ avoidance} + B_{recycling\ and\ substitution} \tag{22}$$

The cost-benefit model of mulch film management is summarized in Figure 3-2.

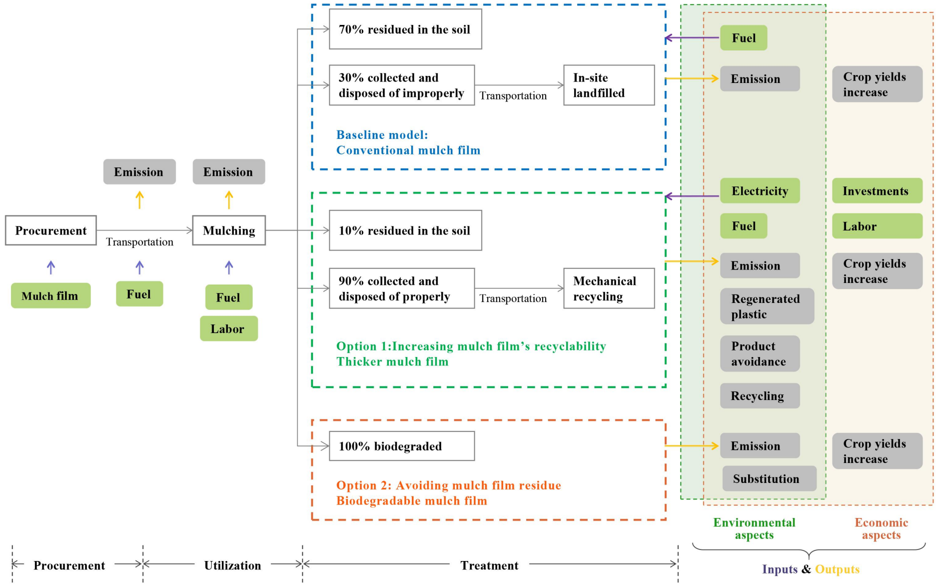

Figure 3-2 The boundary of mulch film management in the study. Source: Diagrammed by the author.

2.4. Data

2.4.1. Scenario assumption of mulch film application area

In the study, the mulch film management area follows the pilot demonstration of mulch film scientific utilization and recycling as the reference for scenario assumptions. According to the pilot arrangements, by 2022, the nationwide adoption of biodegradable and thicker mulch films reached 0.3 million ha and 3.3 million ha, respectively. By 2025, the government aims to expand the application of these environmentally friendly mulch films across 2 million ha and 13 million ha, respectively. Based on the schedule, within the study region, the adoption of biodegradable and thicker mulch films amounts to 106.7 thousand ha and 2.0 million ha, respectively (Business as usual scenario). The second scenario is based on the successful progress of the pilot policy (Management policy smoothly progressed).

Assuming that biodegradable mulch film is applied to all potato-planting farmland and thicker mulch film is applied to all corn- and cotton-planting farmland in the study region, the area of the two kinds of mulch films will expand to 1.0 million ha and 9.2 million ha, respectively, by 2025. A more upgraded scenario would apply biodegradable mulch film to all crops suitable for its application, including potato, peanut, and garlic, and apply thicker mulch film for other film mulching crops, including cotton, corn, and vegetables. Extending the simulation to the whole country under the ideal scenario, the application of thicker and biodegradable mulch film would reach 68.5 million ha and 10 million ha, respectively. Considering the application area of environmentally friendly mulch films, three scenarios are developed, as shown in Table 3-1.

Table 3-1 Scenario description and required management fund estimation.

Scenario	Background of simulation	Area of mulch film management	Cost of mulch film management (billion CNY)
Business as usual	In March 2022, the Chinese government launched the “mulch film scientific utilization and recycling” pilot demonstration nationwide in 9 key mulch film utilization provinces (autonomous regions). The initiative supports the promotion of the application of thicker mulch film on 3.3 million ha and biodegradable mulch film on 0.3 million ha.	In the study region, 2.0 million ha of thicker mulch film and 106.7 thousand ha of biodegradable mulch film have been introduced, while the rest of mulching farmland applies conventional mulch film.	1.1
Management policy smoothly progressed	According to the pilot demonstration plan, environmentally friendly mulch film management will be further intensified, striving to promote the application of 13.3 million ha of thicker mulch film and 2.0 million ha of biodegradable mulch film by 2025.	In the study region, thicker mulch film is applied to 2.5 million ha of cotton and 6.7 million ha of corn, while biodegradable mulch film is applied to 1.0 million ha of potato.	5.9
Ideal situation	Assuming that the plan is thoroughly implemented nationwide, thicker mulch film is applied to crops such as cotton, corn, and vegetable, and biodegradable mulch film is applied to crops such as potato, peanut, and garlic.	Nationally, thicker mulch film will be applied to 3.0 million ha of cotton, 43.1 million ha of corn, and 22.4 million ha of vegetable, while biodegradable mulch film will be applied to 4.5 thousand ha of potato, 4.7 thousand ha of peanut, and 0.8 million ha of garlic.	49.6

Source: Summarized by the author.

2.4.2. Parameter estimation for this study

The parameter values from the study are summarized in Table 3-2.

Table 3-2 Parameter values in the study.

Parameter	Value	Parameter	Value
$UP_{mulching}$	CNY 9.0/kg for thicker mulch film and conventional mulch film; CNY 26.0/kg for biodegradable mulch film.	$PC_{enterprise}$	10,000 tons
$UQ_{mulching}$	92.0 kg/ha for conventional mulch film; 138.0 kg/ha for thicker mulch film; 126.0 kg/ha for biodegradable mulch film.	$L_{employee}$	150 tons
$D_{transportation}$	10 km	β	30%
$UC_{transportation}$	CNY 1.1/(ton·km)	$Q_{material}$	2889,000 kW·h/year for electricity; 882 L/year for fuel; 10,000 ton/year for mulch film waste
$C_{fuel} + C_{labor}$	CNY 450/ha	$UP_{material}$	CNY 1.80/kW·h for electricity; CNY 7.49/L for fuel; CNY 600/ton for mulch film waste.
UP_{GHG}	CNY 59.68/ton	η	5
$Q_{fuel\ consumption}$	15 L/km for transportation; 7.5 L/ha for mulching.	$UC_{storage}$	CNY 9/m^3
EF_{fuel}	3.12 kg CO_2/L	Q_{sludge}	300 tons
θ	90%	$UC_{sludge\ removal}$	CNY 41.5/ton
$UC_{collection}$	CNY 600/ha	τ	25%
$D'_{transportation}$	10 km for conventional mulch film; 100 km for thicker mulch film; 0 km for biodegradable mulch film.	UP_{crop}	CNY 2.56/kg for corn; CNY 2.49/kg for potato; CNY 6.97/kg for cotton.
$V_{initial}$	Table S3-1	IY_{crop}	Table S3-2
n	15 years	μ	0.25
λ	5%	$UP_{regenerated\ product}$	CNY 5975/ton
α	2%	$GHG_{plastics}$	2.67 kg CO_2/kg
$W_{local\ average}$	CNY 59,739/year	$GHG_{emission}$	6.53 kg CO_2/kg for landfill; −0.09 kg CO_2/kg for mechanical recycling; 3.9 CO_2/kg for biodegradable material degradation.

Source: Summarized by the author.

Specifically, the concrete parameters are assigned the following values.

During the procurement stage, field surveys and the relevant literature indicate that 92.0 kg/ha of conventional mulch film is required, while 138.0 kg/ha is required for thicker mulch film (Tan et al. 2023). Based on industry data, the price of plastic mulch film is CNY 9.0/kg. The utilization of biodegradable mulch film which typically has a thickness of 0.010 mm, is 126.0 kg/ha, with a price of CNY 26.0/kg.

The transportation process refers to parameters of road traffic, with a unit cost of CNY 1.1/(ton·km) (Liu et al. 2020). The transportation distance from manufacturer to farmland is preset at 10.0 km. According to the field survey, the total economic cost of mulching is CNY 450/ha, with fuel consumption for transportation at 15.0 L/km and for mulching at 7.5 L/ha. Regarding the monetization of GHG emissions during fuel consumption, the carbon EF of fuel is calculated as 3.12 kg CO_2/L (IPCC 2006). The emission price of CO_2 is based on the Fudan Carbon Price Index, calculated at the median price of the carbon emission quota in August 2023, which was CNY 59.68/ton (FDRCSD 2023). The monetization of carbon emissions for transportation and mulching are CNY 2.8/km and CNY 1.4/ha, respectively.

For treatment, the field survey showed that collecting and transporting mulch film waste to a treatment site costs CNY 600/ha. The recovery rate of mulch film waste, θ, is 90% (Xiong et al. 2023). Fuel consumption for collection is estimated at 23.8 L/ha (Xiong et al. 2023). The value of r is set at 8% (NDRC 2006). Following government regulations and industry practices, the average depreciation life is calculated as 15 years, with a salvage rate of 5%. Rate α for equipment maintenance is 2% (Liu et al. 2020). The average workload per employee is estimated by the enterprise manager to be 150 tons/year. The average wage is calculated to be CNY 59,739/year under industry standards (NBSC 2023b). β for enterprise management costs is calculated to be 30% (Liu et al. 2020). According to the enterprise survey, the electricity consumption for processing 1 ton of mulch film waste is 288.9 kW·h. The electricity price is CNY 1.8/kW·h based on the industrial electricity price in the study region (GSDRC 2013). For an enterprise with a processing load of 17,000 tons of mulch film waste per year, the annual fuel consumption is 1,500 L, with an average fuel price in the study region of CNY 7.5/L (Cngold 2024). The industry survey indicates that the price of mulch film waste is CNY 600/ton. Briefly, 1 ton of mulch film waste from thicker mulch film is about 5 m^3, denoted as η equals 5. The enterprise survey indicates that approximately 300 tons of sludge will be generated for processing 10,000 tons of mulch film waste. The operating service charges catalog list specifies that the standard for removing non-residential waste is CNY 30-53/ton in the study region (NDRC 2023). The sludge removal cost is calculated based on a median value of CNY 41.5/ton.

Regarding the parameters for the benefits, the yields of corn, potato, and cotton after the application of different mulch films are taken from the studies of Cui (Cui et al. 2024), Wu (Wu 2023), Zhang (Zhang et al. 2023), and Liu (Liu et al. 2021). Market prices for different crops are obtained from the National Grain and Material Reserves Bureau (NFSRA 2023), the Information Center of the Ministry of Agriculture and Rural Affairs (ICMOA), and the China Cotton Information Network (Cotton China 2024). Enterprise surveys indicate that 4 tons of mulch film waste from thicker mulch film can produce 1 ton of regenerated plastic pellets. Thus, the value of μ is calculated to be 0.25. The industry price of regenerated plastic pellets fluctuates in the range of CNY 4,600-6,550/ton (Oilchem 2024). The study takes the medium value, which is CNY 5,575/ton. Based on linear low-density polyethylene (LLDPE) standards, the carbon EF for plastic pellets is 2.67 kg CO_2/kg (BIPT 2020). Plastic residues in the soil are resistant to degradation and gradually transform into microplastics over time, and the carbon EF associated with the process is 6.53 kg CO_2/kg (Dong et al. 2022). The carbon emissions resulting from mechanical recycling amount to -0.09 kg CO_2/kg (Xiong et al. 2023).

3. Results

3.1. Costs and benefits of environmentally friendly mulch film management

Considering the procurement, utilization, and treatment of mulch film waste, the management cost for conventional mulch film is CNY 1,788.0/ha, with benefits amounting to CNY 4,743.0/ha (Table 3-3 and Figure 3-3). Due to the increase in the procurement cost and additional treatment cost, the management cost of thicker mulch film is higher than that of conventional mulch film. Within the management lifecycle of thicker mulch film, there will be a cost PV of CNY 2,567.6/ha and a benefit PV of CNY 5,776.4/ha. The management cost and benefits of biodegradable mulch film are the highest of the three options, at CNY 3,606.7/ha and CNY 5,851.3/ha, respectively.

In terms of management costs, conventional mulch film waste is primarily landfilled after collection, so its treatment cost only involves the collection cost and transportation cost. Among the costs, the procurement cost of mulch film accounts for the most prominent proportion, at 46.3%. It is followed by the collection cost during the treatment stage, constituting 33.6% of the total. For thicker mulch film, the management cost includes the procurement cost, utilization cost, and treatment cost. Similar to conventional mulch film, the procurement cost contributes the highest share at 48.4%. The treatment cost comes next, at 38.7% of the total costs, among which the collection cost is the highest, while the mechanical recycling cost only represents 3.9% of the total. Regarding biodegradable mulch film, the management cost consists only of two items, which are the procurement cost and utilization cost, since this mulch film naturally degrades over time. Owing to the higher price of biodegradable mulch film, 90.8% of its cost is attributed to the procurement cost.

Regarding the management benefits, the benefits of conventional mulch film come entirely from the benefits of a crop yield increase. In the case of thicker mulch film, regenerated plastic pellets yield both economic and environmental benefits. Among them, the benefits of a crop yield increase make up a significant proportion of the management benefit, accounting for 96.0% of the total. The proportion of environmental benefits, which include the benefits of plastic avoidance and the benefits of recycling and substitution, is 0.9%. The benefits of biodegradable mulch film include the benefits of crop yield increase and the benefits of recycling and substitution, with 99.7% of the total being derived from the former.

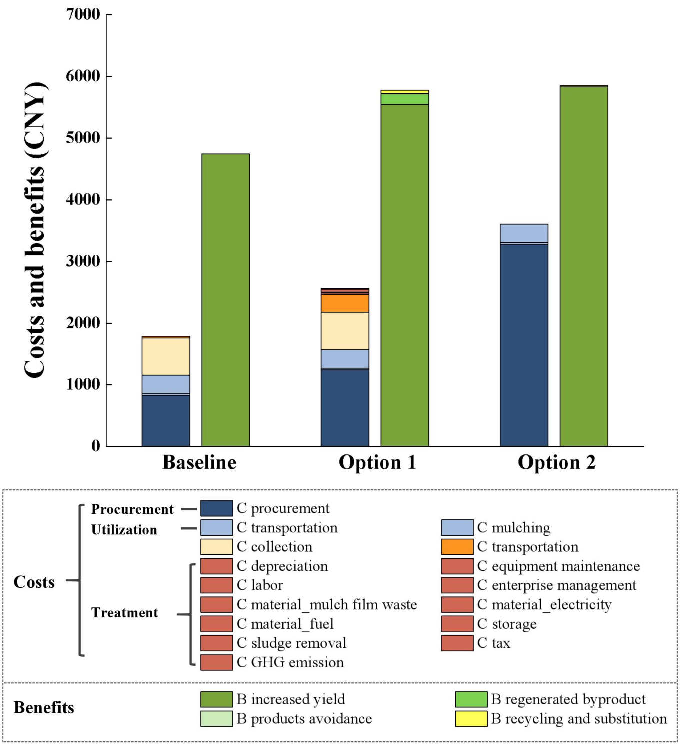

Figure 3-3 The costs and benefits of mulch film management. Source: Data gained from the cost-benefit analysis results and diagrammed by the author.

Table 3-3 Results of the costs and benefits of different mulch films.

				Baseline: conventional mulch film		Option 1: thicker mulch film		Option 2: biodegradable mulch film	
				CNY	%	CNY	%	CNY	%
Costs	Procurement cost			828.0	46.3	1,242.0	48.4	3,276.0	90.8
	Utilization cost	Transportation cost		29.0	1.6	29.5	1.1	29.3	0.8
		Mulching cost		301.4	16.9	301.4	11.7	301.4	8.4
	Treatment cost	Collection cost		601.4	33.6	601.4	23.4	0.0	0.0
		Transportation cost		28.2	1.6	293.1	11.4	0.0	0.0
		Mechanical recycling cost	Depreciation cost	0.0	0.0	1.7	0.1	0.0	0.0
			Equipment maintenance cost	0.0	0.0	1.9	0.1	0.0	0.0
			Labor cost	0.0	0.0	23.5	0.9	0.0	0.0
			Enterprise management cost	0.0	0.0	7.0	0.3	0.0	0.0
			Material cost_mulch film waste	0.0	0.0	42.5	1.7	0.0	0.0
			Material cost_electricity	0.0	0.0	18.5	0.7	0.0	0.0
			Material cost_fuel	0.0	0.0	0.0	0.0	0.0	0.0
			Mulch film waste storage cost	0.0	0.0	3.2	0.1	0.0	0.0
			Sludge removal cost	0.0	0.0	0.1	0.0	0.0	0.0
			Tax	0.0	0.0	0.5	0.0	0.0	0.0
		External cost_Mechanical recycling		0.0	0.0	1.2	0.0	0.0	0.0
	Subtotal			1,788.0	/	2,567.6	/	3,606.7	/
Benefits	Benefit of crop yield increase			4,743.0	100.0	5,546.7	96.0	5,831.6	99.7
	Benefit of generated byproduct			0.0	0.0	175.6	3.0	0.0	0.0
	Benefit of products avoidance			0.0	0.0	5.0	0.1	0.0	0.0
	Benefit of recycling and substitution			0.0	0.0	49.1	0.8	19.8	0.3
	Subtotal			4,743.0	/	5,776.4	/	5,851.3	/

Source: Summarized by the author.

3.2. Comprehensive performance of environmentally friendly mulch film management

Applying conventional mulch film yields a net benefit of CNY 2,955.0/ha. Despite the increase in agricultural inputs, the payoff is quite considerable. The result affirms the recognized notion that mulch film application substantially contributes to increasing agricultural production and raising farmers' earnings (Gao et al. 2019). Thicker mulch film application can result in a net profit of CNY 3,208.8/ha, which is higher than that of conventional mulch film, with a BCR of 2.19. Such a measure not only accomplishes the goal of increasing the recyclability of mulch film waste, thereby reducing threats that plastic poses in terms of soil safety and environmental pollution, but also guarantees food security and boosts agriculture income. The result indicates that the promotion of thicker mulch film is a compelling initiative to promote mulch film management and is the appropriate approach to strengthening agricultural non-point pollution management.

Although applying biodegradable mulch film can lead to the greatest total benefits, its net benefit is lower than that of conventional mulch film and thicker mulch film, owing to its excessively high total cost, at CNY 2,244.6/ha. The major contributors to the costs and benefits of biodegradable mulch film application are the procurement costs and the benefits of crop yield increase. The procurement cost of biodegradable mulch film far exceeds that of plastic mulch film, with its unit cost being 4.0 times higher than that of conventional mulch film and 2.6 times higher than that of thicker mulch film. Nevertheless, biodegradable film has not exhibited outstanding superiority over plastic mulch film regarding the promotion of crop yields, resulting in relatively lower net benefits. The result suggests that despite the unrivaled superiority of biodegradable film in terms of increased crop yield and the alleviation of mulch film waste, its promotion in actual agricultural production may encounter significant obstacles due to its economic unacceptability.

In summary, thicker mulch film and biodegradable film can alleviate agricultural white pollution by enhancing mulch film waste's recyclability and eliminating the waste at the source. However, it is worthwhile to point out that mulch film management comes with considerable economic costs. Based on the three scenarios outlined in Section 4.1, for the application of mulch film, an annual investment of CNY 1.1 billion is required from the government or third-party financiers to sustain the management of the 2.14 million ha of farmland for the pilot demonstration in the study region (Scenario 1). Assuming, in Scenario 2, that the management area is expanded to include all the three main mulch film crops in the study region, the funding requirement increases to CNY 5.9 billion/year. Further, if the management area is expanded to the whole country and if the policy is adjustment to include more film-mulching crops, the annual management investment requirement will surge to CNY 49.6 billion.

A sensitivity analysis is applied to evaluate the impacts of relevant factors in the study on the NPV of different mulch film management measures (Figure 3-4). The prices of biodegradable mulch film, electricity, CO_2, and regenerated plastic pellets, and the crop yields are selected as the main factors for this analysis given that these parameters are likely to fluctuate widely in real life to potentially affect the results, or may shed light on government policy decision-making. Among them, the prices of biodegradable film and electricity decreased by 40% with a 10% change rate. The price of regenerated plastic pellets and crop yields saw a 20% decrease and a 20% increase, respectively, with a 10% change rate. The results demonstrate that fluctuations in crop yields have the most significant impact on the economic performance of different mulch film management measures. In particular, fluctuations in corn yield have a greater effect on the NPV. When applying thicker mulch film, a 10% variation in corn and cotton yields will bring about 10.2% and 7.1% changes, respectively, in the NPV with Option 1. When applying biodegradable film, a 10% variation in corn and potato yields will result in 20.8% and 4.9% changes in the NPV, respectively, with Option 2. In addition, the price of biodegradable film is another primary factor affecting the economic performance observed under Option 2. When it increases by 10%, the NPV of Option 2 increases by 14.4%. Comparatively, fluctuations in the prices of electricity, CO_2, and regenerated plastic pellets exhibit minor impacts on the economic performance of different mulch film management measures.

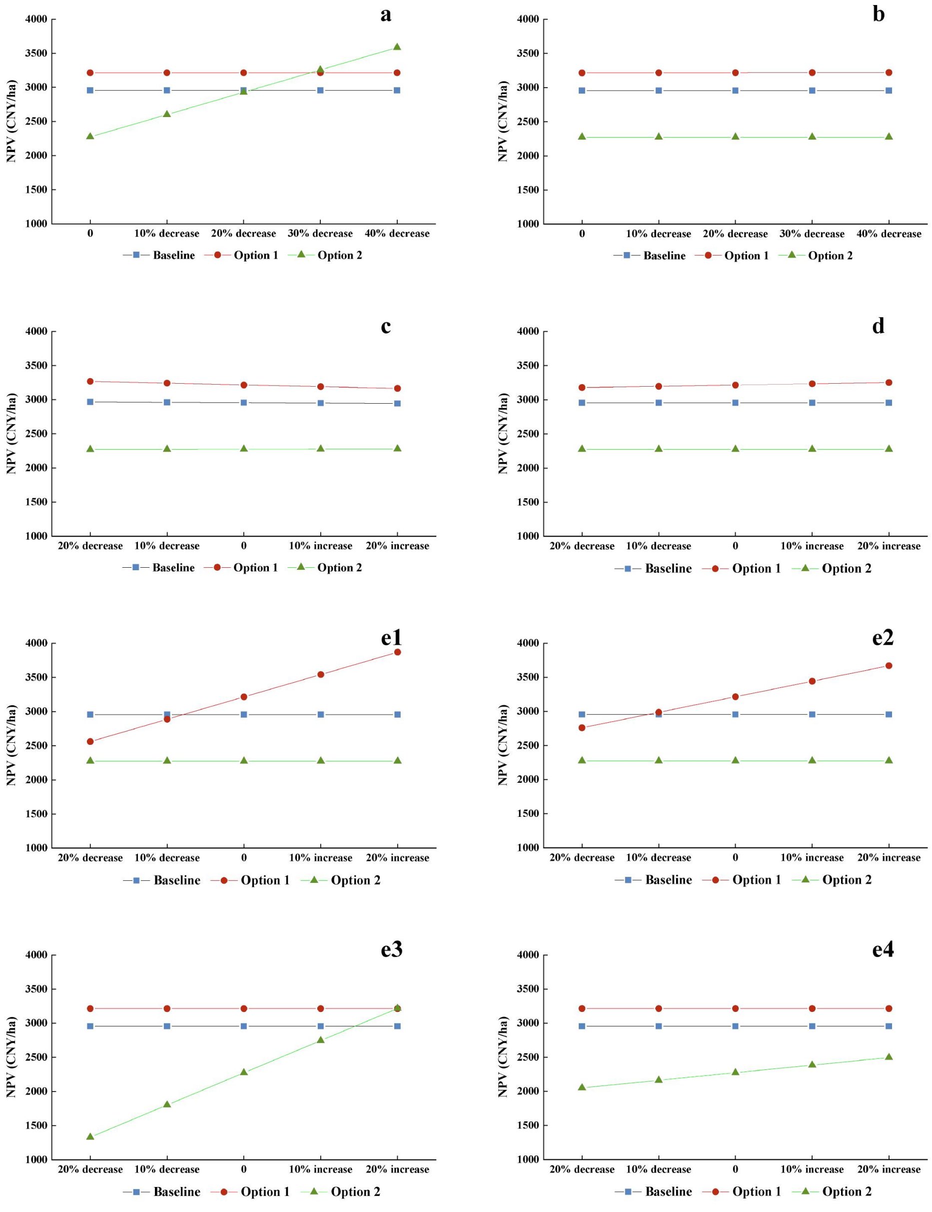

Figure 3-4 The results of sensitivity analysis: (a) the price of biodegradable film; (b) the price of electricity; (c) the price of CO_2; (d) the price of regenerated plastic pellets; (e1) the corn yield with the application of thicker mulch film; (e2) the cotton yield with the application of thicker mulch film; (e3) the corn yield with the application of biodegradable mulch film; (e4) the potato yield with the application of biodegradable mulch film. Source: Data gained form the results of sensitivity analysis and diagrammed by the author.

4. Discussion

Mulch film management is a pressing issue in China. However, it is unsustainable to maintain the current subsidy standards for the widespread promotion of the initiative of mulch film scientific utilization and recycling. Efforts should be made to optimize subsidy policies for mulch film management to maximize the effectiveness of government resources in agricultural white pollution control. Scientifically accounting for the cost-benefit performance of mulch film management measures allows us to provide a scientific reference for developing rational mulch film management policies.

4.1. Thicker mulch film application is cost-effective, and the key to its promotion lies in improving farmers' attitudes and optimizing subsidy dimensions

As stated in the economic analysis in Section 3.2, thicker mulch film presents notably positive economic benefits compared with conventional mulch film. Theoretically, thicker mulch film can be adopted proactively, owing to its economic advantages, even without subsidies. While the government subsidy of CNY 450/ha for thicker mulch film may stimulate its application, it results in somewhat inefficient utilization of fiscal resources. Indeed, farmers are inclined to purchase thicker mulch film only when its usage costs are subsidized and essentially equivalent to those of conventional mulch film. Bridging the gap between theory and reality can guide the government to optimize its policies for mulch film management.

The results of Section 3.1 on costs and benefits reveals that the cost disparity between thicker mulch film and conventional mulch film manifests primarily in the procurement and treatment phases. In the procurement phase, thicker mulch film incurs an additional cost of CNY 414.0/ha compared with that of conventional mulch film. The benefits, in contrast, are not realized until the crop is harvested in the following year, signifying a considerable time lag. Given the considerable uncertainty about the future, especially for agricultural production, which faces a significant "weather-dependent" dilemma, farmers with bounded rationality may prioritize immediate economic loss (Haushofer and Fehr 2014). In other words, farmers may experience psychological resistance when faced with the need to incur a higher cost to purchase thicker mulch film. Therefore, it is imperative to promote widespread knowledge of the advantageous outcomes of applying thicker mulch film, particularly in terms of its ability to generate significant economic gains, to elevate farmers' comprehensive and scientific understanding of mulch film management.

Regarding the treatment phase, the results of the cost-benefit analysis of mulch film recycling, which was conducted for the 15-year life cycle of the recycling enterprise, show an NPV of CNY 1.4 million and a BCR of 1.01. The indicators demonstrate that the mulch film recycling project will yield more favorable outcomes than expected (at a social discount rate of 8%). Despite the project's profitability, previous studies have shown that enterprises can operate steadily when the BCR remains at 1.1-1.2 (Liu et al. 2018). Given the current costs and benefits of mulch film recycling, enterprises lack sufficient motivation to sustain mulch film recycling activities. To achieve a BCR of 1.1, an annual subsidy of CNY 698,564 is required for an enterprise with an annual processing capacity of 10,000 tons. To achieve the goal of APWM through the widespread adoption of thicker mulch film, the backend of management-waste treatment-cannot be ignored. Future policies need to appropriately shift their focus on the treatment phase, exploring incentives to provide enterprises with more impetus to carry out mulch film recycling activities.

4.2. Biodegradable mulch film application will require continuous subsidies, cost reductions and efficiency increases in the future

Despite the functional advantages of biodegradable mulch film over conventional mulch film and its unparalleled superiority in mitigating plastic pollution (Gao et al. 2023), it does not outperform conventional mulch film regarding economic performance. In the absence of subsidies, its widespread adoption in agricultural production may encounter significant obstacles due to its economic infeasibility, aligning with the significant barriers of other biodegradable materials (Thrän et al. 2024). As previously stated, in order to promote biodegradable mulch film use and mitigate users' resistance to its utilization, a price subsidy of CNY 1,800/ha was proposed as sufficient to cope with the additional pressure costs of purchasing it (Chen et al. 2019). The result of the economic analysis in 3.2 indicates that, considering the benefits introduced by different types of mulch film application, the benefit discrepancy between biodegradable mulch film and conventional mulch film is CNY 710.4/ha. The present subsidy for biodegradable mulch film far exceeds the benefit losses incurred by its application. The government could optimize the subsidy for biodegradable mulch film based on the cost-benefit performance of the different types of mulch films applied. It is imperative to adjust the subsidies moderately, ensuring they are appropriately higher than the incurred economic losses to guarantee effective incentives for farmers' adoption of biodegradable mulch film, while keeping the allocation of financial resources reasonable.

In addition, the weaknesses of biodegradable mulch film in terms of mechanical performance and hydrophilicity restrict its applicability to specific crops with a short growth cycle (Li et al. 2024). Biodegradable mulch film's duration and degree of degradation vary depending on variations in natural circumstances across different regions (Liu et al. 2021). Currently available biodegradable mulch film does not contain suitable degradation characteristics, a reasonable start-up period, or a degradation rate suited to different crops' growth. In light of this, future considerations may lean toward moderately favoring policy towards mulch film manufacturing enterprises, leveraging the incentivizing effect of government subsidies to stimulate increased investment in research and development (R&D). Through scaled production and technological advancements to lower production costs and enhance product performance, there lies the potential for the more effective promotion of biodegradable mulch film and for the alleviation of agricultural white pollution.

4.3. Sustainable mulch film management entails developing a

mechanism to realize the environmental benefits of management and innovating a governance landscape

It should be noted that this study considers the environmental benefits of recycling thicker mulch film and substituting conventional mulch film with biodegradable mulch film. The results of Section 3.1 on costs and benefits indicate that applying 1 ha of thicker mulch film and biodegradable mulch film instead of conventional mulch film can yield environmental benefits amounting to CNY 54.1 and CNY 19.8, respectively. However, there is no mechanism through which to monetize the environmental benefits of mulch film management in reality. These under-appreciated benefits could have critical implications for increasing the viability of agricultural white pollution control and reducing the burden of external funding requirements. Therefore, the incorporation of mulch film management into the carbon trading market should be actively explored to provide more market incentives and policy support by transforming environmental advantages into economic gains. Generally, it is imperative to establish a comprehensive carbon emission and carbon sink accounting system for the life cycle of mulch film management. The sources of GHGs throughout the lifespan of mulch film management are extensive and scattered, leaving them complicated to quantify precisely. Hence, building upon this study, further research into and the refinement of more scientifically grounded methodologies are warranted, ensuring that the monitoring, accounting, and evaluation of emissions and the carbon sink in mulch film management processes are more standardized and regulated. Subsequently, it would be timely to explore the pilot demonstration for carbon trading in mulch film management. Following the principles of pilot precedence and gradual progression, carbon trading projects for mulch film management should be conducted in regions abundant in mulch film application carbon emission and carbon sink resources, providing replicable experiences for promoting nationwide agricultural plastic carbon trading and advancing sustainable agricultural white pollution control.

In addition, the ecological environment is a quasi-public good. In addressing agricultural white pollution, sole reliance on either government intervention or market mechanism may lead to failure. As the relationship between economic development and environmental conservation deepens, polycentric governance will facilitate the increased sharing of social responsibilities and increase governmental efficiency compared with that of single-subject governance. Within the polycentric governance framework, the government, the market, and societal entities including organizations and the public, form an inseparable triad (Figure 3-5). In a polycentric governance structure, the government predominantly assumes an intermediary role, formulating a macro-framework of a multi-centric landscape for agricultural white pollution control and establishing behavioral norms for participating entities. The market, guided by the principles of supply and demand, engages in producing environmentally friendly mulch film and recycling mulch film waste. This allows for the achievement of an equilibrium between supply and demand, and enhances the efficiency of public goods provision. The public, on the one hand, possesses legally authorized rights to environmental information, decision-making, and supervision. On the other hand, as beneficiaries of agricultural pollution control, members of the public must assume the responsibilities of environmental protection and pollution control. Given the growing environmental consciousness of the large population base, public support introduces great prospects in terms of promoting agricultural white pollution management. Social organizations are significant forces in societal governance, being entitled to environmental investigation and supervision rights. In agricultural white pollution governance, social organizations can foster cooperative partnerships and establish public norms through democratic negotiations with other entities, thereby realizing diversified interests among multiple stakeholders.

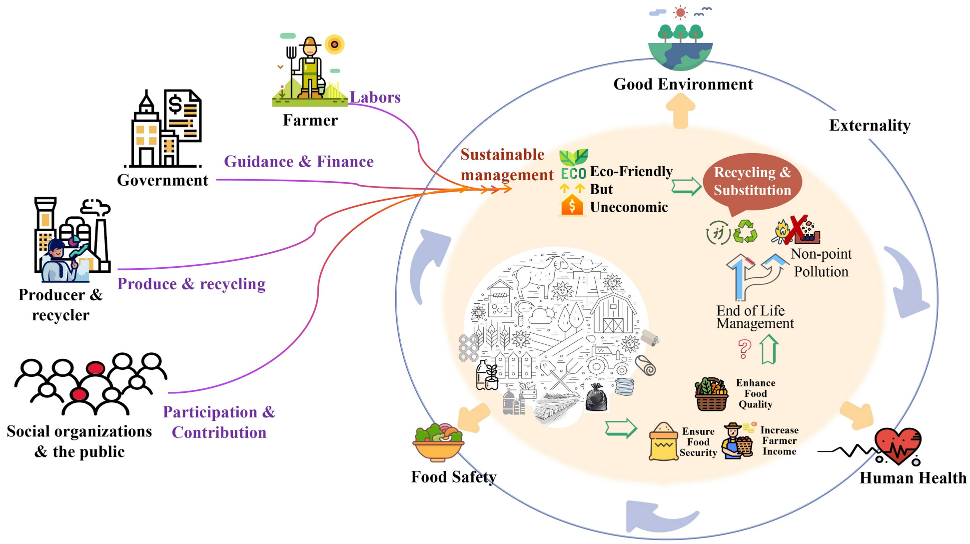

Figure 3-5 Polycentric governance for mulch film management. Source: Diagrammed by the author.

5. Conclusions

This study conducts a cost-benefit analysis of mulch film management in China. It specifically examines two environmentally friendly mulch film management measures: the application of thicker mulch film and that of biodegradable mulch film. The results indicate that applying thicker mulch film is economically feasible, with substantial potential for expansion. However, there are certain limitations to the current government subsidies for it. Theoretically, thicker mulch film can be implemented spontaneously without financial support due to its economic advantages, and since the current government subsidy standard for it results in a certain degree of government economic resource waste. Furthermore, the reason for its inadequate promotion is the lack of recognition of its benefits in waste treatment, which is a weak point, as well as the fact that it is not adequately supported by the current subsidies. Comparatively, biodegradable mulch film is unprofitable due to its high material costs, and its further development requires external funding support. Nevertheless, the current policy exhibits high subsidy standards and leads to financially inefficient utilization. In addition, deficiencies in the product's performance restrict its universal application. In this regard, to promote environmentally friendly mulch film management measures, it is imperative to raise farmers' comprehensive knowledge of them, optimize government subsidy standards and dimensions for management, and explore strategies to reduce the costs and increase the efficiency of mulch films. Further analysis reveals the need to advance sustainable mulch film management by developing a carbon trading mechanism to internalize the environmental benefits of the management, and to introduce funding sources for sustainable agricultural white pollution control.

This study primarily relies on case studies, such as crop yield statistics obtained from the application of different mulch films, which may vary depending on region, climate, and agronomic practices. The sensitivity analysis result also reveals that variations in crop yields have a significant impact on the economic performance of mulch film management. Future studies on the impact of diverse mulch films on crop yields can provide more precise references. In addition, as this study emphasizes the economic feasibility of mulch film management, the external impacts described are simplified to some extent. For example, GHG emissions are only based on CO_2 emissions for accounting. Moreover, this study does not consider the environmental impacts of mulch film manufacturing, and the differences in GHG emissions between biodegradable materials and plastics during production may also influence the proposed mulch film's cost-effectiveness (Li et al. 2024). Future studies could expand the study's boundaries and employ life cycle assessment (LCA) to systematically evaluate the precise environmental and economic performance of different mulch film management measures.

Supplementary materials

SM 1. The calculation for the initial value of the assets in the study.

Capital costs are the one-time expenditure derived from land, plant, equipment and other fixed assets. The land acquisition cost refers to previous study by taking the land price published by the Ministry of Natural Resources of China (Chen et al. 2023), and the average value of the study region was taken for the study, which is CNY 648,000/ha (Ministry of Natural Resources of the People's Republic of China 2024). According to the enterprise survey, an footprint of 2 ha is appropriate for enterprises with an annual processing capacity of 10,000 tons. The costs related to the plant and equipment are obtained through enterprise survey, as specified in Table S3-1. V initial is the sum of each item's cost.

Table S3-1 Fixed assets in the mechanical recycling of mulch film waste.

Items of fixed asset	Unit price (CNY)	Quantity
Building	500,000	1
Loader	150,000	2
Crusher	200,000	1

Items of fixed asset	Unit price (CNY)	Quantity
Conveyor belt	240,000	3
Cleaning equipment	400,000	1
Dehydration equipment	160,000	1
Feeder	60,000	1
Screw extruder	400,000	2
Cooling equipment	40,000	1
Pelletizer	50,000	1
Barrel	50,000	1
UV photocatalytic device	50,000	1
Flocculation device	60,000	1
Plate filter press	50,000	1

Source: Field survey of enterprises in study region.

SM 2. The description for the crop yield increase when applying different mulch films.

In 2022, the planting area of corn, potato and cotton in the study region (Gansu, Inner Mongolia, Ningxia and Xinjiang) was 6.8 million ha, 0.9 million ha, and 2.5 million ha, respectively. The proportion of the three main mulching crops is 0.665 : 0.088 : 0.247. The unit of accounting for costs and benefits in this study is 1 ha of farmland. The area of the three crops per ha of farmland is allocated according to ratio stated above.

Table S3-2 Parameter of IY crop in the study.

		Corn	Potato	Cotton
Increased yield (compared with no mulch film) (kg/ha)	Conventional mulch film	1,572.0	2,194.1	923.1
	Thicker mulch film	1,755.0	/	1,204.9
	Biodegradable mulch film	2,090.5	3,813.2	/
	Data resource	Table S3-3	Table S3-4	Table S3-5 - S3-7

Note: Thicker mulch film film is generally not used for potato, and biodegradable mulch film is generally not used for cotton in the study region.

Table S3-3 Yields for corn in different mulching conditions.

Treatment	Yield (kg/ha)	Increased yield (kg/ha)
No mulch film	11,359.5	
Conventional mulch film	12,931.5	1,572.0
Thicker mulch film	13,114.5	1,755.0
Biodegradable mulch film	13,450.0	2,090.5

Data source: Cui et al., 2024 (Cui *et al.* 2024).

Table S3-4 Yields for potato in different mulching conditions.

Treatment	Yield (kg/ha)	Increased yield (kg/ha)
No mulch film	47,950.65	/
Conventional mulch film	50,144.76	2,194.11
Thicker mulch film	51,763.83	3,813.18

Data source: Wu, 2023 (Wu 2023).

Table S3-5 Yields for cotton mulching with conventional mulch film and thicker mulch film.

Treatment	Yield (kg/ha)	The rate of yield increase (%)
Conventional mulch film	5,765.1	5.12
Thicker mulch film	6,060.15	

Data source: Zhang et al., 2023 (Zhang *et al.* 2023).

Table S3-6 Yields for cotton mulching with conventional mulch film.

Treatment	Yield (kg/ha)
No mulch mulch film	4,582.35
Conventional mulch film	5,505.45

Data source: Liu et al., 2021 (Liu *et al.* 2021).

With a cotton yield increase of 5.12%, the yield of cotton with thicker mulch film would be 5,787.2 kg/ha in this scenario. That is:

Table S3-7 Yields for cotton in different mulching conditions.

Treatment	Yield (kg/ha)	Increased yield (kg/ha)
No mulch film	4,582.35	/
Conventional mulch film	5,765.10	923.10
Thicker mulch film	6,060.15	1,204.86

Data source: Summarized by the author.

SM 3. The description of the calculation for each cost and benefit.

3.1Conventional mulch film

(1) Management cost

$$C_{management} = C_{procurement} + C_{utilization} + C_{treatment}$$

1)Procurement cost

$$C_{procurement} = UP_{mulch\,film} \times UQ_{mulching} \times S_{mulching}$$

The price of plastic mulch film is CNY 9.0/kg. 92.0 kg/ha of conventional mulch film is required.

2)Utilization cost

$$C_{utilization} = C_{transportation} + C_{mulching} =$$
$$UQ_{mulching} \times S_{mulching} \times D_{transportation} \times UC_{transportation} + \left(C_{fuel} + C_{labor}\right) \times S_{mulching} + M_{GHG}$$

The transportation distance from the manufacturer to farmland is preset at 10.0 km. The unit cost of the transportation process is set as CNY 1.1/(ton·km). The total economic cost of mulching (fuel and labor) is CNY 450/ha. The monetization of GHG emissions from fuel consumption is assessed by the unit price for CO_2 (CNY 59.68/ton), the quality of fuel consumed (fuel consumption for transportation is 15.0 L/km and for mulching is 7.5 L/ha) and its carbon emission factor (3.12 kg CO_2/L).

3)Treatment cost

As for conventional mulch film, 30% of the film is collected and transported to the fields or informal landfill sites around the farmland for landfilling. This part of the film only incurs costs during the collection and transportation process. The remaining 70% of the film remains in the soil and does not incur any economic costs because it is not disposed of.

$$C_{treatment} = C_{collection} + C_{transportation}$$

$$C_{collection} = \theta \times UQ_{mulching} \times UC_{collection} \times S_{mulching} + M_{GHG}$$

θ for conventional mulch film is 30%. The monetization of GHG emissions here is calculated the same as the process of mulching.

$$C_{transportation} = (\theta \times UQ_{mulching} \times S_{mulching} \times D'_{transportation} \times UC_{transportation}) + M_{GHG}$$

The transportation distance from the farmland to landfill site is set at 10.0 km. The monetization of GHG emissions here is calculated the same as the process of transportation above.

(2)Management benefit

The benefit of applying conventional mulch film comes from the benefit of crop increase.

$$B_{management} = B_{increased\ yield}$$

$$B_{increased\ yield} = IY_{crop} \times S_{crop} \times UP_{crop}$$

The market prices for corn, potato and cotton are 2.56/kg, CNY 2.49/kg and CNY 6.97/kg , respectively. Increased yield for applying different crops are stated above in Table S3-2.

3.2Thicker mulch film

(1)Management cost

$$C_{management} = C_{procurement} + C_{utilization} + C_{treatment}$$

1)Procurement cost

$$C_{procurement} = UP_{mulch\ film} \times UQ_{mulching} \times S_{mulching}$$

The price of plastic mulch film is CNY 9.0/kg. 138.0 kg/ha of thicker mulch film is required.

2)Utilization cost

$$C_{utilization} = C_{transportation} + C_{mulching} =$$

$$UQ_{mulching} \times S_{mulching} \times D_{transportation} \times UC_{transportation} + \left(C_{fuel} + C_{labor}\right) \times S_{mulching} + M_{GHG}$$

Each parameter is the same as the case of conventional mulch film.

3)Treatment cost

$$C_{treatment} = C_{collection} + C_{transportation} + C_{mechanical\ recycling}$$

Thicker mulch film has good collectability and processability. In the study, 90% of thick film can be collected and transported to the mulch film processing plant, where it is recycled through a series of processes such as crushing, washing, melting, and extrusion. Thicker mulch film incurs collection, transportation, and disposal costs in the treatment phase.

$$C_{treatment} = C_{collection} + C_{transportation} + C_{mechanical\ recycling}$$

$$C_{collection} = \theta \times UQ_{mulching} \times UC_{collection} \times S_{mulching} + M_{GHG}$$

Collection cost is the same as conventional mulch film.

$$C_{transportation} = (\theta \times UQ_{mulching} \times S_{mulching} \times D'_{transportation} \times UC_{transportation}) + M_{GHG}$$

Transportation cost is also the same as conventional mulch film except for the transportation distance is 100 km.

$$C_{mechanical\ recycling} = C_{depreciation} + C_{equipment\ maintenance} + C_{labor} + C_{enterprise\ management} +$$
$$C_{material\ procurement} + C_{storage} + C_{sludge\ removal} + C_{tax}$$

$$C_{depreciation} = (V_{initial} - V_{salvage})/n = [V_{initial} \times (1-\lambda)]/n$$

Initial value of the assets is shown in the Table S3-1. Following government regulations and industry practices, the average depreciation life (n) is calculated as 15 years, with a salvage (λ) of 5%.

$$C_{equipment\ maintenance} = C_{depreciation} \times \alpha$$

The rate α for equipment maintenance is 2%.

$$C_{labor} = W_{local\ average} \times PC_{enterprise} \div L_{employee}$$

Local average wage for the manufacturing in the study region is CNY 59,739.25/yr. The enterprise's annual processing load is 10,000 tons and the working load for each employee annually is 150 tons.

$$C_{enterprise\ management} = C_{labor} \times \beta$$

The rate β for enterprise management cost is calculated to be 30%.

$$C_{material} = \theta \times UQ_{mulching} \times S_{mulching} \times Q_{material} \times UP_{material}$$

The cost of the mulch film treatment is calculated based on a case of the enterprise with an annual processing capacity of 10,000 tons. So, Q material for mulch film waste is 10,000 tons. The price of mulch film waste is CNY 600/ton. The electricity consumption for processing 1 ton of mulch film waste is 288.9 kW·h. The electricity price is CNY 1.8/kW·h based on the industrial electricity price in the study region. For an enterprise with a processing load of 17,000 tons mulch film waste per year, the annual fuel consumption is 1,500 L, so fuel required is calculated to be 882 L for such a case. The average fuel price in the study region of CNY 7.5/L.

$$C_{storage} = \theta \times UQ_{mulching} \times S_{mulching} \times \eta \times UC_{storage}$$

1 ton of mulch film waste from thicker mulch film is about 5 m^3, denoted as η equals 5. According to the field survey that the annual storage cost of 100 m^3 of mulch film waste is about CNY 900, that is, CNY 9/m^3.

$$C_{sludge\ removal} = Q_{sludge} \times UC_{sludge\ removal}$$

Enterprise survey indicates that approximately 300 tons of sludge will be generated for processing 10,000 tons of mulch film waste. The standard for removing non-residential waste is CNY 30-53/ton in the study region. The sludge removal cost is calculated applying a median value of CNY 41.5/ton.

$$C_{tax} = PBT \times \tau$$

According to the Enterprise Income Tax Law of China, the tax rate for enterprise income tax is 25%.

(2)Management benefit

$$B_{management} = B_{increased\ yield} + B_{generated\ product} + B_{product\ avoidance} + B_{recycling\ and\ substitution}$$

1)Benefit from crop yield increase

$$B_{increased\ yield} = IY_{crop} \times S_{crop} \times UP_{crop}$$

The market prices for corn, potato and cotton are 2.56/kg, CNY 2.49/kg and CNY 6.97/kg, respectively. Increased yield for applying different crops are shown in Table S3-2.

2)Benefit from sale of generated products

$$B_{generated\ byproduct} = \theta \times UQ_{mulching} \times S_{mulching} \times \mu \times UP_{generated\ byproduct}$$

4 tons of mulch film waste from thicker mulch film can produce 1 ton of regenerated plastic pellets. Thus, the value of μ is calculated to be 0.25. The industry price of regenerated plastic pellets fluctuates in the range of CNY 4,600 - 6,550/ton. The study takes the medium value, which is CNY 5,575/ton.

3)Environmental benefit from plastic avoidance

$$B_{products\ avoidance} = \theta \times UQ_{mulching} \times S_{mulching} \times \mu \times GHG_{plastics}$$

Based on linear low-density polyethylene standards, the carbon EF for plastic pellets is 2.67 kg CO_2/kg.

4)Environmental benefit from the avoidance of GHG emission due to recycling

$$B_{recycling\ and\ substitution} = \theta \times UQ_{mulching} \times S_{mulching} \times \mu \times GHG_{emission\ gap}$$

Plastic residues in the soil are resistant to degradation and gradually transform into microplastics over time, and the carbon EF associated with the process is 6.53 kg CO_2/kg. The carbon emission resulting from mechanical recycling is -0.09 kg CO_2/kg.

3.3Biodegradable mulch film

(1)Management cost

Biodegradable mulch film is composed primarily of polysaccharides and polyesters, and will break down into H_2O, CO_2, and microbial biomass. After crop harvest, biodegradable mulch film is plowed into the soil and excepts to decompose over time, eliminating any need for treatment.

$$C_{management} = C_{procurement} + C_{utilization}$$

1)Procurement cost

$$C_{procurement} = UP_{mulch\ film} \times UQ_{mulching} \times S_{mulching}$$

The price of plastic mulch film is CNY 26.0/kg. 126.0 kg/ha of biodegradable mulch film is required.

2)Utilization cost

$$C_{utilization} = C_{transportation} + C_{mulching} =$$
$$UQ_{mulching} \times S_{mulching} \times D_{transportation} \times UC_{transportation} + \left(C_{fuel} + C_{labor}\right) \times S_{mulching} + M_{GHG}$$

Each parameter is the same as the case of conventional mulch film.

(2)Management benefit

The benefits of applying biodegradable mulch film come from crop yield increase and environmental benefit from the avoidance of GHG emission

$$B_{management} = B_{increased\ yield} + B_{recycling\ and\ substitution}$$

1)Benefit from crop yield increase

$$B_{increased\ yield} = IY_{crop} \times S_{crop} \times UP_{crop}$$

The market prices for corn, potato and cotton are 2.56/kg, CNY 2.49/kg and CNY 6.97/kg, respectively. Increased yield for applying different crops are shown in Table S3-2.

2)Environmental benefit from the avoidance of GHG emission due to substitution

$$B_{recycling\ and\ substitution} = \theta \times UQ_{mulching} \times S_{mulching} \times \mu \times GHG_{emission\ gap}$$

The carbon emission from biodegradable material (PBAT) is 3.9 CO_2/kg.

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4

Chapter IV: How to enhance agricultural plastic waste management in China? Insights from public participation

Adapt from:

Hao A, Dogot T, Yin C. 2024. How to enhance agricultural plastic waste management in china? Insights from public participation. Journal of Integrative Agriculture, 23, 2127-2143.

Abstract

Agricultural plastics play a pivotal role in agricultural production. However, due to high costs, APWM encounters a vast funding gap. As one of the crucial stakeholders, the public deserves to make appropriate efforts for APWM. Accordingly, identifying whether the public is willing to pay for APWM and clarifying the decisions' driving pathways to explore initiatives for promoting their payment intentions are essential to address the dilemma confronting APWM. To this end, by applying the extended TPB, the study conducted an empirical analysis based on 1,288 residents from four provinces (autonomous regions) of northern China. Results illustrate that: 1) respondents hold generally positive and relatively strong payment willingness towards APWM; 2) respondents' attitude (AT), subjective norm (SN), and perceived behavioral control (PBC) are positively correlated with their payment intentions (INT); 3) environmental cognition (EC) and environmental emotion (EE) positively moderate the relationships between AT and INT, and between SN and INT, posing significant indirect impacts on INT. The study's implications extend to informing government policies, suggesting that multi-entity cooperation, specifically public payment for APWM, can enhance agricultural non-point waste management.

Keywords

agricultural plastic waste, extended theory of planned behavior, public payment, environmental cognition, environmental emotion

1. Introduction

APWM is conducive to attaining the intended targets of the UN-SDGs (UN 2015). As critical agricultural inputs, agricultural plastics play a vital role in guaranteeing food security and raising farmers' income (Gao et al. 2019; Feng et al. 2022). Globally, 12.5 million tons of agricultural plastics are utilized annually (FAO 2021), while only a tiny fraction of APW is properly disposed of (Yan et al. 2010). A large amount of APW is either left untreated or improperly disposed of (open burning and on-site landfill), turning the "white revolution" deteriorate into severe "white pollution" (Liu et al. 2014). APW inevitably leads to a succession of issues, including visual pollution, water contamination, farmland degradation, and agricultural products quantity decrease (Rillig et al. 2021). Simultaneously, generated microplastics can enter the food chain and pose potential crises to human health and well-being (Rillig et al. 2021; Leslie et al. 2022; He et al. 2023).

While APWM is indeed a global issue, China confronts unique challenges. To begin with, China is the world's largest agricultural plastics consumer, accounting for approximately half of the total (FAO 2021). Particularly, mulch film, which is more challenging to recycle than other kinds of APW for its poor mechanical strength, makes up half of the agricultural plastics utilized in China (NBSC 2022a) and 3/4 of the world (FAO 2021). It is broadly and diversely utilized in the vast northern Chinese farmland, further complicating recycling.

In recent years, the Chinese government has progressively recognized the significance, urgency, and arduousness of APWM and primarily promoted it by subsidizing recycling utilization enterprises. During 2012-2015, the central government cumulatively funded APWM with more than CNY 900 million in 10 pilot provinces. Local governments also allocated special funding following financial capacity and actual APWM demands. Nevertheless, APWM faces the profound challenge of a vast funding gap. To achieve the target of an 80% recycling rate, CNY 7.1 billion would be required for nationwide mulch film recycling (SM 1). Notably, the gap may expand considerably, assuming other kinds of APW are taken into the estimation. APWM is so costly that it narrows the profit margin of recycling utilization. Without follow-up financial subsidies after piloting, it is challenging for recycling enterprises to maintain stable profitability and even sustain operations. In this regard, the government has explored innovative schemes. Represented by EPR and deposit return, multi-entity, including the government, farmers, agricultural plastic producers, and recycling enterprises, are incorporated in the management system.

The agricultural environment is closely relevant to everyone, and the environmental pollution, food security, and human health threats offset by APWM will benefit all people. Yet the existing APWM scheme does not account for the public's potential cooperation. The public, the crucial APWM stakeholder with triple identities of the service recipient of agricultural plastics, the victim of the APW, and the beneficiary of APWM, should not be left as an outsider. Meanwhile, the public's environmental awareness is steadily growing along with the progress of society and the improvement in citizen literacy. As the Environmental Kuznets Curve (EKC) indicates, people would be more attentive to environmental pollution and ecological degradation as income increases and thus seek more environmental investments than before (Grossman and Krueger 1995; Panayotou 1997). People donate to special funds and charities to satisfy their demands for more effective environmental management (Wu et al. 2020). Accordingly, as a public issue, APWM requires the public's assistance to enable a more sustainable and resilient APWM scheme. If the public is willing to participate and pay for APWM, they will conduce to mitigating the APWM funding gap to some extent while satisfying their advanced demands (Figure 4-1).

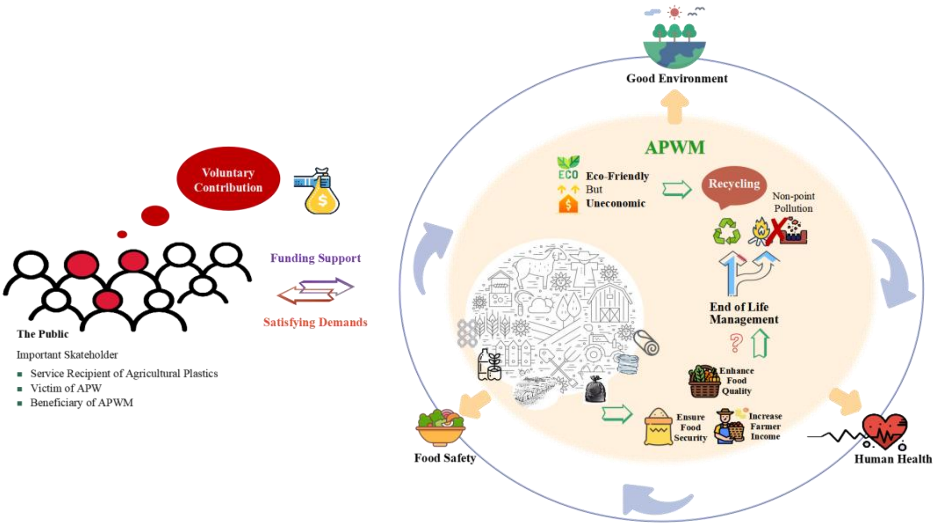

Figure 4-1 A win-win solution accomplished by public payment for APWM. Source: Diagrammed by the author.

The public's payment willingness towards environmental management has been investigated in three fields: Air pollution, water pollution and solid waste. According to relevant research, 53-83% of the respondents were willing to pay for air pollution management (Sun et al. 2016; Zahedi et al. 2019; Khuc et al. 2022). The majority of the respondents, accounting for 77-87%, expressed positive payment intentions towards water pollution remediation (Jiang et al. 2011) or water quality improvement (Ureta et al. 2022). There are no exceptions for solid waste management. The amounts respondents intended to pay were even higher than waste removal and disposal costs (Véliz et al. 2022). Comparable results on waste electrical and electronic equipment (Islam et al. 2016) and municipal solid waste (Liang et al. 2021) have also been found. Moreover, research on the public's payment willingness towards plastic waste has gradually emerged along with the rising knowledge of plastics. Relevant research indicated that respondents in Indonesia showed high concern for marine plastic pollution and positive payment willingness for plastic pollution mitigation (Tyllianakis and Ferrini 2021). Most respondents (85%) in Norway supported initiatives to reduce marine plastics (Abate et al. 2020). Similar studies were also conducted in Australia (Borriello and Rose 2022), South Korea (Choi and Lee 2018), Ecuador (Zambrano-Monserrate and Ruano 2020), Greece (Latinopoulos et al. 2018), and Bulgaria and the Netherlands (Brouwer et al. 2017). To sum up, the public is normally willing to pay for the management of waste that is closely related to them. Studies concerning plastic waste management concentrate mainly on marine plastics, congruent with the reality that the perception of plastic pollution originates from marine sources (Santos et al. 2021). A limited number of studies regarding APW were conducted merely from the perspective of farmer payment (Wang et al. 2019). As the major agricultural plastics consumer, China should place greater emphasis on APW. Moreover, explicit evidence indicates that plastic waste from soil sources is even worse (Bläsing and Amelung 2018; Santos et al. 2021), implying APWM deserves to attract due attention.

Parallel to identifying the payment willingness, clarifying the pathways that drive the public's payment intention facilitates understanding the mechanism that motivates the public's payment decision. The socio-psychological paradigm allows to provide detailed information on behavioral decision-making mechanism and unlocks the black box of decision-making in which the public is willing to pay for APWM. As a typical socio-psychological analytical framework, TPB is an established, empirically validated theoretical framework for understanding, explaining, and predicting a specific or a category of behavior (Ajzen 1991, 2020). It has been favored and widely applied because of its simple structure, thoughtful analysis of the interplay between individual, social, and environmental components, and universal validity in different domains (Morren and Grinstein 2021). To obtain a robust conclusion on the public payment for APWM, the study adopts TPB as the theoretical framework. According to TPB, behavior is predicted by INT, which in turn is jointly determined by AT, SN and PBC (Chan and Bishop 2013; Morren and Grinstein 2021). Notwithstanding the applicability and predictability of TPB in environmental behaviors, the average explanation of the variance in behavioral intentions by the three antecedent constructs of TPB is 44.3% (Yuriev et al. 2020). There is a certain proportion of variance that the TPB framework cannot explain. Extending the TPB framework with extra constructs is a common practice to improve understanding and interpretation (Ajzen 2005; Bird et al. 2018). The study appends EC and EE to TPB and applies extended TPB to provide more information on the formation mechanism of the public's decision to pay for APWM.

Therefore, the study aims to explore whether public payment can be a promising solution to mitigate the APWM funding gap. Specifically, the study offers some new insights into the following two aspects. Foremost, the payment willingness towards APWM is innovatively investigated to determine the possibility of raising APWM funding through public payment. Subsequently, applying the extended TPB, the driving pathways of the public's payment decision are clarified to guide initiatives for promoting public payment. The findings offer two-fold contributions.

Theoretically, the study innovatively applies TPB to public payment for APWM and extends the framework by environmental cognition and environmental emotion. The extended TPB is proven to have great explanatory and predictive power for target behavioral intentions, contributing to the application and development of TPB. Practically, the study also provides the scientific basis for developing a sustainable and resilient agricultural non-point waste management scheme to promote the public's participation in APWM.

The paper is structured into 6 sections. Section 2outlines the theoretical framework and research hypotheses. Section 3 describes the data and methods. Section 4 presents the research results. Section 5 discusses the results. Section 6 provides the conclusion.

2. Theoretical framework and research hypotheses

According to the logic of collective action, public payment for APWM can be conceptualized as a collective payment by contributors to set up a public pool to provide public goods without explicit tangible rewards (Olson 1965). It has a broad public interest to create better living conditions for the whole society and is a typical case of the private provision of public goods (Bergstrom et al. 1986; Fraser 1992). Accordingly, public payment for APWM is in line with the logic of the economic theory. Then, is the public willing to pay for APWM? What are the factors that influence their payment intentions? What are the pathways that drive the public's payment decision? These are fascinating and vital topics to be investigated.

2.1 Theory of planned behavior

Public payment is an envisioned scheme to mitigate the funding gap for APWM. There is no actual payment behavior in reality, so the study only examines the public's payment intention. As stated above, INT is guided by AT, SN, and PBC.

AT indicates individuals' positive or negative evaluations of specific behaviors (Ajzen 1991). Individuals with a positive attitude towards a behavior are more likely to perform it (Hori et al. 2013; Akhtar et al. 2018). APWM can alleviate agricultural non-point waste, mitigate the potential environmental pollution, food safety, and human health threats, and benefit multiple entities, including individuals, society, and the whole ecosystem. Individuals may thus have a favorable evaluation for APWM, manifested as a tendency to pay for it. Six indicators characterize individuals' AT towards APWM, including that they consider APWM to be "enjoyable and satisfying for themselves," "good for the society," "sensible as a government policy," "good for the ecosystem," "important and urgent," and "responsible for the future".

SN refers to the perceived social pressure to perform or not a behavior, reflecting the social influence on individuals' behavioral decisions (Chen and Tung 2014). When individuals perceive social pressure for not acting, they are more inclined to perform it to avert pressure (Ajzen 1991). SN explicitly refers to the norms of relatives, friends, social media, communities, and governments in the study. When these people or groups suggest paying for APWM, individuals perceive social pressure if not implemented, and their payment intentions are thus motivated.

PBC describes the degree of difficulty that individuals perceive in performing a behavior (Lazzarini et al. 2018). Individuals are less likely to engage in it if they perceive limited behavioral control. For instance, there are seen to be numerous uncertainties involved, or it lacks the necessary external conditions to perform (Yuriev et al. 2020). If individuals perceive control over their payment for APWM, including knowing how to pay for APWM, believing that there is no financial burden for them to pay, and trusting the payment would bring about the expected outcomes, they would have more confidence and enthusiasm and show stronger payment intentions.

Based on the above analysis, the following hypotheses are proposed:

Hypothesis 1a: AT positively affects payment INT.

Hypothesis 1b: SN positively affects payment INT.

Hypothesis 1c: PBC positively affects payment INT.

2.2 Extension of the TPB

EC, the understanding of the severity of environmental pollution and the urgency of environmental waste management, is the prerequisite for the public's payment decision (Kollmuss and Agyeman 2002; Gifford and Nilsson 2014). Environmental education and publicity initiatives have increased the public's EC to some extent and significantly promoted pro-environmental behaviors like recycling (Chen et al. 2021), energy conservation (Zhang et al. 2022), and green consumption (Trivedi et al. 2018). As previously stated, the environmental and health threats posed by APW, as well as the vast funding gap of APWM, are objective. If the public's EC can arouse their awareness of voluntary payment to APWM, it can undoubtedly assist in tackling the dilemma. Accordingly, it is essential to investigate the influence of EC on individuals' decisions to pay for APWM.

Besides, TPB assumes that people's decision-making is guided by rationality and deliberation and is always the outcome of self-interest driven by cost-benefit trade-offs (Reiling 1986). It indicates that TPB disregards the emotional factor, which is an essential part of practically human decisions (Ajzen 1991; Mellers et al. 1999; Koenig-Lewis et al. 2014). It is one of the major arguments why TPB is contested (Conner and Armitage 1998). Some studies introducing emotional factors to individuals' behavioral decisions inaccurately confound them with perception, knowledge, and awareness (Wang 2015). Appending individuals' psychological reaction of satisfaction or not to the environmental status and environmental behaviors (Koenig-Lewis et al. 2014; Yan et al. 2018), namely EE, into the TPB framework as an independent dimension can compensate for the lack of irrational decisions (Ajzen 1991; Mellers et al. 1999) and enhance the understanding of individuals' payment decisions.

Accordingly, the study appends EC and EE to construct an extended TPB framework to offer comprehensive insights for driving pathways of individuals' payment decisions.

Environmental cognition Individuals with a high level of EC possess a profound understanding of environmental knowledge and environmental quality (Barney et al. 2005). They can thoroughly capture the broad impacts of environmental pollution (Kotchen and Reiling 2000). Individuals involved in environmental conservation activities more actively have a higher level of EC than others; the same goes for environmental public welfare donations (Lu et al. 2023). Vice versa, those with a higher level of EC are more likely to exhibit responsible environmental behaviors (Kotchen and Reiling 2000; Halkos and Matsiori 2014; Yu and Yu 2019). Studies have verified that individuals' payment intentions towards environmental services can be reinforced by EC (Halkos and Matsiori 2014; Yu and Yu 2019). EC not only directly evokes a sense of urgency to carry out APWM but also helps to transform psychological motivations into responsible behavioral intentions (Yang et al. 2021), expressed in a stronger payment intention towards APWM. Six indicators, including environmental pollution status cognition, environmental pollution threat cognition, and waste management importance cognition, are applied to characterize EC to examine its influence on the public's payment decision. Accordingly, the following hypotheses are proposed.

Hypothesis 2: EC has a positive impact on INT.

Hypothesis 3: EC positively moderates the relationship between AT and INT, SN and INT, and PBC and INT, respectively.

Environmental emotion Individuals with strong EE have more emotional energy than those indifferent to the environment (Kalantari et al. 2015). Their emotional reactions to the changes in environmental situations and different environmental behaviors are more likely to be aroused (Kals et al. 1999; Meneses 2010). EE can evoke individuals' sense of environmental connections and environmental loyalty affecting environmental behaviors (Loewenstein et al. 2001; Kollmuss and Agyeman 2002). Individuals with stronger EE are more likely to put forth efforts and make sacrifices for environmental preservation once conscious of the environmental threats (Song and Qu 2017). Positive emotions, like aspiration and appreciation for environmental improvement and pro-environmental behaviors, generate immediate positive feedback, reinforcing previous pro-environmental behaviors. Negative emotions, like anxiety and disgust for environmental deterioration and eco-unfriendly behaviors, induce cognitive dissonance and psychological distress, which the individuals eliminate by modifying behavioral motivations and adjusting behavioral patterns (Forgas 1995; Bamberg and Möser 2007). Further, EE is compatible with multiple processes that affect behavioral decisions both directly, and indirectly through emotional information that affects the relationship between rational cognition and behavioral intentions (Forgas 1995). Six indicators are used to define EE and verify the role of EE in the public's payment decision, which involve the aspiration for a better living environment, anxiety about environmental degradation, approval of pro-environmental behaviors, and disapproval of eco-unfriendly behaviors. As a result, the following hypotheses are proposed:

Hypothesis 4: EE has a positive impact on INT.

Hypothesis 5: EE positively moderates the relationship between AT and INT, SN and INT, and PBC and INT, respectively.

The analysis framework and research hypotheses are shown in Figure 4-2.

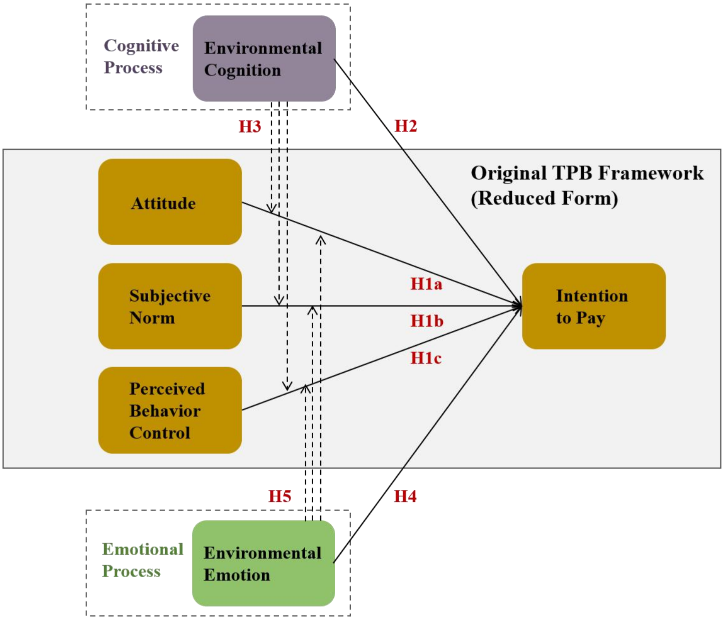

Figure 4-2 Analysis framework of the extended TPB and research hypotheses in the study. Source: Refer to the TPB framework (https://people.umass.edu/aizen/) and diagrammed by the author.

3. Data and methods

3.1 Questionnaire design and survey procedure

The questionnaire survey was conducted online. Public payment for APWM is similar to donation-based crowdfunding (DCF) (Stanko and Henard 2017), commonly relying on dedicated websites and social applications (Colombo et al. 2015; Ghobadi 2022). The online survey also has the advantages of a broad target population, low cost, and fast response (Fricker and Schonlau 2002; Wright 2005). Questionnaire Star (https://www.wjx.cn/), the largest online survey platform in China with over 300 million active users, was commissioned to survey in June-July 2022.

The questionnaire comprises three main parts. The first part includes the demographic characteristics of the respondents. The second part is the respondents' payment willingness towards APWM. It begins with a Likert scale investigating respondents' payment intentions towards APWM, ranging from 1 (not at all) to 5 (very much), and then the maximum amount they are willing to pay (i.e., WTP) per household per year. The third part, aiming to assess the constructs of the extended TPB framework, contains six latent variables, totaling 32 observable variables (SM 2). In this part, respondents rate their degree of agreement or disagreement with each statement, using a Likert scale ranging from 1 (completely disagree) to 5 (completely agree). The questionnaire was placed in the user pool of Questionnaire Star to collect data. After eliminating ones outside the study region, with terse completion times or with apparent errors, 1,288 valid questionnaires are obtained, and the effective rate of the questionnaire is 91.7%. It is verified the sample size satisfies the sample reasonableness test (Li et al. 2021).

3.2 Data analysis

AMOS 24.0 was applied to perform the SEM to simulate and estimate the relationships of different constructs in extended TPB (Wu 2010; Qiu and Lin 2019). Moreover, hierarchical regression was used to test the moderation effects of EC and EE by applying SPSS 25.0.

4. Results

4.1 Descriptive statistics

The demographic characteristics of the respondents (Table 4-1) show that approximately half of the respondents are male and married. The distribution of residence places in urban and rural areas is roughly equal, at 43.5 and 56.5%, respectively. The majority are 18-39 years old and 80% of respondents have a high school or college education, indicating the younger and the educated population are over-represented to a certain degree. Nevertheless, as a typical DCF behavior, the initiative of public payment for APWM is supposed to rely on digital interactive platform (Colombo et al. 2015; Ghobadi 2022), and the observation of the study aligns with research on online surveys (Couper, 2000; Sterrett et al., 2017). Most respondents have a household size of 3-8 persons, with less than three teenagers and less than three elderly. Half of the respondents' annual household income is CNY 7,000-210,000. Respondents' characteristics of household population and income are consistent with the statistics in the study region (NBSC 2022b).

Table 4-1 Demographic characteristics of respondents

Characteristics	**Frequency**	**Percent**	**Characteristics**	**Frequency**	**Percent**
Gender			Number of household		
Male	611	47.4	＜3	45	3.5
Female	677	52.6	3-5	1,032	80.1
Age			6-8	207	16.1
＜18	95	7.4	＞8	28	2.2
18-29	629	48.8	Number of teenager		
30-39	367	28.5	＜3	1,232	95.7
40-49	136	10.6	3-4	56	4.3
＞49	61	4.7	Number of the elderly		
Place of residence			＜3	1,244	96.6
Urban	560	43.5	3-4	44	3.4
Rural	728	56.5	Household annual income (CNY)		
Education level			＜10,000	105	8.2
Primary school	42	3.3	10,000-29,999	127	9.9
Junior high	141	10.9	30,000-69,999	268	20.8
Senior high	201	15.6	70,000-129,999	328	25.5
College	822	63.8	130,000-209,999	318	24.7
Postgraduate	82	6.4	210,000-310,000	100	7.8
Marital status			＞310,000	42	3.3
Unmarried	589	45.7			
Married	699	54.3			

Data source: Questionnaires from the study region.

4.2 Estimation of payment willingness and TPB constructs

A significant portion of the respondents, specifically 40.9%, express positive payment intentions towards APWM. The average WTP of all the respondents is CNY 482.6. The 95% confidence interval of WTP is CNY 375.2–538.9, statistically significant at the 5% level (Queralt 2012). The statistics of constructs (SM 2) demonstrate that respondents generally have moderate AT and SN, relatively low EE, and relatively high EC and PBC. Eventually, they have a moderate payment INT.

4.3 Reliability testing

The internal consistency coefficient, Cronbach's α, is applied to conduct the reliability testing. The Cronbach's α for the six latent variables are 0.905 (AT), 0.919 (SN), 0.871 (PBC), 0.871 (PBC), 0.925 (EC), and 0.853 (INT). Each statistic exceeds the general discriminant of 0.800 (Garrett 1926), confirming the reliability of the study.

4.4 Validity testing

Construct validity, convergent validity, and discriminant validity are conducted for validity testing (Wu 2010). The construct validity testing (SM 3) indicates the extended TPB framework provides a good fit for the data (Wu 2010; Qiu and Lin 2019). The convergence validity testing shows that all constructs are convergent (SM 2) for the standardized factor loading greater than 0.6, composition reliability (CR) greater than 0.7, and average variance extracted (AVE) greater than 0.36 (Wu 2010). Cross-loadings, Fornell-Larcker criterion, and Heterotrait-Monotrait Ratio (HTMT) are applied to test the discriminant validity, and the results indicate that the discriminant validity test is passed (Appendices D–F) (Fornell and Larcker 1981; Wu 2010; Henseler et al. 2015).

4.5 Common method variance and multi-collinearity testing

Harman one-way test is performed to exclude common method variance (CMV) (Podsakoff et al. 2003). The result shows that one component explains at most 30.23% of the model variance, bellowing the 40% threshold to exclude CMV. None of the standardized regression coefficients is greater than 1 (Marsh et al. 2004), and the variance inflation factor (VIF) for each measure is less than 10, ruling out covariance problems (Qiu and Lin 2019).

4.6 Hypotheses testing

AT, SN, and PBC exert significant positive effects on INT (Figure 4-3), verifying H1a, H1b, and H1c. Besides, EC and EE significantly affect INT, thus validating H2 and H4. EC and EE improve the overall understanding of INT, increasing the proportion of explained variance from 55.9% to 61.5%. Multiple regression analyses are performed to test the moderating effects of EC and EE on AT→INT, SN→INT, and PBC→INT, respectively (SM 7). The regression coefficients of AT×EC and SN×EC are positive and significant. In contrast, the regression coefficient of PBC×EC is not statistically significant. Results reveal that EC enhances the relationship between AT and INT, between SN and INT, but not between PBC and INT. Likewise, EE improves the relationship between AT and INT and between SN and INT. Hypothesis H3 and H5 are partially confirmed.

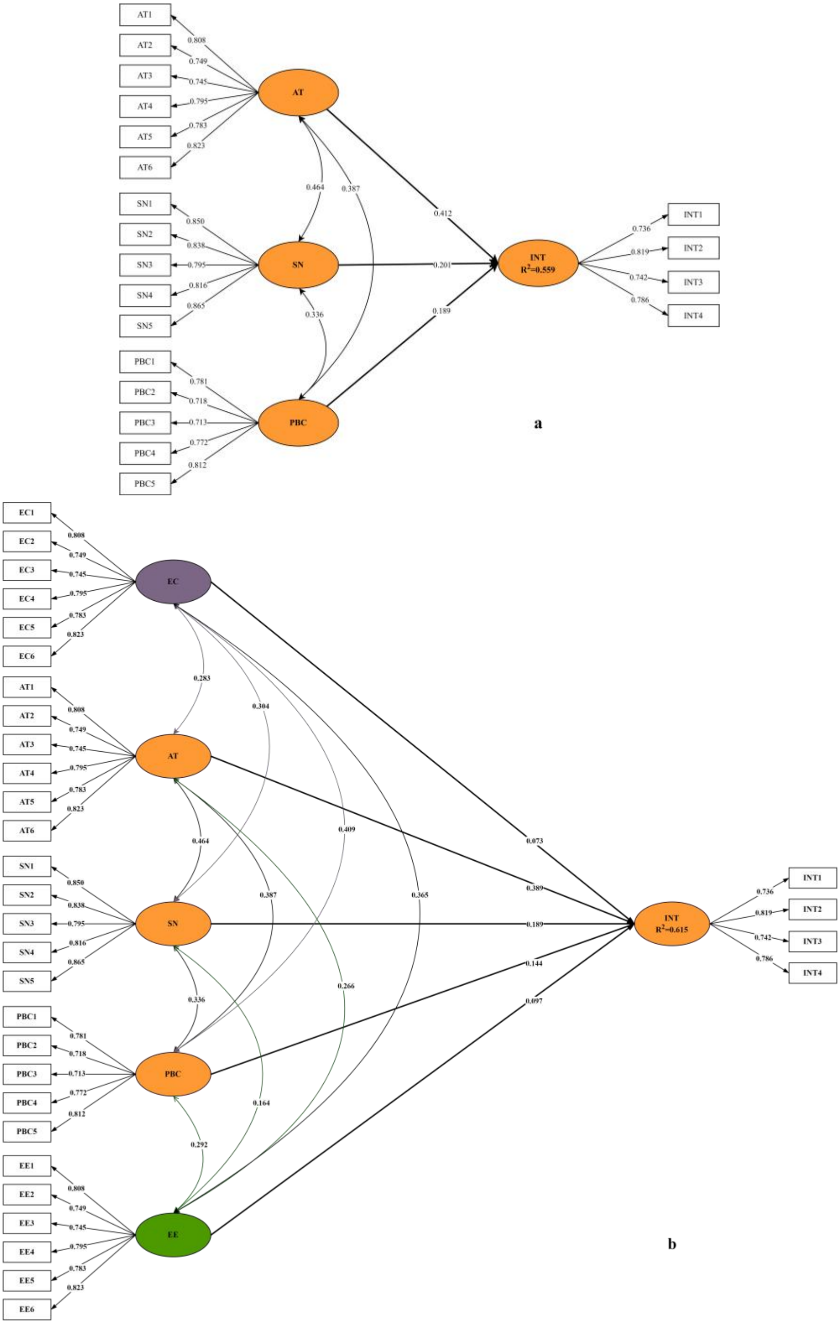

Figure 4-3 Original(a) and extended(b) TPB framework with standardized path coefficients (PCs). Source: Summarized by the author.

To sum up, AT, SN, and PBC all have significant positive effects on INT, with AT exerting the most prominent effect. In addition, EC and EE influence INT significantly and positively, yet their direct effects are relatively small compared to the three antecedent constructs of TPB. They positively moderate the relationship between AT and INT and between SN and INT, posing indirect effects on INT (SM 8).

5. Discussion

It is challenging to sustain APWM with existing funding in China, leaving the threats posed by APW to persist and trigger social concern. The result reveals the possibility of public payment in addressing the funding gap. Further, the driving pathways of payment decisions are investigated by applying the extended TPB framework. The findings enhance the understanding of the public's voluntary contribution to APWM and shed light on critical initiatives to strengthen individuals' payment intentions.

5.1 Individuals' payment willingness towards APWM

More than 2/5 of the respondents are willing to pay for APWM, and the average WTP is CNY 482.6 per household per year, approximately 0.5% of their annual household income. The amount exceeds most yearly WTP for marine plastic waste management, which was USD 2.6 for South Korean residents (Choi and Lee 2018), USD 0.7-8.1 per visitor in Greece, Bulgaria and the Netherlands (Brouwer et al. 2017), USD 4.9-14.5 for Ecuadorian families (Zambrano-Monserrate and Ruano 2020), and USD 11.9-34.6 per household for Australians (Borriello and Rose 2022). However, it is lower than NOK 5,485 (1 NOK = 0.091 USD) per household per year of Norwegian households for eliminating marine plastic pollution (Abate et al. 2020), which surpasses the WTP found in other comparable studies. The result demonstrates the public's payment willingness towards APWM is relatively strong in general. Referring to respondents' reported WTP, the public of four provinces (autonomous regions) in the study region will raise a total of CNY 12.2 billion APWM funding. It implies the initiative of public payment can be a promising supplement to the existing APWM scheme, which is beneficial to mitigate the funding gap. Of course, according to the ladder of citizen participation (Arnstein 2019), public payment which is currently being verified may remain at the ladder's bottom rung. How to gradually climb the higher rungs of public participation in environmental issues through institutional construction may be a core topic in the future.

5.2 Driving pathways of individuals' payment decisions

Attitude AT exerts the most significant positive influence on INT among all the five constructs studied. Studies on green purchase (Ajzen 2005; Martinho et al. 2015) and renewable energy support (Cass et al. 2010) backed up the proposition. Indicators' PCs suggest that evaluation from a self-needs perspective (AT1) occupies an absolute advantage, followed by the evaluations from the surrounding environment (AT4), with comparatively small impacts from others (AT2) and society (AT3). It aligns with the degree of impact on individuals, enlightening that positive evaluations towards APWM may derive from self-interest realization motivations rather than altruism (Sugden 1984). That is to say, individuals' payment decisions stem more from the desire to satisfy ego needs, which accords with earlier observations in charitable donations (Chang 2014). Additionally, evaluations based on future demands matter more than present-based ones. The preference for "investing for the future" may be attributed to the fact that although the APW threats are perceived, it is silent and invisible. Out of rational and prudent consideration, individuals deem that APWM is of the essence to lessen possible future threats.

The result corroborates the crucial role of environmental education and advocacy in enhancing the public's comprehensive evaluation and good attitude towards APWM, which can further motivate their payment decisions. The forms of education and advocacy should be innovatively diversified in practice. On one hand, traditional mass media such as books, newspapers, radio, film and television should be utilized (Xu 2020). Outstanding public service announcements should be produced and broadcasted, and slogans and posters can be displayed outdoors and on public transportation to publicity vividly. On the other hand, social media, video websites, mobile applications and other online promotional platforms should be applied actively (De Fano et al. 2022). Environmental education-themed online literature, animation, audiobooks, games, and short videos allow the public to grasp a more comprehensive understanding of agricultural non-point pollution enjoyably and subtly. As for designing public education and advocacy, it is necessary to give full consideration to the critical impacts of APWM on themselves and future sustainable development.

Subjective norm Individuals with higher SN are more prone to pay for APWM, in harmony with previous study (Wang et al. 2016). Indicators' PCs reveal that social pressures, from relatives (SN1) and friends (SN2) to social media (SN4) and authorities (SN3), are diminishing. It indicates that pressure from closely connected others is the most significant source of SN, with others being less influential. A possible explanation might be that public payment is typical behavior with public welfare attributes and altruistic tendencies, and the resulting norms are mainly reflected in informal public opinion and moral restraint. The external pressure individuals perceive diminishes from relatives and friends to social media and authorities, consistent with social distances and connection tightness to the pressure sources. The finding that donation willingness enhances along with social proximity corroborates earlier findings (Fong and Luttmer 2011).

Specifically, expectations from relatives and friends are pivotal components of SN. In an acquaintance society, individuals gain social inclusion by following what others consider good (Taylor and Todd 1995). Individuals' decisions are generally influenced by relatives and friends of the tradition of collectivism (Fei 2009). Besides, the finding enables us to conclude that exposure to APWM-themed information on social media can enhance payment INT, in line with the announcement that exposure to media information regarding pro-environmental behaviors effectively engages people in them (Zhang et al. 2021). Furthermore, the norms from the authorities cannot be ignored. While public payment holds weak mandatory binding (Bergstrom et al. 1986), the appeal and encouragement from authorities with high credibility are practical (Osbaldiston and Sheldon 2003). The result is in line with studies on curbside recycling programs (Gamba and Oskamp 1994) and food waste management (Soorani and Ahmadvand 2019).

The critical role of SN should be fully aware of in public payment schemes. Consensus concerning the hazards of APW and the importance of APWM should be thoroughly reached and spread out within personal circles. Individuals, groups, and organizations that made special contributions to APWM should be highly praised and widely publicized. The demonstration and guidance role of models should be sufficiently exhibited to inspire everyone to cooperate and make efforts for APWM. Engaging celebrities, public figures, and other influencers in public payment schemes can also be beneficial in amplifying social norms. In addition, social media can also be developed as a tool to disseminate public payment schemes. Web-based publicity with the theme of public cooperation in environmental management should be carried out to advocate positive energy in social interaction. Furthermore, authorities' publicity also makes sense and serves to assist the public in identifying their entity identity in environmental governance, which can foster the public's civic responsibility and social awareness to promote a "mission community" for environmental public welfare (Zhong and Luo 2021).

Perceived behavior control Individuals who have more confidence in the controllability and self-efficacy of paying for APWM are more willing to pay, which has been discerned earlier (Khan et al. 2019; Shang and Xiong 2021). Indicators' PCs suggest that a sense of self-control (PBC4) and expected effectiveness (PBC5) are major elements of PBC, followed by available opportunity (PBC2), while financial burden (PBC3) exerts relatively little.

As the homo economicus, one of the individuals' behavioral motivations is to lessen damage or benefit. Paying for APWM is a sacrifice for individuals, and the promotion of altruistic behaviors primarily originates from the belief that they will reap the rewards (Liu and Hao 2017). Respondents expect their payment can alleviate the APW and bring about an improved living environment rather than being futile. Consequently, institutions that guide public payment schemes should have high social credibility. With a convincing institution to endorse, the public will be inclined to eliminate indecision and be convinced that their efforts will be rewarded. In addition, making sure the feedback concerning APWM is available to contributors may be effective in promoting payment intentions as well.

Being an envisaged scheme, the absence of payment channels may be the major challenge. The finding emphasizes the necessity of opening up the payment access of APWM to create favorable conditions. Based on intelligent terminals and mobile payments, the Internet shows great potential to aggregate numerous contributors. The online payment platform seems to be a promising choice for not only simplifying the payment process but also enlarging information dissemination through social applications (Zhang and Li 2022). Enlarging the information disclosure of public payment schemes, including constantly announcing the progress and effectiveness of APWM's efforts and timely response to issues that are highly concerned, enables the potential contributors to know more about the details of the scheme and their associated benefits (Zhao and Shneor 2020). This will allow greater transparency and accountability of the scheme and increase public trust (Ferreira et al. 2022). It's worth noting that the amount individuals are willing to pay is a basic attribute to evaluate. The voluntariness principle can lower the threshold and ease the perceived difficulty.

Environmental cognition EC strengthens the relationships between AT and INT and between SN and INT. Individuals with a higher level of EC have a more profound comprehension of APW (Sauer and Fischer 2010; Juvan and Dolnicar 2014) and are more inclined to make reasonable decisions on APWM (Weber 2017). EC strengthens INT by facilitating the conversion of rational motivations into responsible behavior decisions. However, EC does not affect the relationship between PBC and INT. PBC closely correlates with individuals' perceived control over targeted behaviors based on their experiences and expected obstacles (Ajzen 1991). The discrepancy could be attributed to the fact that PBC is closely tied to objective reality, which EC cannot alter.

Indicators' PCs reflect that the perceived threat to food safety (EC4 and EC6) is the major source of EC. The reason may be that scientific researches on the risks of plastics are on the upsurge, notably the threats to the food system and human health (Leslie et al. 2022; Zhu et al. 2023), and related reports are becoming ubiquitous in social media like Weibo, Tiktok, and WeChat. In this context, the consensus has emerged among the public that plastics are "invisible killers," causing vast public concern. Next, environment pollution cognition (EC1) makes up a reasonable proportion of EC. The study region is located in the Loess Plateau area of China, which is poor in natural endowments with scarce precipitation, arid climate and rare vegetation, making the locals acutely aware of environmental crises. However, ecosystem importance cognition (EC2) and environmental threat cognition (EC3 and EC5) are comparable and relatively minimal. This may signal that respondents' cognition of environmental pollution lies at a relatively unilateral level.

Efforts should be made continuously to popularize environmental knowledge and deliver the facts about the seriousness of environmental pollution and the urgency of taking action to mitigate environmental degradation. Environmental education should be further deepened so that the public can acquire more systematic learning on the intrinsic logic of "environmental pollution-food safety-human health". The psychological anchor that individuals attach great concern to food safety and human health can be grasped in popularization and education to strengthen environmental cognition and stimulate the motivation to perform responsible behaviors. Furthermore, the key moment of environmental education such as World Environment Day, focusing on "Solutions to Plastic Pollution" in 2023 (UNEP 2023), can be leveraged to foster public environmental literacy on a larger scale. This can be done by utilizing digital media with extensive reach (Yuan et al. 2023), as well as by creating local events such as workshops, lectures, and other activities to broaden the impact of the education campaigns.

Environmental emotion Similarly to EC, EE enhances the relationships between AT and INT and between SN and INT. Limited association between rational motivations and behavioral decisions is a typically embarrassing dilemma, presenting a violation of "knowledge as action". It may be that such perception and awareness fail to match with equivalent emotional empathy (Thomas et al. 2009). By reinforcing the bond that individuals identify with the environment, EE facilitates rational motivations to transform into responsible environmental behaviors (Adhami and Akbarzadeh 2010). Decisions reinforced by emotional factors are more respectful and generous to the environment, even beyond self-interest (Olivos et al. 2011). If perceptions of environmental issues rise from rational levels to emotional ones, individuals' comprehension of payment for APWM will be elevated to a profound and stable spiritual touch.

Indicators' PCs suggest that positive emotions are the core elements of EE compared to negative ones. The finding supports the evidence that pro-environmental behaviors were more correlated with positive emotions (Meneses 2010; Kostka and Mol 2013; Zelenski and Desrochers 2021). Specifically for positive EE, individuals who appreciate the beautiful environment (EE1) are more likely to make efforts and sacrifices for it (Hartmann and Apaolaza-Ibáez 2008). In addition, if individuals appreciate (EE4) and approve of (EE6) pro-environmental behaviors, they are likely to be appealed to and assimilated to perform the same behaviors (Kals et al. 1999). In light of this, initiatives like experience and participation in environmental practices can be applied to encourage individuals to discover the beauty of nature, understand the value of ecology, and thereby strengthen their EE to enhance payment intentions. Furthermore, environmental protection ambassadors can be set to subtly stimulate individuals' positive emotional energy and promote their identification with the cooperation to environmental management. Negative emotions are minor but meaningful to EE. Environmental anxiety (EE2) is a sense of worry developed by cognition, reflecting emotional shock at environmental deterioration (Böhm 2003). Additionally, individuals may feel disgusted (EE3) and guilty (EE5) about eco-unfriendly behaviors (Kollmuss and Agyeman 2002; Harth et al. 2013). These feelings can cause cognitive dissonance, leading to psychological suffering (Böhm 2003). Individuals thus modify former behavioral motivations and patterns (Carrus et al. 2008). In this regard, information that the environment is continuously getting worse and the ecosystem crisis is progressively increasing should be appropriately disseminated to create a sense of anxiety and crisis. Additionally, typical ecological damage behaviors should also be disclosed timely. Negative incentives like criticism and education can stimulate feelings of disgust and guilt for eco-unfriendly behaviors.

In summary, the direct effects of EC and EE on INT are minor compared to AT, SN, and PBC, implying that the public's payment decision is driven more by motivations associated with APWM than by pro-existing EC or stable EE. Given their inspiration in understanding the public's payment decision, it is equally compelling to enhance EC and EE through the aforementioned initiatives.

Furthermore, it is worth pointing out that the study extends TPB by EC and EE. Indeed, many other factors may affect the public's payment intention. Upcoming research would consider other determinants as extended constructs to obtain in-depth knowledge.

5.3 Government's guidance to promote APWM

The public is an essential component of a systematic environmental governance system (Kostka and Mol 2013), and multi-entity cooperation is a comprehensive solution to environmental pollution (Mauerhofer 2016; Carvalho et al. 2019). Pursuing sustainable and resilient APWM necessitates seeking open-ended and innovative schemes through increasing awareness and cooperation among all stakeholders, which is aligned with the common interests and shared values of humanity. Accordingly, the government can undertake the following efforts.

Foremost, the government should actively foster the social atmosphere of public payment for APWM. Aiming at consolidating the consensus of multi-entity cooperation in environmental management, the government can strengthen education and publicity to improve the public's comprehensive evaluation of APWM and upgrade their environmental cognition, reinforce the subjective norm of public payment for APWM, and nurture the public's environmental emotion. Especially, the government should assist in constructing authoritative and accessible public payment channels. As stated, public payment for APWM is essentially the DCF, which consists of the creator, platform, and funder (Shneor and Maehle 2020). Creators in China are primarily foundations, charities, government departments, and social organizations. Enterprises, individuals, and social organizations can fund a specific DCF on 32 online fundraising information platforms designated by the Ministry of Civil Affairs of China. The government can guide authoritative creators, such as the China Environmental Protection Foundation and the Inner Mongolia Autonomous Region Charity Federation, to take the lead in initiating public payment for APWM. The government's guidance and endorsement will efficiently facilitate the construction of public payment channels, increase the public's trust in online donations (Liu et al. 2022), and mobilize the public to pay.

Additionally, the government should upgrade financial support for APWM. The public interest is the origin and destination of the government's environmental management. Thus, financial expenditures on environmental protection should be directed towards fields of great social concern and pressing public demands. The public's high payment willingness towards APWM implies that the government should restructure the financial allocation of environmental protection funding and place more emphasis on agricultural non-point waste such as APW. The government can consider setting up a particular category for APW inside the "211 Energy Conservation and Environmental Protection" (SM 9) and provide precise and differentiated financial support to different stakeholders and management links. For plastics production enterprises, government purchases of APW-based regenerated products can be increased to enhance their market competitiveness. For APW recycling enterprises, APW categories that are eligible for the VAT instant refund policy could be expanded, interest discounts for purchasing and upgrading environmental equipment could be offered, APW processing equipment could be included in the agri-machinery subsidy category, and the investment in recycling station construction should be enlarged. Additionally, farmers who purchase APW-based regenerated mulch film ought to be subsidized.

6. Conclusion

The study conducts an empirical analysis based on 1,288 residents in four provinces (autonomous regions) of northern China. Under the premise of verifying the applicability of public payment for APWM, the extended TPB is applied to investigate the driving pathways of the public's payment decision. Results illustrate that: 1) Public payment scheme holds potential promise in alleviating the fund gap confronting APWM; 2) AT, SN, PBC, EC, and EE have significant positive influences on payment INT towards APWM, with AT exerting the greatest impact, followed by SN and PBC, and EC and EE showing minimal direct effects; 3) the extended TPB framework has better interpretability to INT, and EC and EE strengthen the relationship between AT and INT and between SN and INT.

The study provides a new perspective on public payment in tackling the APWM dilemma, which is quite revealing. The initiatives highlighted by the driving pathways of the payment decision, which include strengthening the public's comprehensive evaluation of APWM and environmental cognition, reinforcing subjective norms of paying for APWM, establishing the payment platform to open up channels for the public to pay, and nurturing the public's environmental emotions, can be served as the entry point for formulating an open and diverse APWM scheme. In this regard, the government should play its guidance, organization and support role in APWM. Practical collaborations among multiple entities should be actively promoted along with the planning of public payment schemes. The combined efforts of multiple entities will highlight the synergy between the non-market value and the market value of APWM and ultimately achieve sustainable and resilient agricultural non-point waste management. Furthermore, agricultural non-point waste may also occur in pursuing economic development in other developing countries. Public participation can be an innovative approach to enhance agricultural waste management.

Supplementary materials

SM 1. Cost accounting in the recycling of mulch film waste

The recycling utilization of mulch film waste consists of the following stages: First, farmers collect the mulch film waste from their farmland or entrust a company to collect and then hand it to a nearby recycling station. Then, the recycling station centrally integrate the mulch film waste and sell it to recycling utilization enterprises (hereinafter referred to as "recycling enterprises"). Finally, recycling enterprises realize the resource regeneration of mulch film waste through sorting, cleaning, and reprocessing. According to the recycling processes, the cost of the recycling utilization is mainly composed of raw material purchase cost, manual sorting cost, and granules production cost. In addition, there are fixed costs, including the expense in environmental protection, asset depreciation, and machine maintenance (Table S4-1).

Material purchase cost: The average purchase price of mulch film waste is CNY 120 per cubic meter. According to the actual situation, 20 cubic meters of mulch film waste can produce 1 ton re-produced plastic granules. It is estimated that the material purchase cost of producing 1 ton re-produced plastic granules is CNY 2400.

Manual sorting: The collected mulch film waste needs pre-processing of manual sorting to remove the contamination such as sand and crop straw. Following the actual situation, each person could sort 300 kg of mulch film waste per day, and the output rate of sorted mulch film waste is 60%, that is, 1.67 tons sorted mulch film waste can produce 1 ton re-produced plastic granules. Based on a daily wage of CNY 200 per labor, the cost of manual sorting is estimated as CNY 1100 for 1 ton re-produced plastic granules.

Processing: The sorted mulch film waste will be sent to the production plant for crushing, cleaning, processing, and pelletizing, which requires labor and electricity. The labor cost for 1 ton of re-produced plastic granules is about CNY 600. The electricity consumption of 1 ton of re-produced plastic granules is 1300 kWh. Based on the current industrial electricity tariff of CNY 0.9 per kWh and the transformer losses, the electricity tariff turns to CNY 1.0 per kWh. The aggregated cost of electricity is CNY 1300 for 1 ton re-produced plastic granules.

Fixed cost: The fixed cost is CNY 880 for 1 ton re-produced plastic granules, including: the cost of purchasing environmental protection equipment and the treatment of waste water and waste gas (CNY 150/ton), equipment maintenance cost (CNY 260/ton), oil cost for loading (CNY 40/ton), sludge cleaning cost (CNY 50/ton), mulch film waste storage cost (CNY 180/ton), and the assets depreciation cost (CNY 200/ton).

Based on the average mulch film utilization of 1.41 million tons from 2015-2020, a total of CNY 7.08 billion is required to achieve the recycling rate of 80%, and CNY 8.85 billion for 100%.

Material purchase	Manual sorting	Processing		Fixed cost	Total
		Labor	Electricity		
2400	1100	600	1300	880	6280

Data source: Summarized by the author. Unit: CNY/t

SM 2. Descriptive statistics and results of the convergence validity test

Construct	Code	Measurement Items	Mean ± standard deviation	Standardized Factor Loading	SMC	CR	AVE
Attitude	AT1	Conducting APWM is enjoyable and satisfying for me.	3.44±1.07	0.808	0.653	0.906	0.616
	AT2	Conducting APWM is good for the society.		0.750	0.562		
	AT3	Conducting APWM is sensible as the government policy.		0.745	0.556		
	AT4	Conducting APWM is good for the ecosystem.		0.795	0.632		
	AT5	Conducting APWM is important and urgent right now.		0.783	0.613		
	AT6	Everyone should take responsibility for APWM in the future.		0.823	0.677		
Subjective Norm	SN1	My relatives suggest me to pay for APWM.	3.40±1.27	0.85	0.722	0.919	0.694
	SN2	My friends suggest me to pay for APWM.		0.838	0.702		
	SN3	Community and government suggest me pay for APWM.		0.795	0.632		
	SN4	Social media suggests me to pay for APWM.		0.816	0.666		
	SN5	I would feel morally condemned if I do not pay for APWM.		0.865	0.748		
Perceived Behavior Control	PBC1	It is easy for me to pay for APWM.	3.56±1.11	0.781	0.61	0.872	0.578
	PBC2	I know how to pay for APWM.		0.718	0.515		
	PBC3	There is no financial burden for me to pay for APWM.		0.714	0.509		
	PBC4	It is entirely up to me whether to pay for APWM or not.		0.774	0.599		
	PBC5	My efforts will be paid off if I pay for APWM.		0.809	0.655		
Environmental Cognition	EC1	Environmental pollution is currently a major problem.	3.61±1.17	0.806	0.649	0.925	0.674
	EC2	It is important to protect the ecosystem.		0.775	0.601		
	EC3	Environmental pollution affects human health.		0.819	0.671		
	EC4	Environmental pollution affects food safety.		0.823	0.677		
	EC5	Improper disposal of plastic waste can lead to environmental pollution.		0.829	0.687		
	EC6	Microplastics can enter the food chain and threaten human and animal health.		0.87	0.758		
Environmental Emotion	EE1	I aspire to a better living environment.	3.26±1.14	0.774	0.6	0.898	0.595
	EE2	I am anxious about the current environment state.		0.771	0.594		
	EE3	I am disgusted by others' environmental damage behaviors.		0.738	0.544		
	EE4	I am appreciative of others' environmental protection behaviors.		0.714	0.51		
	EE5	I feel guilty for my environmental damage behaviors.		0.777	0.603		
	EE6	I am proud of my environmental friendly behaviors.		0.846	0.715		
Intention to Pay	INT1	I am in favour of paying for APWM.	3.44±1.01	0.737	0.544	0.854	0.595
	INT2	I am willing to pay for APWM.		0.819	0.671		
	INT3	I intend to pay for APWM.		0.741	0.549		
	INT4	The better the management, the more I am willing to pay.		0.786	0.618		

Note: KMO=0.930; Bartlett's Test of Sphericity=25810.680 at df=496 with a significance of 0.000. Source: Summarized by the author.

SM 3. Results of the model fit test for SEM analysis

Fit Index	Fit Criteria or Critical Values	Original TPB framework		Extended TPB framework	
		Estimate	Fit Test	Estimate	Fit Test
Absolute Fit Index					
λ2/df	1-3, excellent; 3-5, good	3.035	S	2.800	S
Goodness of fit index (GFI)	＞0.9	0.964	S	0.943	S
Adjusted Goodness of fit index (AGFI)	＞0.9	0.954	S	0.934	S
Root Mean Square Residual (RMR)	＜0.05	0.029	S	0.034	S
Root mean square error of approximation method (RMSEA)	＜0.05	0.040	S	0.037	S
Incremental Fit Index					
Normed fit index (NFI)	＞0.9	0.968	S	0.952	S
Relative fit index (RFI)	＞0.9	0.962	S	0.947	S
Incremental fit index(IFI)	＞0.9	0.978	S	0.968	S
Tacker-Lewis index (TLI)	＞0.9	0.975	S	0.965	S
Comparative fit index (CFI)	＞0.9	0.978	S	0.968	S
Parsimony fit indices					
Parsimony goodness of fit index (PGFI)	＞0.5	0.753	S	0.802	S
Parsimony normed fit index (PNFI)	＞0.5	0.835	S	0.862	S

Note: S = Supported. Source: Summarized by the author.

SM 4. The result of cross-loadings

	AT	SN	PBC	EC	EE	INT
AT1	**0.808**	0.375	0.313	0.228	0.215	0.467
AT2	**0.750**	0.347	0.290	0.212	0.199	0.434
AT3	**0.745**	0.346	0.288	0.211	0.198	0.431
AT4	**0.795**	0.368	0.307	0.225	0.211	0.460
AT5	**0.783**	0.363	0.303	0.221	0.208	0.453
AT6	**0.823**	0.381	0.318	0.233	0.219	0.476
SN1	0.394	**0.850**	0.286	0.258	0.139	0.387
SN2	0.389	**0.838**	0.282	0.255	0.137	0.382
SN3	0.369	**0.795**	0.268	0.241	0.130	0.362
SN4	0.378	**0.816**	0.275	0.248	0.134	0.372
SN5	0.401	**0.865**	0.291	0.263	0.142	0.394
PBC1	0.302	0.263	**0.781**	0.320	0.228	0.325

	AT	SN	PBC	EC	EE	INT
PBC2	0.278	0.242	**0.718**	0.294	0.210	0.299
PBC3	0.276	0.240	**0.714**	0.292	0.208	0.297
PBC4	0.299	0.260	**0.774**	0.317	0.226	0.322
PBC5	0.313	0.272	**0.809**	0.331	0.236	0.337
EC1	0.228	0.245	0.330	**0.806**	0.294	0.269
EC2	0.219	0.235	0.317	**0.775**	0.283	0.259
EC3	0.232	0.249	0.335	**0.819**	0.299	0.274
EC4	0.233	0.250	0.337	**0.823**	0.300	0.275
EC5	0.234	0.252	0.339	**0.829**	0.302	0.277
EC6	0.246	0.264	0.356	**0.870**	0.317	0.291
EE1	0.206	0.127	0.226	0.282	**0.774**	0.232
EE2	0.205	0.126	0.225	0.281	**0.771**	0.231
EE3	0.196	0.121	0.215	0.269	**0.738**	0.221
EE4	0.190	0.117	0.208	0.260	**0.714**	0.214
EE5	0.206	0.127	0.227	0.283	**0.777**	0.233
EE6	0.225	0.138	0.247	0.308	**0.846**	0.254
INT1	0.427	0.336	0.307	0.247	0.221	**0.737**
INT2	0.474	0.373	0.341	0.274	0.246	**0.819**
INT3	0.429	0.337	0.308	0.248	0.222	**0.741**
INT4	0.455	0.358	0.327	0.263	0.236	**0.786**

Source: Summarized by the author.

SM 5. Results of the discriminant validity test for the original TPB model and the extended TPB model

Variables	AT	SN	PBC	INT
AT	**0.784**			
SN	0.464 ***	**0.833**		
PBC	0.387 ***	0.336 ***	**0.760**	
INT	0.579 ***	0.456 ***	0.416 ***	**0.772**

Variables	AT	SN	PBC	EC	EE	INT
AT	**0.785**					
SN	0.464 ***	**0.833**				
PBC	0.387 ***	0.336 ***	**0.760**			
EC	0.283 ***	0.304 ***	0.409 ***	**0.821**		
EE	0.266 ***	0.164 ***	0.292 ***	0.365 ***	**0.771**	
INT	0.579 ***	0.456 ***	0.416 ***	0.334 *	0.300 ***	**0.771**

Note: All significance tests are two-tailed. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. The diagonals exhibit the square root of the AVE and the off-diagonals exhibit the correlations. Source: Summarized by the author.

SM 6. Results of HTMT test

	AT	SN	PBC	EE	EC	INT
AT	/					
SN	0.467	/				
PBC	0.387	0.336	/			
EE	0.268	0.171	0.292	/		
EC	0.280	0.305	0.416	0.371	/	
INT	0.581	0.458	0.417	0.306	0.340	/

Source: Summarized by the author.

SM 7. Results of moderating effect testing by multiple regression

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
AT	0.452*** (0.024)			0.463*** (0.024)		
SN		0.274*** (0.020)			0.289*** (0.019)	
PBC			0.268*** (0.026)			0.295*** (0.025)
EC	0.160*** (0.021)	0.185*** (0.022)	0.165*** (0.023)			
AT×EC	0.044* (0.021)					
SN×EC		0.059** (0.018)				
PBC×EC			0.006 (0.023)			
EE				0.138*** (0.022)	0.191*** (0.023)	0.170*** (0.024)
AT×EE				0.056* (0.024)		
SN×EE					0.051* (0.020)	
PBC×EE						0.028 (0.024)
Constant	3.428*** (0.020)	3.419*** (0.022)	3.436*** (0.023)	3.427*** (0.020)	3.430*** (0.021)	3.432*** (0.022)
Adjusted R2	0.293	0.208	0.16	0.284	0.209	0.161
F	179.091***	113.585***	83.004***	171.114***	114.402***	83.074***
N	1288	1288	1288	1288	1288	1288

Note: Model 1, Model 2 and Model 3 are applied to test the moderate effect of EC on AT→INT, SN→INT and PBC→INT, respectively. Model 4, Model 5 and Model 6 are applied to test the moderate effect of EE on AT→INT, SN→INT and PBC→INT, respectively. Standard errors are shown in parentheses. *p＜0.05, **p＜0.01, ***p＜0.001.
Source: Summarized by the author.

SM 8. Paths and hypotheses testing

Hypotheses	Paths	Estimate	S.E.	P	C/R
H1a	AT→INT	0.389	0.031	0.000	C
H1b	SN→INT	0.189	0.022	0.000	C
H1c	PBC→INT	0.144	0.028	0.000	C
H2	EC→INT	0.073	0.023	0.016	C
	Moderation of EC on AT→INT	0.044	0.021	0.037	C
H3	Moderation of EC on SN→INT	0.059	0.018	0.001	C
	Moderation of EC on PBC→INT	0.006	0.023	0.792	R
H4	EE→INT	0.097	0.025	0.000	C
	Moderation of EE on AT→INT	0.056	0.024	0.022	C
H5	Moderation of EE on SN→INT	0.051	0.020	0.011	C
	Moderation of EE on PBC→INT	0.028	0.024	0.239	R

Note: C = Confirmed; R = Rejected. Source: Summarized by the author.

SM 9. "211 Energy Conservation and Environmental Protection" category in China

In 2007, China established the "Environmental Protection" expenditure category, which has evolved into the "211 Energy Conservation and Environmental Protection" category with 14 items and 60 categories. These categories include four major accounts: environmental protection, energy conservation and utilization, natural ecological protection, and others. Environmental protection expenditure includes 4 items including Environmental Conservation Management Affairs, Environmental Monitoring and Supervision, Pollution Prevention, Pollution Reduction, and 1 category of Rural Environmental Conservation (in the Natural Ecology Conservation item). In 2021, fiscal expenditure on environmental protection is CNY 332.21 billion, accounting for 60.13% of the total expenditure on energy conservation and environmental protection, 1.35% of the national fiscal expenditure and 0.29% of the GDP.

Number Item	Number Category	Item Name	Category Name	Number Item	Number Category	Item Name	Category Name
	1		Administrative Operations		1		Fallow Cash
	2		General Administration Affairs		2		Food Discount Subsidy
	3		Agency Service		3		Food Expense Subsidy
	4		Eco-environmental Conservation Publicity	6	4	Grain for Green	Engineering Construction
	5		Environmental Conservation Regulations, Planning and Standards		99		Other Expenditure
1	6	Environmental Conservation Management Affairs	International Cooperation and Compliance		1		Beijing and Tianjin Desertification Source Control Project Construction
	7		Eco-environmental Conservation Administrative License	7	99	Desertification Control	Other Desertification Control Expenditure
	8		Climate Change Management Affairs		1		Returning Grazing to Grassland Project Construction
	99		Other Environmental Conservation Management Affairs Expenditure	8	99	Returning Grazing to Grassland	Other Expenditure
2	1	Environmental Monitoring and	EIA Review and Supervision of Construction Projects	9	1	Energy Saving and Utilization	

Number Item	Number Category	Item Name	Category Name	Number Item	Number Category	Item Name	Category Name
	2	Supervision	Nuclear and Radiation Safety Supervision	10	1	Pollution Reduction	Eco-environmental Monitoring and Information
	99		Other Environmental Monitoring and Supervision Expenditure		2		Eco-environmental Enforcement and Supervision
3	1	Pollution Prevention	Atmosphere		3		Emission Reduction Special Expenditure
	2		Water		4		Clean Production Special Expenditure
	3		Noise		99		Other Pollution Reduction Expenditure
	4		Solid Waste and Chemicals	11	1	Renewable Energy	
	5		Radioactive Sources and Radioactive Waste Regulation	12	1	Circular Economy	
	6		Radiation	13	1	Energy Management Affairs	Administrative Operations
	7		Soil		2		General Administration Affairs
	99		Other Pollution Prevention Expenditure		3		Agency Service
4	1	Natural Ecology Conservation	Ecology Conservation		4		Energy Forecast Alert
	2		Rural Environmental Conservation		5		Energy Strategic Planning and Implementation
	3		Biology and Species Resources Conservation		6		Energy Technology Equipment

Number Item	Number Category	Item Name	Category Name	Number Item	Number Category	Item Name	Category Name
	99		Other Natural Ecology Conservation Expenditure		7		Energy Industry Management
	1		Forest Conservation		8		Energy Management
	2		Social Insurance Subsidy		9		Informatization Construction
	3		Policy-based Social Expenditure Subsidy		10		Rural Grid Construction
5	4	Natural Forest Conservation	Natural Forest Conservation Project Construction		11		Project Operations
	5		Stop-logging Subsidy		99		Other Energy Management Affairs Expenditure
	99		Other Natural Forest Conservation Expenditure	14	1	Other Energy Conservation and Environmental Protection Expenditure	

Source: Ministry of Ecology and Environment of the People's Republic of China

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5

Chapter V: Effect of information intervention on enhancing the public payment scheme for agricultural plastic waste management

Adapt from:

Hao A, Yin C, Dogot T. 2024. Effect of information intervention on enhancing the public payment scheme for agricultural plastic waste management. Journal of Environmental Management, 372, 123302.

Abstract

Information intervention has been verified to be effective in influencing individual behavior. Thus, can information intervention reverse the common discrepancy of high intention but poor action among the public about participating in environmental management? Clarifying the issue is critical to facilitating the public payment scheme for APWM to evolve from idea to reality, as well as harnessing potential contributions from the public to promote the sustainability of APWM. In light of these inquiries, the study seeks to reinforce the public's payment for APWM by applying an information strategy based on the Theory of Planned Behavior (TPB) and to verify the effect of information intervention on the respondents' WTP by a RCT. Results showed that the public's WTP for APWM is generally malleable, with information targeting normative beliefs and control beliefs significantly increasing the WTP by CNY 307.2 and CNY 400.5, respectively. Findings imply that the public payment scheme for APWM is characterized by the high perception but weak social norm and lack of effective mechanism. Consequently, it is imperative to prioritize strengthening relevant norm and constructing public payment mechanism, thereby promoting multi-entity cooperation to enhance the APWM in sustainability.

Keywords

Agricultural plastic waste management; information intervention; public payment; randomized controlled trial; Polycentric governance

1. Introduction

The SDGs map out the direction toward "the future we want" with a balance between human welfare and environmental sustainability (Sachs, 2012). APWM contributes greatly to reducing the risk posed by APW to environment sustainability, food safety, and human health (Rillig and Lehmann, 2020). Therefore, it is a significant driver of SDGs, especially toward SDG-2: Zero Hunger, SDG-3: Good Health and Well-being, and SDG-13: Climate Action (UN, 2015). As the world's largest producer and consumer of agricultural plastics (FAO, 2021), China attach great emphasis on APWM. It is ranked as one of the five-pronged approaches for agriculture green development, which is the pivotal initiative to promote non-point pollution prevention and control and to establish a sustained mechanism for high-quality development in the agricultural sector.

Currently, the APWM operates on the government subsidy and market operation model, which proves economically challenging for enterprises and their normal operations heavily rely on government subsidies. Taking mechanical recycling, currently the most economical and prevalent plastic recycling technologies (Gopinath et al., 2020) as an example, a total investment of CNY 11.85 billion is required to attain the targeted recycling rate of 80% in 2021 (Appendix, A1). If entirely borne by the government, the deficit would occupy 0.5% of the total public budget expenditure allocated to energy conservation and environmental protection (MOF, 2023), imposing a considerable financial burden on the government. Furthermore, anticipated in the long run, with the end of the APW recycling pilot demonstration and the downslope in government subsidies, it is inevitable for APWM to encounter the funding gap (Zhang et al., 2020; Zhang et al., 2019). In 2020, the Chinese government issued the Guiding Opinions on Building the Modern Environmental Governance System, aiming to establish an collaborative environmental governance system in which the government plays a leading role, enterprises act as the primary agents, and social organizations and the public actively cooperate (The General Office of the CPC Central Committee and The General Office of the State Council, 2020). As the crucial stakeholder, the public's participation in environmental management has been confirmed as necessary and logical in public management theories (Ostrom, 1999; Ostrom, 2010). The feasibility of public payment for APWM has also been validated in previous study (Hao et al., 2023). Based on this premise, exploring effective strategies to harness individual efforts and incentivize broad public participation in APWM has become a critical direction for advancing APWM in sustainability.

However, public participation in environmental management typically exhibits the characteristics of positive attitude, moderate willingness, and low engagement (PRCEEC, 2020; PRCEEC, 2021). According to the Citizen Environmental Behavior Survey in 31 Chinese provinces, 95.9% of the 72,163 respondents demonstrated a rational understanding and favorable attitude of environmental protection actions, 79.7% expressed a willingness to contribute to environmental protection efforts, yet only 55.1% reported having participated in such activities (PRCEEC, 2021). Deviations between individual attitude, intentions and behaviors are primarily attributed to individual decision-making biases triggered by insufficient information (PRCEEC, 2020; PRCEEC, 2021). Information intervention serve as a common strategy aimed at altering individuals' perceptions, intentions, and behaviors by providing information addressing deficiencies in individuals' cognition, norms, and capabilities (Bamberg and Schmidt, 2003; Nisa et al., 2019). Information dissemination activities like education and public campaigns can enhance individuals' environmental awareness, boost confidence in the effectiveness of environmental management, foster a social atmosphere that encourages everyone participation in environmental protection, disseminate effective mechanism and channel for such involvement, and thus positively influence a rang of environmentally responsible behaviors (Lacroix, 2018; Wang et al., 2018). As a typical environmental behavior, public participation in APWM remains in its nascent stage, with limited public awareness and a lack of established mechanism for participation. Therefore, it will be highly beneficial for promoting a more sustainable APWM to investigate the impact of information interventions on the public's willingness to engage in APWM, and scientifically leverage information strategies to garner broader public financial support for APWM.

In summary, public participation is not only a practical necessity for advancing sustainable APWM but also an insightful exploration in the development of a modernized environmental management system. As a strategy capable of broadly enhancing individuals' willingness and actions to engage in environmental behaviors, information intervention offers a promising avenue for exploring whether and how it can promote the public payment scheme for APWM. However, there is a scarcity of research focused on the role of information intervention in public participation in agricultural white pollution. Additionally, existing studies have yet to reach a consensus on the mechanism through which information interventions influence behavior. The primary contributions of the study lies in addressing thee following unresolved questions: Q1: Is information intervention effective in increasing respondents' WTP for APWM? Q2: If the answer to Q1 is YES, how does information take effect in this matter? Q3: What enlightenment does the intervention provide for scheme initiators or policymakers to enhance the public payment scheme for APWM? By addressing the three research questions, the research seeks to shed light on the motivated mechanism for promoting the public to pay for APWM, thereby offering strategic insights to facilitate the public payment scheme evolving from idea to reality.

2. Literature review

Based on the three research questions proposed in the study, the literature review focuses on three key areas: (1) public payment for waste management initiatives, (2) the impact of information interventions on individual behavioral intentions and behaviors, and (3) the application of behavioral theories in information intervention.

As a crucial actor, the public has garnered considerable attention from academia regarding its role in pollution management. Research has primarily focused on public payment for pollution management, with particular attention paid to domestic solid waste (Benyam et al., 2020; Chen et al., 2021; Liang et al., 2021; Schuermann and Woo, 2022; Yang et al., 2021), electronic and electrical waste (Afroz et al., 2013; Islam et al., 2016), construction waste (Li et al., 2018; Véliz et al., 2022; Wang and Wu et al., 2019) and other waste that are relevant to the public. Basically, such studies revealed that people were generally inclined to pay for waste management. Besides, with the increasing severity of plastic pollution in recent years, studies investigating public payment for plastic waste management have gradually emerged. These studies typically assess respondents' willingness to contribute financially to these efforts (Abate et al., 2020; Borriello and Rose, 2022; Brouwer et al., 2017; Choi and Lee, 2018; Latinopoulos et al., 2018; Tyllianakis and Ferrini, 2021; Zambrano-Monserrate and Ruano, 2020). Additionally, factors influencing individuals' payment willingness have also been investigated, including demographic characteristics, such as gender, age, education, and household income; psychological characteristics, such as environmental responsibility, environmental awareness, and environmental love; and the external factors, such as experience of participation in environmental protection activities, frequency of exposure to plastic pollution and so on. It is evident that most research concentrated chiefly on marine plastic waste, while the few studies concerned about payment for agriculture-source plastic waste narrowly examined farmers' perspectives (Wang and Wang et al., 2019). Despite growing evidence that land-based plastic pollution is significantly more severe than marine-based pollution (Bläsing and Amelung, 2018; Qadeer et al., 2021; Santos et al., 2021), there remains a scarcity of research examining the public's payment for APWM. Furthermore, researchers' viewpoints are mostly similar in investigating the payment willingness and identifying the influencing factors. While these studies offer valuable insights, a more pressing research focus involves identifying the incentive mechanism that could enhance the public's WTP and uncovering the potential obstacles that may hinder it. Addressing this gap is crucial for advancing sustainable pollution management from the perspective of public payment, yet this remains a notable knowledge gap in the current research.

Information intervention is a commonly used strategy for behavior change (Verplanken and Wood, 2006). From the theoretical perspective, according to rational choice theory, information is the prerequisite for behavior (Edwards, 1954). Acquiring fresh knowledge can alter individuals' cognition and subsequently lead to changes in their actions (Lorenzoni et al., 2007). Similarly, the knowledge-attitude-practice (KAP) model also posits that the basis for behavioral decision-making is belief formation driven by information accumulation (Salazar et al., 2022). Information interventions leverage initiatives such as education, persuasion, training, and role modeling to convey targeted information and knowledge, reduce information asymmetry, and correct biases, thereby influencing individual decisions and steering behavior in the desired direction (Brown et al., 2017; Geng et al., 2016; Wei et al., 2020). From the empirical perspective, the impact of information intervention on behavioral intention and behavior has been widely validated. For instance, Wharton er al. (Wharton et al., 2021) performed an information intervention experiment significantly improved individuals' attitudes, subjective norms, perceived behavioral control, and intentions regarding food waste, which effectively reduced household food waste. Ling et al (Ling et al., 2023) applied a longitudinal field experiment verified that social norms messaging about household recycling yielded significant positive effects on recycling behavior and public support for waste prevention and harmless disposal policies. Similar conclusions have been drawn regarding green consumption (Filippini et al., 2021), energy consumption (Andor and Fels, 2018), and other environmental behaviors. Moreover, the influence of information intervention on individuals' WTP for pro-environmental behaviors has also been confirmed. For example, Wei et al. (Wei et al., 2020) carried out a survey of 1,381 residents on carbon consumption demonstrated that conveying information related to low-carbon values, cultural norms, and social expectations helped enhance public capability and WTP for low-carbon initiatives. Su et al. (Su and Li, 2024) investigated the effect of information intervention on consumer choices through an online survey and found that both gain and loss-framed information effectively increased consumers' WTP a premium for pro-environmental hotels. Jiang et al. (Jiang et al., 2023) explored the importance of information intervention on public participation in air quality improvement by a deliberative choice experiment, and results revealed that the public exhibited a stronger willingness to improve air quality with more environmental information, with WTP increasing by CNY 35.2 to CNY 46.8.

Current research on information interventions predominantly emphasizes the development and validation of different types of interventions, often overlooking the antecedents and pathways that drive changes in behavioral intentions and behaviors. For instance, Grilli et al. (Grilli and Curtis, 2021) reviewed the methods and approaches encouraging pro-environmental behaviors and identified five types of treatments: education and awareness, outreach and relationship building, social influence, nudges and behavioral insights and incentives. Nemati et al. (Nemati and Penn, 2020) conducted a meta-analysis of information-based interventions for environmental behaviors, revealing that information based on consumption feedback, environmental prompts, and community comparisons effectively reduced residential customers' consumption of electricity, gas, and water. While these types of information strategies undoubtedly have a broad impact on manipulating individual behavior towards desired outcomes, the researches lack systematic examination in terms of the antecedents and pathways why behavioral intention and behavior change. This gap prevents a detailed understanding of how information strategies function in behavior change processes, which is crucial for policymakers in designing targeted information interventions. In this regard, Michie et al. and Uehara et al. have contributed meaningful improvements to the study of behavior interventions. Specifically, Michie et al. (Michie et al., 2014; Michie et al., 2011) introduced the Behavior Change Wheel, utilizing the Capability-Opportunity-Motivation-Behavior (COM-B) model to attribute behavior changes induced by different types of interventions to alterations in capability, opportunity, and motivation, thus providing valuable guidance for the design of behavioral interventions. Through the development of the Behavioral Barrier-Based Framework (BBBF), Uehara et al. (Allison et al., 2022) offered a clear approach for policymakers on how to select appropriate interventions from a multitude of options by setting policy targets, identifying desirable behavioral changes, identifying critical barriers, and selecting suitable intervention measures. Despite these advances, existing studies remain focused on qualitative analysis and have yet to conduct comprehensive empirical examinations. Such empirical research is necessary to validate the specific antecedents and pathways through which informational interventions exert their influence, providing a scientific basis for the design of evidence-based informational strategies for policymakers.

Leveraging behavioral theory to categorize information can unveil the mechanism through which information interventions influence individuals' payment decisions for APWM (Kwasnicka et al., 2016). As one of the most extensively applied theories in individual behavior research, the Theory of Planned Behavior (TPB) provides a robust theoretical framework for designing behavior interventions (Steinmetz et al., 2016). Research has demonstrated that TPB is among the most effective models for developing interventions aimed at environmental behaviors (Yuriev et al., 2020) and has been shown effective in explaining the public's payment for APWM (Hao et al., 2024). According to TPB, payment intentions are jointly determined by attitudes, subjective norms, and perceived behavioral control (Figure 5-1) (Ajzen, 1991). Among them, attitudes reflect individuals' positive or negative evaluations of conducting APWM. Subjective norms describe perceived social pressure when paying or not, which is determined by the reference groups' approval and implementation of the payment. Perceived behavioral control refers to the degree of difficulty individuals perceive in paying for APWM, specifically relating to the payment's accessibility, affordability and expected outcomes. TPB states that beliefs are antecedents of behavioral intentions. Interventions can introduce new salient beliefs or make existing beliefs more salient, triggering changes in attitudes, subjective norms and perceived behavioral control, thereby leading to a transformation in individuals' behavioral intentions and behaviors (Ajzen and Fishbein, 1980). More precisely, interventions can effectively influence payment by modifying individuals' beliefs about positive or negative evaluations of APWM, their perceived social pressure of paying or not, and their sense of control and efficacy to pay.

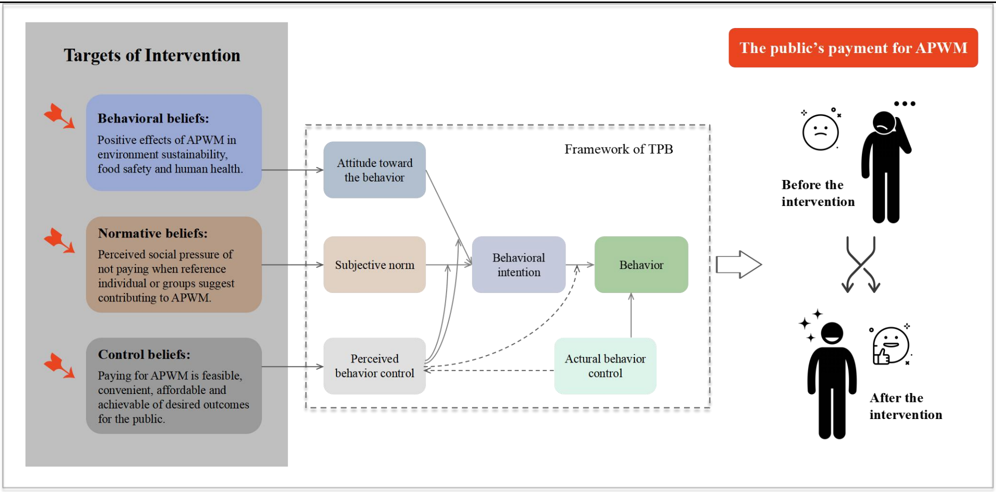

Figure 5-1 Targets of information intervention based on TPB framework. Source: Diagrammed by the author.

Based on the above analysis, the study aims to shed light on the motivated mechanism for promoting the public to pay for APWM through information intervention, thereby bringing insights into developing strategies to facilitate the public payment scheme evolving from idea to reality. Specifically, grounded in the TPB framework, the study designs interventions targeting different belief structures and conducts a RCT. By exposing different groups to distinct informational treatments, the trial seeks to differentiate the effects of belief-based information. The objective of the study is to determine whether information interventions can influence public WTP for APWM and to elucidate the pathways through which these interventions exert their effects. The findings of the study can not only validate the effectiveness of information strategies in enhancing public WTP for APWM but also clarify the pathways through which these information function. This understanding will contribute to revealing the incentive mechanism that promote public payment and thus providing critical insights for the implementation of APWM public payment scheme.

3. Methodology

3.1 Participants and survey

The study was conducted in Xinjiang, Gansu, Ningxia, and Inner Mongolia (Figure 5-2). The study applied the online survey approach. Public payment for APWM is comparable to crowdfunding, generally facilitated through dedicated websites or social applications (Stanko and Henard, 2017). Online surveys also boast the benefits of accommodating broad target audiences, being cost-effective, and generating timely responses (Ghobadi, 2022). Questionnaire Star (https://www.wjx.cn/), China's most prominent online survey platform with over 300 million active users, was commissioned to survey in June and July 2022.

Questionnaires were distributed on a large scale via online distribution to individuals residing in the study region. The feedback was administered via Cloud Research, which comes with the platform. From the initial pool of 1,405 questionnaires, 1,288 valid responses were identified after excluding low-quality submissions. The effective response rate is 91.7%. According to Huang et al. (Huang et al., 2019), the required sample size was determined. The minimum sample size for the study region, which has a population of 82.1 million (NBSC, 2023b), is calculated to be 664 with a margin of error of 5% and a confidence level of 99%, confirming that the sample size in the study is sufficient. A prior analysis was conducted applying G.Power (version 3.1.9.7) to determine the minimum sample size necessary for each group. Assuming a medium-small effect size (d = 0.25) and 80% efficacy (Prelez et al., 2023), the sample size was estimated to be 253. The sample size for each group in the study satisfies the requirement.

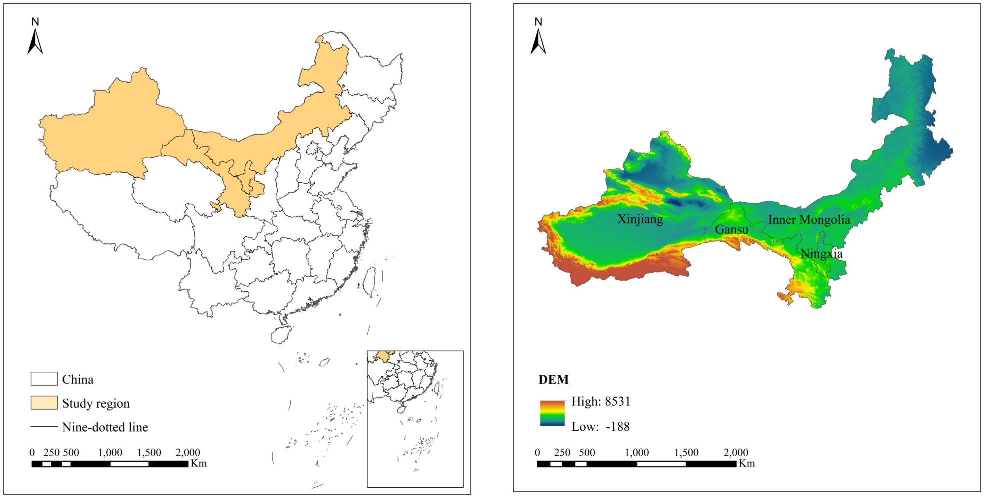

Figure 5-2 Study region. Source: Data from Geospatial Data Cloud (https://www.gscloud.cn/) and diagrammed by the author.

Table 5-1 briefly summarizes the individual and household characteristics of the 1,288 respondents. Overall, the sample reasonably represents the population in the study region. Respondents were evenly distributed by gender (male v.s. female = 47.4% v.s. 52.6%), marital status (married v.s. unmarried = 54.3% v.s. 45.7%), and place of residence (urban v.s. rural = 43.5% v.s. 56.5%). The respondents generally being in relatively good health. However, it should be acknowledged that the sample may slightly over-represent the young and educated population, especially those between 18-39 years old and with a high school or college education. This observation aligns with research on online surveys (Couper, 2000; Sterrett et al., 2017). Meanwhile, household size and income are generally consistent with those reported in the China Statistical Yearbook (NBSC, 2023b).

Table 5-1 Demographic characteristics of respondents.

Characteristics	Frequency	Percent	Characteristics	Frequency	Percent
Gender			Marital status		
Male	611	47.4	Unmarried	589	45.7
Female	677	52.6	Married	699	54.3
Age			Number of household		
＜18	95	7.4	＜3	45	3.5
18-29	629	48.8	3-5	1,032	80.1
30-39	367	28.5	6-8	207	16.1
40-49	136	10.6	＞8	28	2.2
＞49	61	4.7	Number of teenager		
Place of residence			＜3	1,232	95.7
Urban	560	43.5	3-4	56	4.3
Rural	728	56.5	Number of the elderly		
Health status			＜3	1,244	96.6
Bad	12	0.9	3-4	44	3.4
Not very good	24	1.9	Household annual income (CNY)		
Just OK	255	19.8	＜10,000	105	8.2
Good	624	48.4	10,000-29,999	127	9.9
Very Good	373	29.0	30,000-69,999	268	20.8
Education level			70,000-129,999	328	25.5
Primary school	42	3.3	130,000-20,9999	318	24.7
Junior high	141	10.9	210,000-310,000	100	7.8
Senior high	201	15.6	＞310,000	42	3.3
College	822	63.8			
Postgraduate	82	6.4			

Data source: Questionnaire in the study region.

3.2 Experiment design and procedure

The impact of information intervention was evaluated applying the RCT approach, wherein changes in the respondents' WTP for APWM between different treatment groups before and after the intervention were compared with those of the control group. Specifically, Q1, whether the information intervention affects the public's WTP for APWM, can be addressed by examining whether respondents' WTP changed before and after the information intervention. By assessing the degree of changes in respondents' WTP for APWM in different treatment groups compared with the control group after information intervention, Q2, the mechanism by which information affects the public's WTP for APWM, can be answered. Finally, incorporating the answers to Q1 and Q2, the motivated mechanism of the public payment scheme for APWM and enlightenment to promote the scheme, i.e., Q3, will be clarified.

Figure 5-3 exhibits the process of the RCT. After a brief introduction to the purpose of the questionnaire and obtaining consent, respondents' demographic characteristics were collected, and their WTP for APWM was pretested. WTP was quantified on an open-ended format by the maximum amount respondents were willing to pay annually on a household basis. Afterward, participants were randomly assigned to different groups. Randomization is necessary for the study to guarantee no systematic differences among the groups other than the intervention, which was achieved by the automated assignment process embedded in the Questionnaire Star platform. 1,288 participants were randomly assigned to one of five groups. One group functioned as the control and received only a piece of brief information. Four treatment groups were exposed respectively to information about specific belief categories in the TPB displayed in Figure 5-1. TG_{AT} provided participants with information targeting behavioral beliefs related to paying for APWM. TG_{SN} presented information about normative beliefs concerning the payment. TG_{PBC} offered information that could reinforce payment control beliefs. Participants in TG_{COM} received the combined-belief information mentioned above. Table 5-2 outlines the detailed information provided to each group. After the information intervention, respondents were re-surveyed on their WTP in a post-test format. The study was a rigorous double-blind trial to avoid biased results by the placebo effect or observer-expectancy effect (Angrist and Pischke, 2010).

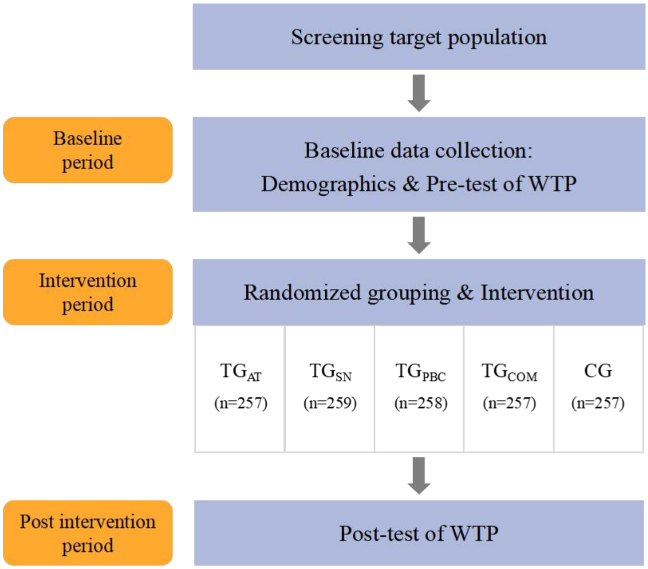

Figure 5-3 Flowchart of randomized controlled trial. Source: Referred to the RCT paradigms and diagrammed by the author.

Table 5-2 Experiment design and information description

Objected variable	**General information**	**AT**	**SN**	**PBC**
Targeting beliefs	None	**Behavioral beliefs:** APWM can mitigate agricultural non-point pollution and reduce the potential environment sustainability, food safety and human health threats posed by APW.	**Normative beliefs:** When reference people and groups, such as relatives, friends, communities and the government suggest paying for APWM, individuals are likely to show a positive payment willingness to avoid social pressure.	**Control beliefs:** If individuals perceive a sense of control over the payment, including knowing how to pay for APWM conveniently, anticipating with no financial burden, and believing their payment will bring about better APWM, they will feel more confident and enthusiastic about paying for APWM.
Detailed information	China is the largest agricultural plastics consumer in the world. Agricultural plastic waste refers to post-consumed mulch film, greenhouse film, pesticide and fertilizer packaging, irrigation pipes and so on. Currently, agricultural plastic waste, especially mulch film waste, is mismanaged, resulting in widespread farmland white	Robust evidence has shown that APW will damage crop yields and quality in the long term if discarded on farmland. Plastic residues can break down over time into microplastics, spreading in terrestrial, aquatic and atmosphere systems. Microplastic may enter the food chain and thus threaten human health. APW can be disposed of by open burning, landfill and recycling. Among them, recycling is the best management practice for not	According to our nationwide survey of different individuals, and groups companies, the majority are willing to make their contributions to APWM for better tackling the problems caused by APW. Managers from government organizations, scientific institutes, media and companies will take the lead to donate and call on everyone who cares about the environment and health to join together. Let's participate in and donate to APWM together, help keep farmland clean and express our	With government permission and regulation, relevant charity organizations are setting up an APWM Fund to effectively and sustainably mitigate agricultural white pollution. Through access to WeChat, Weibo, Alipay and other applications, the public can make voluntary donations to the fund in a convenient manner. The government and charity organizations will monitor the use of the funds, ensure the effectiveness of APWM, and regularly and truthfully disclose relevant information to society.

Objected variable	**General information**	**AT**	**SN**	**PBC**
	pollution.	only solving environmental pollution and health threats but also turning waste into resources.	sense of responsibility and mission.	Little giving, large gains, every coin you donate will help create cleaner farmland.
TG_{AT}	√	√		
TG_{SN}	√		√	
TG_{PBC}	√			√
TG_{COM}	√	√	√	√
CG	√			

Source: Developed by the author.

3.3 Analysis methods

The DID model assessed the effect of information intervention by applying Stata 16. DID compares discrepancies in participants' WTP before and after the intervention between treatment and control groups. With the DID model, unobservable factors that affect the changes in WTP can be excluded, allowing the net effect of the intervention on these changes to be identified. The DID model is presented as follows:

$$WTP_{it} = \alpha + \beta Post_t \times Treat_i + \gamma X + \varepsilon_{it}$$

where WTP_{it} denotes the WTP for the APWM of individual i in time t. $Post_t$ is a dummy variable, which equals to 1 if after the information intervention, otherwise 0; $Treat_i$ is also a dummy variable, which equals to 1 if individual i laid in the treatment group, otherwise 0. X represents a set of covariates, which includes respondent's gender, age, place of residence, education level, marital status, household size and income. ε_{it} is an error item. β, the coefficient on the interaction term of $Post_t \times Treat_i$, measures the impact of information intervention on individuals' WTP, that is, the intervention efficacy. A positive estimate of β indicates an increase of WTP by information intervention and vice versa.

DID tests the null hypothesis that the changes in WTP are attributed to information intervention. There are three critical requirements for a DID analysis to yield internal validity for such a hypothesis test, which include i) the assignment of treatment and control group is independent of the baseline levels; ii) there is no spillover effect between treatment and control groups; iii) baseline levels of both groups feature parallel trends before the intervention implementation (Angrist and Pischke, 2009). Completely randomized assignment to the treatment and control group caters to requirement i), and the mutual independence between treatment and control groups guarantees requirement ii). Requirement iii) would be proved validated in 4.1.

4. Results

4.1 Baseline analysis

Demographic characteristics of the respondents from different groups were initially compared to ascertain the validity of randomization. Age, education level, and other continuous variables were examined using Kruskal-Wallis H non-parametric tests to determine whether there were significant differences among different groups. Chi-Square tests were then applied to check categorical variables, such as gender, place of residence, and marital status. Table 5-3 indicates that there were no significant differences between the covariates among the five groups, thus ensuring that there were no systematic differences across groups. The result validates requirement iii).

Table 5-3 The statistics of the Kruskal-Wallis and Pearson Chi-Square Tests

	Estimae Kruskal-Wallis H(K)	Pearson Chi-Square	df	Sig.
Age	4.042	/	4	0.400
Health status	8.272	/	4	0.082
Education level	1.541	/	4	0.819
Number of household	3.147	/	4	0.534
Number of teenager	3.481	/	4	0.481
Number of the elderly	4.007	/	4	0.405
Household annual income	3.789	/	4	0.435
Gender	/	1.173	4	0.883
Place of residence	/	1.259	4	0.868
Marital status	/	3.085	4	0.544

Note: The statistical significance is determined on 5% significance level by a two-tailed test.
Source: Summarized by the author.

4.2 Efficacy of information intervention

Table 5-4 and Figure 5-4 illustrate the WTP of respondents for APWM across each group, both pretest and posttest. Compared to the pretest, the WTP in the four treatment groups increased to varying degrees in the posttest. Information intervention enhanced the respondents' WTP both economically and statistically (Greene, 2017), indicating the answer to Q1 is YES. In contrast, it declined for the control group, which may stem from the anchoring effects where respondents were more rational and more prudent toward their reported WTP (Simonson and Drolet, 2004). Table 5-5 summarizes the regression results for the impact of information intervention on WTP. The interaction term coefficient for TG_{SN} v.s. CG was 307.23 and significant at a 5% statistical level, indicating an increase of CNY 307.23 in WTP for respondents in TG_{SN} after the intervention compared to the control group. Similarly, the interaction terms coefficients for TG_{PBC} v.s. CG and TG_{COM} v.s. CG were 400.45 and 542.75, respectively, and were both significant at a 1% statistical level. In contrast, the coefficient for TG_{AT} v.s. CG did not show significant result. The results demonstrated that control beliefs have the most decisive influence on the public's WTP, followed by normative beliefs, while the impact of behavioral beliefs on WTP was less pronounced. It yielded the answer to Q2 that information primarily affected the public's WTP for APWM by influencing perceived behavioral control and subjective norms regarding the payment. Correspondingly, the focus of promoting the APWM public payment scheme lies in strengthening the public payment norms and establishing the public payment mechanism, revealing the answer to Q3.

Table 5-4 The estimation of WTP in different groups

	All sample		TG_{AT}		TG_{SN}		TG_{PBC}		TG_{COM}		CG	
	pretest	posttest	pretest	posttest	pretest	posttest	pretest	posttest	pretest	posttest	pretest	posttest
Observation	1,288		257		259		258		257		257	
Mean (CNY)	482.6	708.6	430.6	560.7	408.6	653	394.1	731.8	458.9	938.9	721.5	658.7
Std. Dev.	812.32	1292.61	488.42	678.94	463.34	1171.52	555.38	1481.45	573.68	1588.26	1466.18	1322.3

Source: Summarized by the author.

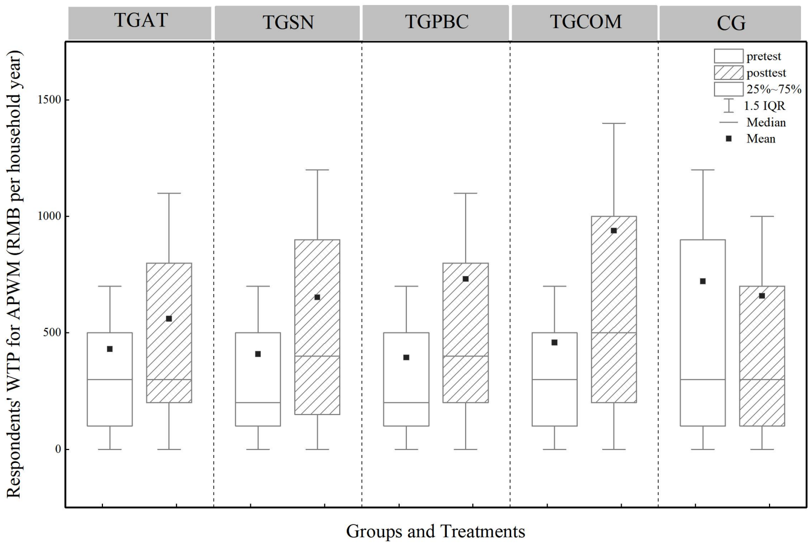

Figure 5-4 Boxplot of WTP by experiment period for treatment groups and the control group. Source: Data gained from the results of the DID and diagrammed by the author.

Table 5-5 Efficacy of information intervention in WTP for APWM

Variables	DID between TG_{AT} and CG	DID between TG_{SN} and CG	DID between TG_{PBC} and CG	DID between TG_{COM} and CG
Treat×Time	192.88	307.23**	400.45***	542.75***
	(128.67)	(139.29)	(152.88)	(154.80)
Constant	1255.57***	1300.15**	1436.91**	1051.64*
	(443.19)	(653.92)	(557.56)	(600.75)
Controls	Yes	Yes	Yes	Yes
Observations	514	516	515	514
Adj R-squared	0.0815	0.0929	0.0677	0.1006

Note: Treat×Post is an interaction term of treatment dummy and time dummy variable. Standard Errors are estimated by linear regression and shown in parentheses, and statistical significance of the two-sided t-tests that regression coefficients differ from zero are indicated as: *** p<0.01; ** p<0.05; * p<0.1. Source: Summarized by the author.

5. Discussion and implications

The current APWM model of government subsidy and market operation in China suffers from great uncertainty. Multi-entity cooperation, represented by public participation, is an innovative solution to promote sustainable APWM. Along with an increasing demand for a cleaner environment and the growing awareness of environmental protection, the public's support holds great prospects for promoting APWM. Unlocking the public's potential requires accurately identifying the outstanding issues hindering public participation in APWM and clarifying the motivated mechanism of promoting the public to contribute. In this regard, the study investigates the salient beliefs that can influence the public's payment for APWM through a TPB-based information intervention trial. The insights gained from the study would provide theoretical evidence that can guide policymakers in developing targeted policies and promoting widespread social support toward public payment scheme for AWPM.

5.1 APWM public payment scheme is distinguished by high perception, weak norm and lack of mechanism.

The results indicated that providing information targeting normative beliefs, control beliefs and combined-beliefs significantly increased respondents' WTP by CNY 307.23, 400.45 and 542.75, respectively, compared to the pre-intervention period. It presented a confirmed answer for Q1. The finding implies that there are information deficits in the public's understanding of APWM public payment scheme, and that tailored information can be delivered to increase their WTP. This observation aligns with previous research on air pollution control (Jiang et al., 2023; Urama and Hodge, 2006) and municipal waste management (Wang et al., 2021), which demonstrated that the public is universally poorly informed about contributing to public utilities and that information interventions are generally effective in enhancing their WTP for these matters. By validating the efficacy of information strategy, new financing channels may emerge to support environmental conservation initiatives that face uncertain funding landscapes. Findings pointed towards innovative avenues to overcome financial barriers for sustainable environmental programs through targeted information that inspires public engagement. Further, among the three TPB-based beliefs, control beliefs exerted the greatest influence on the public's WTP, followed by normative beliefs, while behavioral beliefs were less significant. The result highlighted the mechanism by which information intervention promoted the public's payment for APWM was primarily through strengthening social norms and enhancing their sense of control over the payment. This addressed the Q2 on how information strategies took effect, underscoring normalized social obligations and individual agency rather than shifting attitudes for the payment.

Control belief of public payment for APWM, as described in 3.2, comprises four main components: feasibility, achievability of desired outcomes, convenience, and affordability. The public payment scheme is an envisaged solution to promote APWM, and the information that confirms its feasibility can dispel the public's inner doubts (Stern et al., 2022). Secondly, following social learning theory, expected outcomes of a behavior can induce behavioral motivation (Bandura, 1986). Accordingly, emphasizing that the payment will bring about desired benefits stabilizes the public's expectations and paves the way for triggering their payment motivations. Thirdly, highlighting the convenience of paying for APWM reduces uncertainty in individual behavioral choices (Cheng et al., 2022), making payment decisions primarily depend on individual perceptions and preferences (Liobikienė and Miceikienė, 2022). Additionally, convenience can also strengthen outcome expectations and self-efficacy in performing the behavior (Aschemann-Witzel et al., 2018; Knickmeyer, 2020), indirectly facilitating payment decisions. Lastly, public payment for APWM is intrinsically a voluntary donation behavior (Belleflamme et al., 2014), featuring the voluntary principle. Underlining this principle to potential payers overcomes cognitive biases of financial burdens which may hinder such payment (Konrath and Handy, 2017).

Individuals' preferences, attitudes and behavioral choices are commonly affected by others (Becker, 1974), explicating the effectiveness of normative information. In a collective society, reference groups establish the criteria governing right and wrong behavior (Nixon et al., 2009), and individuals follow such criteria to gain social recognition (Collado et al., 2019). When others pay for APWM and expect peers to act as such, people may comply to gain approvals and a sense of social belonging (Taylor and Todd, 1995). Normative information may also work for alleviating the probable assurance problems and free-rider problems, which typically confront private provision of public goods. Individuals may decline to pay for APWM when they believe no one else will pay to save their efforts (Sen, 1967) or when they anticipate that others will pay and they can share the fruits for free (Trivers, 1971). The optimal strategy is to cooperate when others are cooperating and stop when they are not (Schmitz, 2015). Normative information dispels the suspicion that others will not cooperate, signals the social risk of not cooperating, and thus motivates individuals to make payment decisions.

The study shows that the impact of behavioral belief information is insignificant on respondents' WTP. This finding can be attributed to the widespread and continued worsening of the APW issue in China. The prevalence of APW-related news, such as "mulch film stops train incident""A credit card's worth of microplastics ingestion everyday", are evident in the media, increasing residents' perception of APW concerns. Furthermore, the government has vigorously promoted and widely publicized APWM policies, such as EPR system and trade-ins, in recent years. These efforts have led to farmers' increased knowledge, as well as the public's elevated awareness for APW. Post-materialism and EKC indicate that rising income and education level accompany by a corresponding increase in environmental literacy and awareness (Grossman and Krueger, 1995). With China advancing to upper middle-income status (World Bank, 2022) and education level surpassing the average of those upper middle-income countries (NBSC, 2021; NBSC, 2022), the public has upgraded pursue for a more beautiful and cleaner living environment. Consequently, providing information aimed at raising individuals' APWM awareness offers an insignificant marginal contribution.

5.2 The transformation of the public's payment intention into

payment action requires establishing a sound public participation system.

Two-fifths of respondents indicated that they were willing to pay for APWM in the study, the average WTP is CNY 482.6 per household year. Yet it is disputed to anticipate how this demonstrated payment intention will effectively convert into substantive contribution action. China Charity Alliance recorded that, nationwide donations toward environmental conservation is CNY 2.24 billion in 2019, of which one quarter originated from the public contributions (China Charity Alliance, 2020). It can be generally estimated that each person donated no more than CNY 0.4 on average, starkly unveiling the fact that the sum allocated to APWM is bound to be exceedingly restricted. There exists a vast disparity between the public's intention of contributing to environmental management and their actual acts. Despite verbal support for cooperative government policies regarding environmental management, the backing does not definitively convert to significant participation actions. This discrepancy can potentially be attributed to existing policy priorities. First explicitly proposed in the 19th National Congress of the Communist Party of China, the pressing need to "establish an environmental governance system led by the government with enterprises functioning as primary subjects and both social organizations and the public serving as participants," has accorded greater priority to public involvement in these matters. Subsequently, the government initiated two major plans in 2021, "Beautiful China, I am the Actor" and "Citizen Environmental Behavior Guidelines (Trial Implementation)". These efforts focus on elevating public consciousness toward ecological preservation and foster environmental literacy through systematic education and public outreach initiatives, so as to encourage active public involvement in environment governance. However, as the awareness increase of relevant policies and notion endorsement of public cooperation in environmental governance, the government faces an ongoing challenge to recognize emerging issues in public participation and respond with policy adjustments as necessary.

The same is true for APWM. The result reveals that the public payment scheme for APWM is obstructed by the absence of robust mechanism and weakness of social norm. Transitioning from a mere positive intention toward actual payment necessitates added momentum. The study implied the answer to Q3, which is to establish a sound public participation system, especially more conducive external circumstances and an intensified social consensus. Consequently, importance should be placed on instituting a well-structured public payment system, with a primary focus on establishing mechanism and strengthening norm, so as to subsequently facilitate the transformation of everyone is willing to pay into everyone pays.

The foundation for establishing mechanism involves the initiation of a public payment scheme for APWM which will unblock channels for public participation and enhance scheme accessibility. Priority should be given to charitable organizations with crowdfunding qualification, who boast robust user bases and high social credibility, to act as scheme initiators and thereby securing public trust (Choy and Schlagwein, 2016). Secondly, crowdfunding platform is better integrated with social applications, so as to streamline information collection, donation transactions, and interactive communication into a standardized process, thereby increasing convenience (Choy and Schlagwein, 2016). Thirdly, an rigorous information disclosure system that is compliant with the Charity Law and relevant industry regulations, such as “Administration measures for public donation platform services”“Technical specifications for Internet fundraising information platforms for charitable organizations”“Management specifications for internet public fundraising information platforms for charitable organizations”, should be developed. Factual updates regarding the progress of fundraising, spending and project implementation should be made readily available to the public via dedicated websites in a comprehensive and timely manner. Meanwhile, active interaction with donors can also serve to reduce information asymmetry and stabilize public expectations and confidence (Shen and Wang, 2023). Lastly, it is crucial to reaffirm the voluntary principle of the scheme, ensuring that contributions will not impose financial burden on potential donors.

Regarding norm strengthening, it is vital to integrate the contributions of diverse actors, which includes governments, social networks, and individuals. Most importantly, primacy should be given to authoritative entities, such as governments and esteemed environmental organizations, to leverage their persuasive performance (Liu, 2008). By endorsing the public payment scheme for APWM as one of the “Top 10 public participation cases of the year”, these entities can promote the formation of public payment norm (Halder et al., 2021) and encourage widespread public involvement in APWM. Secondly, given that there are approximately 4.62 billion active social media users globally (DataReportal, 2022), and the Chinese internet penetration rate stands at 75.6% (INICC, 2023), the internet embodies immense potential for shaping norms. Moreover, information dissemination through social networks is both interactive and capable of generating substantial emotional resonance (Yin et al., 2021). In view of this, the benefits of social network propagation should be harnessed to maximize the potential of the broad internet users and foster a social ethos of collective giving and shared governance within the expansive digital sphere. Additionally, peer-to-peer information sharing should not be overlooked (Nisar et al., 2022), due to limitations of governmental advocacy and social media opinion in exerting direct interpersonal pressure (Young et al., 2017). The government can consider recognizing individuals who make outstanding contributions to APWM with the “Most eco-friendly volunteer” award. This would serve to encourage environmentally literate individuals with strong convictions to act as opinion leaders (Al-Oraiqat et al., 2022) and champion the cause by sharing the scheme within their social circles and seeking other’s support (Bénabou and Tirole, 2006).

5.3 Multi-entity participation is the inevitable choice for sustainable APWM.

APWM is highly sustained by financial subsidies, posing heavy burdens on the government while introducing considerable uncertainty into the matter. For a sustainable approach to APWM, it is imperative to identify innovative funding sources. The public, a crucial APWM stakeholder with three-fold identity of service recipients of agricultural plastics, victims of APW, and beneficiaries of APWM, is justified in making contributions to APWM. The study reveals that over two-thirds of the respondents exhibit positive payment willingness toward APWM after the information intervention, with an average WTP ranging from CNY 560.7 to CNY 938.9 per household year. Based on a rough estimation of a 10% environmental donation rate (China Charity Alliance, 2020), if such interventions were implemented nationwide, public payment scheme could potentially raise upwards of CNY 28 billion annually for APWM. This would significantly advance APWM and provide substantial impetus to mitigating the widespread non-point pollution resulting from APW and its historical legacies. Beyond the economic value, it's crucial to underscore that public payment scheme also delivers far-reaching social benefits of the modernization of environmental governance systems and capacities. Public payments for APWM can be viewed as fostering partnerships among governments, enterprises, social organizations, and the public, which breaking away from the traditional "government and market" governance model (Ostrom, 1999; Ostrom, 2010). It has the potential to rectify social dilemmas caused by top-down environmental governance, thereby guiding the public to acknowledge their identity as stakeholders in societal affairs, and cultivating both a sense of social responsibility and public awareness.

As a comprehensive and systematic social project, sustainable APWM necessitates collaboration amongst the government, enterprises, social organizations, and the public. The government should reassess its position to facilitate a multi-entity cooperation governance pattern. Acting as the leading authority in environmental governance, the government should precisely diagnose each entity's realistic challenges regarding participating in APWM and accordingly, cultivate favorable external circumstances via guidance, incentives, and constraints. Enterprises should leverage their superiority in capital, technology, and management competence to boost profitability through technological research and development, process optimization, and industrial chain expansion, so as to promote advancement in market-oriented APW recycling and reduce the over-reliance on governmental subsidies. Furthermore, enterprises can proactively seek advanced partnerships with the government through service outsourcing and franchising to fully engage in the entire chain of APWM. Social organizations should leverage their role as a bridge and bond to convey public opinion upwards, advocate for environmentalist groups, and mobilize more social resources to enhance APWM. Downwards, they should serve as effective disseminators and educators by extending their reach into communities in a point-to-surface manner, communicating APWM-related policies, concepts, and knowledge to residents. Concurrently, social organizations should fully exercise their supervisory role, urging enterprises to better conduct APWM cause.

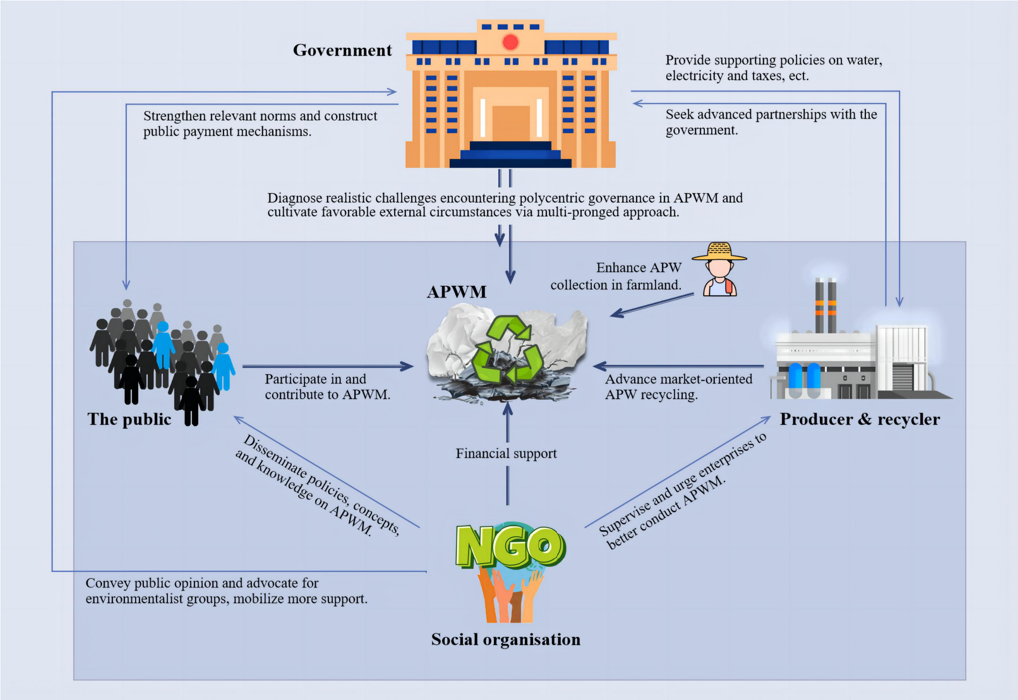

Figure 5-5 Multi-entity cooperation in APWM. Source: Diagrammed by the author.

6. Conclusion and limitation

While there is a generally positive payment intention for APWM among the public, it is challenging to guarantee a desirable transition of intention into tangible payment actions. The study conducted an RCT to unearth the motivated mechanism that promotes the public to pay for APWM by information that notably boosts the public's WTP. Results evinced a general while varied increase in respondents' WTP for APWM by providing information targeted different TPB beliefs. Concretely, information targeting normative beliefs and control beliefs significantly elevated respondents' WTP by CNY 307.2 (75.2%) and CNY 400.5 (101.6%), respectively, revealing the public payment scheme is characterized by high perception, weak norm and lacking mechanism. Further analysis suggests that weak social norm and lacking of payment mechanism are the crux for the public payment scheme. Consequently, the scheme should center efforts on norm strengthening and mechanism establishing, adopting a multi-pronged approach to bridge the deficiencies to public payment for APWM. The findings of the study bring insights into the promotion of social utilities represented by sustainable APWM and provide theoretical reference for developing customized policies and social supports to guide the multi-entity cooperation landscape.

Although the study provides some interesting observations, there are still some limitations. While the experimental approach was effectively applied to validate the effectiveness of information intervention (Falk and Heckman, 2009), the study acknowledges the challenge of universality or external validity of the findings, which is a topic that experimental economics has been grappling with for decades (Falk and Heckman, 2009). Also, the different constructs of TPB before and after the intervention can be further quantified to further validate the effectiveness of the information content in influencing the corresponding intervention targets. Besides, respondents' self-reported WTP may overestimate their actual payment level, representing the inherent limitation when using WTP to assess individual preferences for non-market-value items (Knetsch and Sinden, 1984). Additionally, the study only established short term effectiveness of the information intervention, leaving the long term impact yet to be confirmed. In the upcoming research, with follow up field surveys and advancements in the WTP estimation methodology, the impact of information intervention on the APWM public payment scheme will be further revealed.

Supplementary materials

SM1. Cost accounting for mulch film waste recycling

The mechanical recycling of mulch film waste consists of the following stages: First, farmers collect the mulch film waste from their farmland or entrust a company to collect and then hand it to a nearby recycling station. Then, the recycling station centrally integrate the mulch film waste and sell it to recycling utilization enterprises (hereinafter referred to as "recycling enterprises"). Finally, recycling enterprises realize the resource regeneration of mulch film waste through sorting, cleaning, and reprocessing. According to the recycling processes, the cost of the recycling utilization is mainly composed of raw material purchase cost, manual sorting cost, and granules production cost. In addition, there are fixed costs, including the expense in environmental protection, asset depreciation, and machine maintenance.

Material purchase cost: The average purchase price of mulch film waste is CNY 120 per cubic meter. According to the actual situation, 20 cubic meters of mulch film waste can produce 1 ton re-produced plastic granules. It is estimated that the material purchase cost of producing 1 ton re-produced plastic granules is CNY 2400.

Manual sorting: The collected mulch film waste needs pre-processing of manual sorting to remove the contamination such as sand and crop straw. Following the actual situation, each person could sort 300 kg of mulch film waste per day, and the output rate of sorted mulch film waste is 60%, that is, 1.67 tons sorted mulch film waste can produce 1 ton re-produced plastic granules. Based on a daily wage of CNY 200 per labor, the cost of manual sorting is estimated as CNY 1100 for 1 ton re-produced plastic granules.

Processing: The sorted mulch film waste will be sent to the production plant for crushing, cleaning, processing, and pelletizing, which requires labor and electricity. The labor cost for 1 ton of re-produced plastic granules is about CNY 600. The electricity consumption of 1 ton of re-produced plastic granules is 1300 kWh. Based on the current industrial electricity tariff of CNY 0.9 per kWh and the transformer losses, the electricity tariff turns to CNY 1.0 per kWh. The aggregated cost of electricity is CNY 1300 for 1 ton re-produced plastic granules.

Fixed cost: The fixed cost is CNY 880 for 1 ton re-produced plastic granules, including: the cost of purchasing environmental protection equipment and the treatment of waste water and waste gas (CNY 150/ton), equipment maintenance cost (CNY 260/ton), oil cost for loading (CNY 40/ton), sludge cleaning cost (CNY 50/ton), mulch film waste storage cost (CNY 180/ton), and the assets depreciation cost (CNY 200/ton).

Based on the agricultural plastics utilization of 2,357,944 tons in 2021, a total of CNY 11.85 billion is required to achieve the recycling rate of 80% , and CNY 14.81 billion for 100%.

Table 5-S1 Cost accounting in the recycling of mulch film waste (Unit: CNY/t)

Material purchase	Manual sorting	Processing		Fixed cost	**Total**
		Labor	Electricity		
2,400	1,100	600	1,300	880	6,280

Data source: Summarized by the author.

SM2. Survey description

In light of the study's representativeness and scientific validity, four provinces (autonomous regions) in northwest China - Xinjiang, Gansu, Ningxia, and Inner Mongolia - were chosen for this investigation of APWM in China.

Given that the public payment for APWM is essentially a crowdfunding behavior that is often facilitated through dedicated websites or social applications, in addition to the benefits of accommodating broad target audiences, being cost-effective, and generating timely responses, the study applied an online approach to survey. Questionnaire Star (https://www.wjx.cn/), China's most prominent online survey platform with over 300 million active users, was commissioned to survey in June and July 2022. Questionnaires were distributed on a large scale via online distribution to individuals residing in the study region. The feedback was administered via Cloud Research, which comes with the platform. After excluding low-quality submissions, 1288 valid responses were finally obtained.

In the study, 1288 respondents were randomly assigned to one of five groups. One group functioned as the control and received only a piece of brief information. Four treatment groups were exposed respectively to information about specific belief categories in the TPB displayed in Figure 5-1. Specifically, TG_{AT} provided participants with information targeting behavioral beliefs related to paying for APWM. TG_{SN} presented information about normative beliefs concerning the payment. TG_{PBC} offered information that could reinforce payment control beliefs. Participants in TG_{COM} received the combined-belief information mentioned above. Details of the information respondents received are shown in Table 5-2. Randomized assignments were accomplished through the automated assignment process embedded in the Questionnaire Star platform.

Respondents in the study were required to complete a questionnaire with three parts. The first part concentrated on respondents' demographic and household characteristics. The second part aimed to pretest the respondents' WTP for APWM.

WTP was quantified by the maximum amount respondents were willing to pay annually on a household basis. Afterward, participants were randomly assigned to different groups as described above, where corresponding information was provided for each group (details in Table 5-2). In the third part, respondents were re-surveyed on their WTP for APWM in a post-test format.

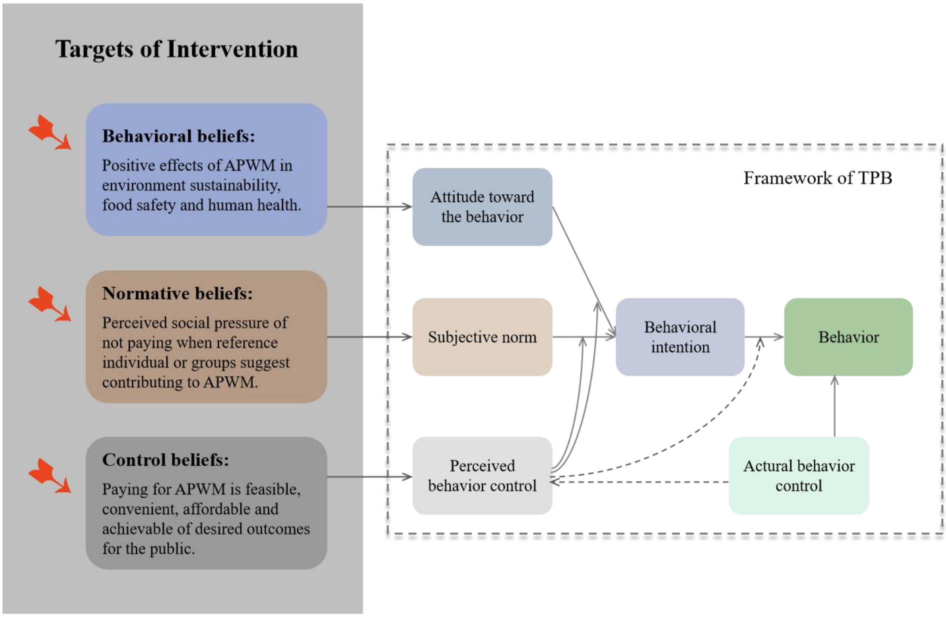

Figure 5-1 Targets of information intervention. Source: Referred to the TPB framework (https://people.umass.edu/aizen/).

Table 5-1 Experiment design and information description.

Objected variable	General information	AT	SN	PBC
Targeting beliefs	None	**Behavioral beliefs:** APWM can mitigate agricultural non-point pollution and reduce the potential environment sustainability, food safety and human health threats posed by APW.	**Normative beliefs:** When reference people and groups, such as relatives, friends, communities and the government suggest paying for APWM, individuals are likely to show a positive payment willingness to avoid social pressure.	**Control beliefs:** If individuals perceive a sense of control over the payment, including knowing how to pay for APWM conveniently, anticipating with no financial burden, and believing their payment will bring about better APWM, they will feel more confident and enthusiastic about paying for APWM.
Detailed information	China is the largest agricultural plastics consumer in the world. Agricultural plastic waste refers to post-consumed mulch film, greenhouse film, pesticide and fertilizer packaging, irrigation pipes and so on. Currently, agricultural plastic waste, especially mulch film waste, is mismanaged, resulting in widespread farmland	Robust evidence has shown that APW will damage crop yields and quality in the long term if discarded on farmland. Plastic residues can break down over time into microplastics, spreading in terrestrial, aquatic and atmosphere systems. Microplastic may enter the food chain and thus threaten human health. APW can be disposed of by open burning, landfill and recycling. Among them, recycling is the best management practice for not only solving environmental pollution and health threats but	According to our nationwide survey of different individuals, and groups companies, the majority are willing to make their contributions to APWM for better tackling the problems caused by APW. Managers from government organizations, scientific institutes, media and companies will take the lead to donate and call on everyone who cares about the environment and health to join together. Let’s participate in and donate to APWM together, help keep farmland clean and express our sense of responsibility and	With government permission and regulation, relevant charity organizations are setting up an APWM Fund to effectively and sustainably mitigate agricultural white pollution. Through access to WeChat, Weibo, Alipay and other applications, the public can make voluntary donations to the fund in a convenient manner. The government and charity organizations will monitor the use of the funds, ensure the effectiveness of APWM, and regularly and truthfully disclose relevant information to society. Little giving, large gains, every coin

	white pollution.	also turning waste into resources.	mission.	you donate will help create cleaner farmland.
TG_{AT}	√	√		
TG_{SN}	√		√	
TG_{PBC}	√			√
TG_{COM}	√	√	√	√
CG	√			

Source: Developed by the author.

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6

Chapter VI: General discussions and perspectives

Agricultural plastics play a pivotal role in enhancing crop yields and increasing farmers' incomes. Nevertheless, it has inevitably engendered significant plastic residues and a consequent array of environmental, economic, and societal challenges. Addressing agricultural white pollution is a global issue, yet China faces unique and formidable difficulties due to the extensive utilization of agricultural plastics, the complexity of application scenarios, and the challenges in recycling. Rational policies and robust mechanism are pivotal to addressing the issue of agricultural white pollution in China, directly influencing the efficacy and sustainability of plastic waste management. Nevertheless, an examination of the current state of agricultural white pollution and the framework of associated management policies reveals that China is still in an exploratory phase regarding this issue. It is imperative to critically analyze the rationality of the existing agricultural white pollution management policy and mechanism from a scientific perspective, and, on this basis, propose recommendations to enhance their effectiveness.

Through the interdisciplinary integration of economics, management, psychology, and sociology, the study provides the scientific basis for evaluating the rationality of the current management policy through rigorous accounting, and lays a solid reference for promoting the adjustment and optimization of the policy. Further, by introducing the concept of polycentric governance into the APWM, it provides innovative research perspectives and solutions for the agricultural non-point waste management through incorporating the public. Effectively resolving agricultural white pollution problem in China is of profound significance not only for promoting sustainable agricultural development and ensuring the harmonious advancement of environmental protection and socio-economic progress within the country but also for providing replicable practices and experiences for the agricultural non-point pollution control in other countries, and even for the public environmental governance globally, which will help to improve the public environment, food safety, and human health, and jointly contribute to the realization of SDGs.

1.General discussions

1.1 The cost-benefit information can provide a beneficial reference for optimizing APWM policies

As a major agricultural country, China stands as the world's largest consumer of agricultural plastics. However, this prominence also poses significant challenges to APWM. Over the past decade, the Chinese government has placed considerable emphasis on addressing agricultural white pollution, channeling substantial financial resources into mitigation efforts. A prime example of the current APWM policy is the pilot program promoting the "mulch film scientific utilization and recycling." The government aims to alleviate agricultural plastic pollution by fostering the widespread adoption of two kinds of environmentally friendly mulch films: thicker and biodegradable mulch film. To incentivize their adoption, the government provides subsidies of CNY 450/ha for thicker mulch film and CNY 1,800/ha for biodegradable mulch film. In 2022, the pilot program covered 3.3 million ha with thicker mulch film and 0.3 million ha with biodegradable mulch film, with plans to expand to 13.3 million ha and 2 million ha, respectively, by 2025.

However, the cost-effectiveness of current APWM measures remains unclear, which may lead to misguided subsidy policies. Presently, the Chinese government's subsidy schemes for both types of environmentally friendly mulch films are determined solely by the cost differential between these and conventional mulch film, without considering the broader economic and social benefits they may confer. This approach suggests that the subsidies for APWM lack scientific rigor and sound justification. Particularly in the context of slowing economic growth and tight fiscal balance in China, there is a heightened need to optimize management policies and improve the efficiency of government expenditure.

Building on the context mentioned above, the study conducts the cost-benefit analysis of two types of environmentally friendly mulch films, applying conventional mulch film as a benchmark for comparison. Overall, the findings suggest that the current policies aimed at promoting APWM exhibit certain inefficiencies, highlighting significant potential for future optimization.

Thicker mulch film serves as a beneficial measure in mitigating agricultural plastic pollution, and efforts should be made to enhance farmers' comprehensive understanding of its application, optimize the dimensions of the subsidies, and further promote its widespread adoption. According to the cost-benefit analysis, thicker mulch film demonstrates significantly greater economic benefits compared to conventional mulch film. Theoretically, even without subsidies, farmers should be intrinsically motivated to adopt thicker mulch film. However, this is not the case in practice-farmers only choose thicker mulch film when government subsidies are in place. This discrepancy between theory and reality may stem from the immediate additional economic costs associated with thicker mulch film, whereas its economic benefits tend to materialize over a longer time horizon. Farmers with bounded rationality may need to strengthen their scientific understanding of thicker mulch film, especially the economic advantages, to increase their willingness to adopt it. Moreover, there is still considerable potential for adjusting the government's subsidy policies for thicker mulch film promotion. At present, subsidies primarily target the purchase stage, focusing on farmers who purchase the thicker mulch film, while largely overlooking the financial difficulties in the treatment stage. The result reveals that the profit margin from mulch film recycling is exceedingly limited, and the current profitability is insufficient to incentivize enterprises to engage in sustained recycling activities. Therefore, future favorable policies should be appropriately tilted toward recycling enterprises, injecting more significant incentives for these enterprises to address the challenges associated with APWM.

The application of biodegradable mulch film requires sustained subsidies, and future efforts should focus on reducing costs while enhancing efficiency. Biodegradable mulch film demonstrates inferior economic performance compared to conventional mulch film, making its widespread adoption in agricultural production largely dependent on continuous external financial support. Nonetheless, the current subsidy for biodegradable mulch film far exceeds the net economic losses associated with its application. In the future, the government could recalibrate the subsidy standards based on the cost-benefit performance of different mulch films to ensure that while farmers are incentivized to adopt biodegradable options, government resources are allocated more efficiently. Additionally, the biodegradable mulch film currently available on the market exhibit certain shortcomings, particularly in terms of degradation initiation and degradation rates. Future policies could provide targeted incentives for biodegradable mulch film manufacturers, encouraging increased investment in research and development. Through scale economies and technological advancements, these efforts could reduce costs and enhance the performance of biodegradable mulch film products.

Equally important is the internalization of environmental benefits and the fostering of innovative governance frameworks, which will make great contribution to APWM in sustainability. Since thicker mulch film enhances recyclability and biodegradable mulch film eliminates plastic residuals at its source, both environmentally friendly mulch films offer tangible environmental benefits. However, in practice, there is currently no mechanism that effectively internalizes the environmental benefits of APWM. These underappreciated advantages could play a crucial role in promoting resilient APWM, especially in light of the significantly unsustainable financial challenges it currently encounters. Thus, exploring the integration of APWM into carbon trading markets could convert environmental benefits into economic returns, offering more significant market incentives and policy support for APWM. Furthermore, as a quasi-public good, APWM may suffer from government or market failures if relied upon solely by either. A multi-centered governance framework-one that includes government, enterprises, farmers, social organizations, and the public-could help distribute social responsibility, enhance management efficiency, and strengthen the effectiveness of APWM initiatives.

1.2 Public participation is a promising scheme for sustainable APWM

APWM represents a vast undertaking in China, requiring sustained and substantial financial investment over the long term. Between 2012 and 2015, the central government allocated explicity over CNY 900 million for APWM, with local governments providing supplementary funds based on their fiscal capacities and the actual management demands. Despite these efforts, a significant funding gap persists. To achieve the targeted 80% recovery rate, an estimated CNY 7.1 billion is needed annually for mulch film recycling alone (Hao et al. 2024). Notably, this funding gap could widen considerably if other kinds of APW are included in the estimate.

Currently, APWM predominantly follows a “government subsidy & enterprise operation” model, with funding needs largely met through government subsidies. This model imposes a substantial fiscal burden on the government, introducing considerable uncertainty. In response to the sustainability challenges encountering APWM, the Chinese government has conducted specific mechanism exploration, such as EPR system and deposit-return schemes. These efforts aim to increase the resilience of APWM by incorporating multiple stakeholders, including farmers, agricultural plastic producers, and recycling enterprises, into the management framework. However, these measures have not adequately addressed the pressing issues of funding shortages and the uncertainty of funding sources. To ensure the sustainability of APWM, it is imperative to explore innovative financing mechanism further to enhance the reliability of funding streams.

Beyond the stakeholders previously mentioned, the general public is also a highly interested party in APWM. The public serves as consumers of agricultural plastics, potential victims of APW, and beneficiaries of APWM, and thus should not be regarded as mere bystanders. Given the sustainability challenges facing APWM, broader stakeholder engagement is essential. If the public is willing to participate in APWM and contribute financial support, they could help alleviate the issues of funding shortages and the unreliability of funding sources to a certain extent.

In this context, a large-scale survey is conducted in northern China to investigate the social foundation that is willing to pay APWM, aiming to assess the feasibility of the public payment scheme for APWM. Furthermore, the study applies an extended TPB to elucidate the decision-making drivers behind individuals' WTP for APWM, thereby offering insights for developing strategies to encourage public contributions toward APWM.

The findings initially affirm the feasibility of the public payment scheme for APWM. Among the 1,288 respondents surveyed, more than two-fifths expressed a positive willingness to pay for APWM, with an average WTP of CNY 482.6 annually. The involvement of the public enhances the reliability of funding for APWM, indicating that the public payment scheme holds significant potential as an effective complement to existing management efforts.

Further, the psychological decision-making pathways influencing public payment willingness for APWM have been clarified. Firstly, attitudes emerged as the most significant factor affecting individuals' payment intention. This finding underscores the critical role of enhancing environmental education and awareness to elevate public comprehension of APWM, thereby motivating their payment decisions. Secondly, subjective norms exert a notable positive influence on payment intention. To leverage this effect, it is essential to foster a societal consensus on the benefits of APWM, utilize social media to cultivate an atmosphere of collective contribution, and bolster official communication efforts to stimulate the public sense of social responsibility. Thirdly, perceived behavioral control also impacts individuals' intention significantly and positively. Measures such as streamlining payment processes, expanding information disclosure related to public payment programs, and reducing participation barriers will facilitate broader public engagement in APWM. Fourthly, environmental cognition enhances the relationships between attitudes and payment intention, as well as between subjective norms and payment intention, thereby indirectly contributing to payment intention. To capitalize on this, it is essential to address individuals' heightened concerns regarding food safety and human health, strategically timing public awareness campaigns while deepening civic environmental education. Fifthly, environmental emotion similarly exerts significant indirect effects on payment intention, particularly positive environmental emotions. In this regard, organizing experiential activities and environmental practices can guide the public to appreciate the beauty of nature and understand the value of ecology, fostering greater recognition and involvement in environmental management. Additionally, negative environmental emotions have positive but minor effects. For example, disseminating information about the deteriorating environment and escalating ecological crises can create a sense of urgency and anxiety. And critiquing typical environmentally destructive behaviors may evoke feelings of aversion and guilt toward ecologically harmful actions, further encouraging public participation in APWM.

1.3 Information interventions can strengthen the APWM public payment scheme

The research above has confirmed the feasibility of the public payment scheme for APWM. However, challenges remain in facilitating its implementation. Previous studies have indicated a common phenomenon where public participation in environmental management is characterized by "positive attitudes, moderate willingness, and low levels of actual engagement" (PRCEEC 2020, 2021). Currently, public awareness regarding participation in APWM is notably limited, and mechanism for public involvement in this initiative have yet to be established. As a typical environmental behavior, the APWM public payment program may encounter a similar dilemma of "positive attitude, moderate willingness, and low engagement," where the public's expressed payment willingness to APWM does not reliably translate into actual payment behavior. Thus, it is imperative to explore strategies to enhance the public's payment for APWM. Providing a scientific basis for policymakers to formulate favorable policies that transform the public payment program from idea into reality is crucial for better leveraging the potential contributions of the public in combating agricultural plastic pollution.

Evidence suggests that the divergence between public attitudes, intention, and behavior primarily stems from informational inadequacies that lead to individual decision-making biases. By disseminating adequate information, it is possible to enhance individual understanding of environmental issues, foster confidence in the efficacy of environmental governance, create a social atmosphere that encourages widespread participation in environmental protection, and promote effective mechanism and channels for engaging in such activities. Consequently, these efforts can exert a positive influence on a variety of environmental behaviors, including reducing energy consumption, minimizing food waste, conserving water, and enhancing waste recycling.

Information intervention is a strategy that disseminates targeted information and knowledge through education, training, and outreach, aimed at reducing information asymmetry and correcting biases to influence individual decision-making and facilitate behavior change in a desired direction. Such interventions typically focus on key variables, including attitudinal evaluation, outcome expectations, norms, self-efficacy, and values, as these factors significantly contribute to the formation of intentions and behaviors related to environmental action. Moreover, by distinguishing the distinct aspects of information through behavioral theories, one can elucidate the mechanism by which information interventions exert their effects, thereby enhancing the understanding of the antecedents and pathways involved. Existing research indicates that the TPB is one of the most effective models for developing interventions targeting environmental behaviors, and it has been shown to adequately explain the public's willingness to pay for APWM. The TPB posits that beliefs serve as precursors to individual behavioral intentions and behaviors; intervention information can effect changes in attitudes, subjective norms, or perceived behavioral control by either introducing new salient beliefs or making existing beliefs more salient, which in turn can lead to shifts in behavioral intentions and actual behaviors.

In this regard, the study applies the TPB framework to design intervention information tailored to different beliefs and conducts a RCT. By providing distinct sets of information to different experimental groups, the research aims to delineate the intervention effects based on the varying belief systems. This approach seeks to ascertain whether information interventions can influence the public's WTP for APWM and to elucidate the mechanism through which these interventions exert their effects.

The findings indicate that information interventions generally enhance respondents' WTP for APWM. This suggests the presence of an information deficit among respondents regarding the public payment scheme for APWM, revealing a substantial degree of plasticity in their WTP. Specifically, information grounded in control beliefs maximally increased respondents' WTP, followed by normative beliefs, while the impact of attitude beliefs was found to be insignificant. Compared to the control group, individuals in the control belief and the normative beliefs group exhibited significant increases in WTP of CNY 400 and CNY 307, respectively, following the intervention. Conversely, the information based on attitude beliefs did not demonstrate a significant effect on respondents' WTP. These results underscore the evident characteristics of the public payment scheme for APWM, which is marked by "high perception, weak norm and lack of mechanism." The absence of a robust institutional framework and the fragility of related norms may represent the most significant barriers to the successful implementation of the APWM public payment scheme.

To address this issue, it is essential to focus on the establishment of a public participation mechanism and the reinforcement of relevant norms to develop the mechanism that facilitates public payment for APWM, so as to effectively transition from a state of "everyone is willing to pay" to one where "everyone pays."

Regarding mechanism development, the first priority is initiating the public payment scheme for APWM, facilitating accessible channels for public participation. Second, it is essential to effectively integrate crowdfunding platforms and social media resources, standardizing the processes for information collection, donation transactions, and interactive communication to enhance the convenience of public contributions. Furthermore, a rigorous information disclosure system should be established to transparently and timely report on fundraising progress, the utilization of funds, and the implementation of funded project, while also fostering interaction with donors to mitigate information asymmetry and stabilize public expectations. Finally, it is crucial to reaffirm the voluntary nature of the public payment scheme.

In norm reinforcement, it is essential to consider the roles of different stakeholders, including government entities, social networks, and the public, in shaping social norms. Initially, authoritative entities such as the government and reputable environmental organizations should lead the charge, vigorously encouraging widespread public participation in APWM. Subsequently, the advantages of social networks in disseminating information should be effectively harnessed to cultivate a societal atmosphere characterized by collective giving and shared governance within the expansive digital sphere. Finally, the importance of peer-to-peer information sharing should not be overlooked; individuals with high environmental literacy and strong philanthropic convictions should be encouraged to take the lead, sharing information about the initiative with their friends and motivating them to lend their support.

1.4 Sustainable APWM necessitates the collaboration of multiple stakeholders, including governments, enterprises, farmers, and the public

Confronted with the pressing challenge of plastic waste, China must urgently implement effective strategies for APWM to enhance the sustainability and resilience. As a complex and systemic societal issue, the sustainable APWM demands all stakeholders' concerted efforts.

Foremost, sustainable APWM necessitates the government to provide scientifically informed financial support and foster a more resilient APWM system through optimized policy design. The promotion of environmentally friendly mulch films, such as thicker and biodegradable mulch films, within pilot demonstration for mulch film scientific utilization and recycling has proven to be a practical approach for mitigating agricultural white pollution. However, as discussed in Section 3.4 of Chapter I, these pilot policies have thus far only demonstrated efficacy under the current government subsidy framework. According to the policy timeline, the pilot program is set to expire in 2025, leaving the stability and prospects of the policy uncertain. Presently, farmers lack a sufficient understanding of environmentally friendly mulch films, and enterprises engaged in APW recycling require ongoing financial support to sustain their operations. A premature withdrawal of government subsidies would inevitably impede the continuity of pilot practices and undermine the effectiveness of APWM. Therefore, it is essential to maintain the stability of these policies in the near term and to leverage fiscal support to further solidify the foundation of mulch film management efforts. In this transitional phase, the government's financial intervention needs to give APWM a leg up to get it going. It's important to emphasize that the scientific rigor of the current policies for the mulch film scientific utilization and recycling requires further refinement. As indicated by the findings in Chapter III, the government's subsidy standards for environmentally friendly mulch films are excessively generous, while critical weaknesses of the treatment phase in the APWM system have not received adequate attention or support. Moving forward, subsidy standards and dimensions should be comprehensively evaluated to enhance policy effectiveness and precision. Moreover, to address the structural challenge of APWM's heavy reliance on fiscal subsidies, policymakers can draw lessons from developed countries such as the European countries and Japan. These countries have successfully established robust management and regulatory frameworks under unified governmental guidance, thereby clarifying the allocation of responsibilities, rights, and benefits among stakeholders. By integrating all relevant entities into a cohesive governance framework, China can advance toward creating a more effective and resilient system for APWM. Nevertheless, no policy implementation is without challenges or immediate success. The establishment of a multi-stakeholder cooperation mechanism must account for the unique contextual realities in China. Considering the complexities of real-world conditions and the multitude of influencing factors, a prudent pathway might involve initiating policy pilot trials to develop a contextually appropriate accountability framework. Such trials could then be followed by legislative action to institutionalize these mechanisms, ensuring a sustainable and adaptable governance structure for APWM.

Moreover, sustainable APWM requires enterprises to fully leverage favorable government policies to establish a more robust market-based mechanism for APW recycling. Integrating government subsidies with market-driven operations represents a pragmatic and contextually appropriate framework for APWM in China. Given the current slowdown in economic growth, tight balance of financial circumstances, and the increasing severe of resource scarcity, APW recycling marketization has emerged as the central trajectory for steering APWM toward greater efficiency and sustainability. A market-oriented recycling mechanism alleviates and optimizes government responsibilities and is a pivotal driver for advancing APWM toward systematization, efficiency, and resource valorization. The experiences and achievements of developed countries such as European countries and Japan in building market-based APWM mechanisms offer valuable insights and guidance for global reforms in this domain. In the process of exploring and implementing market-oriented APWM mechanisms, enterprises should seize policy opportunities and capitalize on the advantageous conditions provided by the government to accelerate the development of APW recycling operations. On the one hand, enterprises can reduce operational costs and enhance the economic viability of recycling and processing activities by applying for government subsidies and taking advantage of tax incentives. On the other hand, with governmental support for technological innovation, enterprises can expedite the research, development, and application of advanced recycling technologies to improve the efficiency of waste processing and resource utilization. Additionally, enterprises should leverage their superiority in capital, technology, and management competence to boost profitability through technological research and development, process optimization, and industrial chain expansion, thereby enhancing profitability and reducing dependence on government subsidies. Ultimately, these efforts will contribute to the evolution of a more efficient, sustainable, and market-driven APWM system.

Additionally, sustainable APWM demands farmers' enhanced awareness and proactive adoption of environmentally friendly agricultural plastic products. As direct participants in agricultural production, farmers' behaviors and choices play a pivotal role in determining the effectiveness of APWM. The findings presented in Chapter III reveal that farmers often exhibit bounded rationality, prioritizing short-term economic costs and favoring inexpensive yet environmentally detrimental conventional mulch films while overlooking the comprehensive and long-term benefits of environmentally friendly alternatives. To achieve sustainable APWM, it is imperative for farmers to elevate their understanding of APWM continuously.

Specifically, they must recognize the potential adverse impacts of APW on the environment and ecosystems, as well as comprehend the significance and urgency of waste management. Farmers can strengthen their environmental awareness and sense of responsibility through targeted education and training initiatives, thereby actively fulfilling their obligations in mulch film residuals collection. Building on this foundation, farmers should embrace environmentally friendly agricultural plastic products, such as thicker and biodegradable mulch films. During the adoption process, it is crucial for farmers to develop a nuanced understanding of the multifaceted advantages these products offer compared to conventional mulch films, spanning dimensions such as cost-effectiveness, environmental preservation, and societal well-being. Such in-depth comprehension and recognition can intrinsically motivate farmers to voluntarily choose and adopt these sustainable products, rather than rely solely on external incentives like government subsidies. Additionally, farmers may consider establishing cooperative relationships with local APW recycling enterprises, enabling more convenient transfer of APW to professional recycling institutions. This collaboration can facilitates proper waste processing and provides farmers with financial returns, further incentivizing their active participation in APWM initiatives.

Finally, sustainable APWM needs broad public participation, particularly in addressing the pressing issue of funding shortages. As an endeavor intimately tied to societal welfare and environmental protection, APWM is inextricably linked to the public. The public should not be regarded as passive bystanders or external observers but as indispensable participants and stakeholders in this process. This connection is especially critical given the severe financial constraints currently confronting APWM. Amid these funding challenges, widespread public engagement can unleash innovative potential and attract additional resources, thereby alleviating financial bottlenecks. A diversified funding model enhances the sustainability and resilience of APWM initiatives and fosters inclusive participation and shared benefits across societal sectors, advancing the modernization of environmental governance systems. The research substantiates the feasibility of public participation in APWM through the empirical analysis presented in Chapter IV, which delineates the decision-making pathways individuals follow when choosing to pay for APWM. Chapter V further explores strategies to encourage more extensive public involvement. Looking ahead, several measures could create favorable conditions for integrating the public into the APWM framework and unlocking their latent potential. These include strengthening the public's comprehensive evaluation of APWM and environmental cognition, reinforcing subjective norms of paying for APWM, establishing the payment platform to open up channels for the public to pay, and nurturing the public's environmental emotions. Collectively, these efforts can serve as a valuable complement to sustainable APWM, channeling public efforts into this critical endeavor and reinforcing the financial and operational foundation necessary for its long-term success.

2.Conclusions

2.1 The application of thicker and biodegradable mulch films is an effective measure to mitigate agricultural plastic waste, but the government promoting policy needs to be further optimized

The application of thicker mulch film is cost-effective, with a net benefit of CNY 3,208.8/ha, CNY 253.8/ha higher than that of conventional mulch film. The finding suggests that applying thicker mulch film is economically feasible with substantial potential for expansion. However, there are certain irrationalities in the current government subsidies for it. Theoretically, thicker mulch film can be promoted spontaneously without financial support due to its economic advantages, and the current government subsidy standard for it results in a certain degree of government economic resource waste. Besides, the inadequacy of its promotion rests in the lack of recognition for waste treatment, which is a weak point but not adequately supported by the current subsidies.

Comparatively, the net benefit for biodegradable mulch film is lower than conventional mulch film, at CNY 2,244.6/ha. Biodegradable mulch film is unprofitable due to the high material cost, and its further development requires stabilized external funding support. Nevertheless, the current policy exhibits high subsidy standards and financially inefficient utilization. In addition, deficiencies in the product's performance restrict its universal application.

In this regard, to promote environmentally friendly mulch film management measures, it is imperative to raise farmers' comprehensive knowledge of them, optimize government subsidy standards and dimensions for the management, and explore strategies to reduce the cost and increase the efficiency of different environmentally friendly mulch films. Further analysis enlightens the need to advance sustainable APWM by developing the carbon trading mechanism to internalize the environmental benefits of the management and innovating funding sources for sustainable agricultural white pollution control.

2.2 The public payment scheme for APWM is feasible and individuals' payment decisions' driving pathways are clarified

The survey based on 1,288 residents in four provinces (autonomous regions) of northern China shows that 40.9% of the respondents hold positive payment willingness towards APWM. The average WTP for all the respondents is CNY 482.6. The result illustrates that the public is generally willing to pay for APWM, and the public payment scheme holds potential promise in addressing the funding gap confronting APWM. Further, the extended TPB framework has better interpretability to INT for the public's payment for APWM. AT, SN, PBC, EC, and EE have significant positive influences on payment INT towards APWM, with AT exerting the most significant impact, followed by SN and PBC. Although EC and EE show minimal direct effects, they strengthen the relationship between AT and INT and between SN and INT and present a substantial indirect effect on INT.

The study provides a new perspective on public payment in tackling the APWM dilemma of lacking reliability and sustainability, which is quite revealing. Multi-entity cooperation, specifically public payment for APWM, can leverage the public's potential contribution to enhance agricultural non-point waste management. Additionally, the framework of extended TPB, which clarifies driving pathways of individuals' payment decisions provides instructive insights into promoting the public's payment willingness. Strengthening the public's positive evaluation of APWM and environmental cognition, reinforcing subjective norms about paying for APWM, establishing the payment platform to open up channels for the public to pay, and nurturing the public's environmental emotions, can serve as the entry point for formulating an open and diverse APWM scheme.

2.3 Information intervention is effective in influencing the public's payment for APWM, and can facilitate the public payment scheme to evolve from idea to reality

The public's WTP for APWM is generally malleable, with information intervention generally but differently enhancing the respondents' WTP. Information targeting normative and control beliefs increased significantly the WTP by CNY 307.2 and CNY 400.5, respectively. Attitude belief also has a positive impact on respondents' WTP, although not significantly. In summary, control beliefs have the most decisive influence on the public's WTP, followed by normative beliefs, while the impact of behavioral beliefs on WTP was less pronounced. Findings imply that the public payment scheme for APWM is characterized by a high perception but weak social norms and a lack of effective mechanism.

The public payment scheme for APWM is obstructed by the absence of a robust mechanism and weakness of social norms. Transitioning from a mere positive intention toward actual payment necessitates added momentum, which primarily lies on norm strengthening and mechanism establishing.

Concerning norm strengthening, it is of significant importance to integrate the potential contributions of governments, social networks, and individuals. Priority should be given to authoritative entities to leverage their great advantages of strong persuasion and appeal. The benefits of social network communication should be harnessed to maximize the potential of the vast Internet users and widely call for their participation. In addition, emphasis should be placed on interpersonal communication to expand the population base that contributes to APWM through personal social relationships. To establish an effective mechanism, a public payment scheme should be launched, prioritizing reputable charities to enhance trust. Integrating crowdfunding platforms with social applications will streamline processes for data collection, donations, and communication, enhancing convenience. A transparent information system should ensure timely updates on progress, and the scheme must be voluntary to ensure no financial strain on potential donors.

3.Limitations and perspectives

Apart from implications, the study has some limitations that can provide inspiration for further research. Firstly, The universality of the research findings could be further enhanced. The surveys for the cost-benefit analysis of mulch film management are conducted in northern China, and the research object is dominated by mulch films, which unlock the opportunity for a larger region and a more comprehensive range of agricultural plastic products that are more representative of the APWM in China (Jaiswal and Kant 2018; Kirmani and Khan 2018). Regarding the studies concerning public participation primarily utilize online surveys for data collection. However, a potential avenue for future improvement lies in integrating offline surveys and other diverse methods. This approach would enhance the representativeness of the findings and contribute to the generalizability of the conclusions, thereby providing a more comprehensive understanding of the research topic.

Secondly, the research approach could be further improved. In the research, WTP was applied to evaluate the respondents' willingness to pay for the APWM. However, self-reported WTP may overestimate the actual payment level, representing the inherent limitation when using WTP to assess individual preferences for non-market-value items (Knetsch and Sinden 1984). Additionally, the research only established short term effectiveness of the information intervention on the public's WTP for APWM, leaving the long term impact yet to be confirmed. In the upcoming research, with follow up field surveys and advancements in the WTP estimation methodology, the impact of information intervention on the APWM public payment scheme will be further revealed.

Thirdly, the research could be further refined. The study that applying cost-benefit analysis to evaluate the comprehensive performance of different mulch film management practices emphasizes more on economic feasibility of mulch film management and the external impacts have been simplified to some extent. And the study does not consider the environmental impacts of mulch film manufacturing, and the differences in GHG emissions between biodegradable materials and plastics during production may also influence the cost-effectiveness (Li et al. 2024). Upcoming studies could expand the study boundary and employ LCA to systematically evaluate the environmental and economic performance of different mulch film management measures.

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Appendix: Survey memorandum and questionnaire

1.Field survey memorandum

The field survey investigates the comprehensive management processes of mulch film within the study region. Main focus includes the fundamental aspects of mulch film utilization and recycling; the implementation status of pilot demonstration for the mulch film scientific utilization and recycling; subsidies for farmers utilizing thicker and biodegradable mulch films; the development of mulch film waste recycling sites and enterprises; central and local government fiscal subsidies for the mulch film waste management; and the economic costs and benefits of mulch film waste recycling.

1.1 For government officials:

1)Agricultural production conditions in the study region

The topography, climate, precipitation, and thermal and photothermal conditions.

Farmland area and crop planting specifics.

Costs and benefits of crop cultivation under varying mulching conditions.

2)Utilization of mulch film

Crop types and areas mulched by mulch film.

Mulch film residual status at monitoring sites.

3)Management of mulch film waste

Management measures encompassing the entire chain of production, sales, utilization, and recycling of mulch film waste.

Records of mulch film waste recycling.

Recycling practices at the county, town, and village levels.

Methods and proportions of mulch film waste treatment

Development and operational models of recycling sites.

Promotion and utilization of biodegradable mulch film, including measures such as production subsidies, government procurement, and purchase price subsidies.

4)Province-, city-, and county-level implementation plans for the mulch film scientific utilization and recycling

Pilot demonstration tasks in distinct regions.

Central and local financial allocations.

Economic, social, and environmental benefits of applying different mulch films (PE and biodegradable mulch films), categorized by mulching crops.

5)Rural household waste treatment

Methods and processes for treatment of non-recyclable and non-compostable rural household waste.

Costs associated with sanitary landfilling and controlled incineration (transportation and treatment costs).

Coverage radius of treatment sites.

Sources of treatment funding.

6)Assessment of challenges and solutions in mulch film waste management from the perspective of government

1.2 For manager and employees of agricultural plastic waste recycling

enterprises

Company Name: ___________________

1)Characteristics of enterprise operations

Establishment date, factory scale, and employment details.

Scope of operations (mulch film production, primary and advanced mulch film waste recycling).

Processing capacity for mulch film waste and the associated technological processes.

Government investment in mulch film waste recycling projects.

Volume of mulch film waste recycled and the radial coverage of the surrounding areas.

Recycling models (transaction modes with farmers, recycling sites, etc.).

Production of thicker and biodegradable mulch films, and the favourable policies enjoyed.

Sale prices of thicker and biodegradable mulch films.

2)Costs and benefits of mulch film waste recycling

Detailed cost items including factory construction, equipment procurement, materials procurement, labor cost, and waste treatment costs.

Detailed benefit items.

3)Enterprise manager's cognition for mulch film waste management

Attitude towards mulch film waste recycling.

Attitude towards thicker and biodegradable mulch film application.

Understanding of policies related to the pilot demonstration of mulch film scientific utilization and recycling.

Perception of national pilot demonstration policies: enterprise responsibilities and rights in mulch film waste management.

Satisfaction with and demands regarding policies on mulch film waste management.

4)Challenges in mulch film waste management, solutions, and enterprise demands

1.3 For farmers

1)Basic agricultural operation situation

Area of farmland, crop types, film mulching duration, and mulching area.

2)Costs and benefits of crop cultivation

Costs: Fertilizers, pesticides, seeds, mulch films (different kinds), and field management.

Utilization of agricultural machinery in crop production.

Benefits: crop yield and selling price under different mulching conditions.

3)Mulch film utilization and recycling

Utilization: Types of mulch films applied, usage and purchase cost of different mulch films, and mulching costs.

Recycling: methods of recycling (manual, mechanical) and the incurred costs.

Effectiveness and difficulty of recovery.

Treatment methods for mulch film waste (If recycled, investigate the details of

recycling).
Perception of different treatment methods: including open burning, landfilling, and recycling.
4)Pilot demonstration on the mulch film scientific utilization and recycling
Willingness to use thicker and biodegradable mulch films.
Matching of mulch film performance with actual agricultural production needs.
Impact on crop yields under different mulch films' mulching (by different crop types).
Affordable price for thicker and biodegradable mulch films.

2.Questionnaire

Survey on the Willingness for Agricultural Plastic Waste Management

Hello, we are the students and researchers at the Chinese Academy of Agricultural Sciences, and we sincerely appreciate your participation in this survey. The questionnaire aims to know your thoughts, perceptions, and anticipated behaviors, as well as basic information such as your age and gender. Your responses will be anonymized and used solely for academic research purposes.

Completing this survey will take about five minutes. Please read each question carefully and respond according to your genuine thoughts. Your real thoughts and patience in filling in the questionnaire are very important to us. Once again, we extend our heartfelt gratitude for your support and cooperation!

1.Gender: ☐ Male; ☐Female
2.Age:________
3.Place of residence: ☐ Rural; ☐ Urban
4.The distance between the place of residence and the nearest farmland is:
☐ ≤500 m; ☐ 500 m -1 km; ☐1-2 km; ☐ 2-5 km; ☐5-10km; ☐10-20 km; ☐＞20 km
5.Health status:
☐ Bad; ☐ Not very good; ☐ Just OK; ☐ Good; ☐ Very Good
6.Level of education:
☐ Primary school; ☐ Junior high; ☐ Senior high; ☐ College; ☐ Postgraduate
7.Marital status:
☐ Married; ☐ Unmarried
8.The number of household people is ___________ . Of these, the number of teenager under the age of 18 is ______ and the number of people over the age of 65 is _____.
9.Family income last year is:
☐ ＜ CNY 10,000; ☐ CNY 10,000 - 30,000; ☐ CNY 30,000 - 70,000;
☐ CNY 70,000 - 130,000; ☐ CNY 130,000 - 210,000; ☐ CNY 210,000 - 310,000;
☐ ＞ CNY 310,000
10. Have you ever participated in public service activities (environmental protection, community service, social assistance, charity, knowledge dissemination, and so on)?
☐ Yes. (If so, then) In the past year, you have participated______ times of public

service activities, of which______ times were related to the theme of environmental protection.

☐ No

11. Have you ever donated to a charity?

☐ Yes. (If so, then) In the past year, you donated a total of CNY ________, of which CNY________was related to environmental protection.

☐ No

12. In the past year, the time you stay in the rural area was about _______ days.

13. How often do you see agricultural white pollution? (Agricultural white pollution refers to the pollution of the landscape caused by the discard of agricultural plastic products such as mulch film, greenhouse film, pesticide/fertiliser bags and so on.)

☐ Never seen it before; ☐ Rare to see it; ☐ Sometimes can see it; ☐ Often can see it; ☐ Anytime can see it

14. How often do you see about agricultural white pollution on social media, video websites, news reports and so on?

☐ Never seen it before; ☐ Rare to see it; ☐ Sometimes can see it; ☐ Often can see it; ☐ Anytime can see it

15. Do you agree with the following points? Strongly disagree (1) - Strongly agree (5)

1)Agricultural white pollution is caused by the improper disposal of agricultural plastics (indiscriminate disposal, irrational disposal). ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

2)Improper disposal of agricultural plastic waste can cause environmental pollution problems. ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

3)Improper disposal of agricultural plastic waste can cause food safety problems. ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

16. How likely are you to spend a portion of your household income on preventing agricultural plastic pollution? Not at all likely (1) - Very likely (5) ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

17. On a household basis, the most you would be willing to pay to support agricultural plastic waste management is CNY________/year.

CNY	50	/year ≈	CNY	4	/month
CNY	100	/year ≈	CNY	8	/month
CNY	200	/year ≈	CNY	17	/month
CNY	300	/year ≈	CNY	25	/month
CNY	400	/year ≈	CNY	33	/month
CNY	500	/year ≈	CNY	42	/month
CNY	600	/year ≈	CNY	50	/month
CNY	700	/year ≈	CNY	58	/month
CNY	800	/year ≈	CNY	67	/month
CNY	900	/year ≈	CNY	75	/month
CNY	1000	/year ≈	CNY	83	/month
CNY	2000	/year ≈	CNY	167	/month
CNY	5000	/year ≈	CNY	417	/month
CNY	10000	/year ≈	CNY	833	/month
CNY	20000	/year ≈	CNY	1667	/month

18. How concerned are you about the following questions? Don't concerned it at all (1) - Strongly concerned it (5)

1)For food safety issues: ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
2)For micro-plastic pollution: ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
3)For agriculture-related issues: ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
4)For agricultural plastic waste issues: ☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

Please read the following material carefully and answer the questions. (Here, participants were randomly assigned to different groups and received different information)

1)For control group:

China is the largest agricultural plastics consumer in the world. Agricultural plastic waste refers to post-consumed mulch film, greenhouse film, pesticide and fertilizer packaging, irrigation pipes and so on. Currently, agricultural plastic waste, especially mulch film waste, is mismanaged, resulting in widespread farmland white pollution.

2)For treatment group targeting behavioral beliefs:

China is the largest agricultural plastics consumer in the world. Agricultural plastic waste refers to post-consumed mulch film, greenhouse film, pesticide and fertilizer packaging, irrigation pipes and so on. Currently, agricultural plastic waste, especially mulch film waste, is mismanaged, resulting in widespread farmland white pollution.

Robust evidence has shown that APW will damage crop yields and quality in the long term if discarded on farmland. Plastic residues can break down over time into microplastics, spreading in terrestrial, aquatic and atmosphere systems. Microplastic may enter the food chain and thus threaten human health. APW can be disposed of by open burning, landfill and recycling. Among them, recycling is the best management practice for not only solving environmental pollution and health threats but also turning waste into resources.

3)For treatment group targeting normative beliefs:

China is the largest agricultural plastics consumer in the world. Agricultural plastic waste refers to post-consumed mulch film, greenhouse film, pesticide and fertilizer packaging, irrigation pipes and so on. Currently, agricultural plastic waste, especially mulch film waste, is mismanaged, resulting in widespread farmland white pollution.

According to our nationwide survey of different individuals, and groups companies, the majority are willing to make their contributions to APWM for better tackling the problems caused by APW. Managers from government organizations, scientific institutes, media and companies will take the lead to donate and call on everyone who cares about the environment and health to join together. Let's participate in and donate to APWM together, help keep farmland clean and express our sense of responsibility and mission.

4)For treatment group targeting control beliefs:

China is the largest agricultural plastics consumer in the world. Agricultural plastic waste refers to post-consumed mulch film, greenhouse film, pesticide and fertilizer packaging, irrigation pipes and so on. Currently, agricultural plastic waste, especially mulch film waste, is mismanaged, resulting in widespread farmland white pollution.

With government permission and regulation, relevant charity organizations are setting up an APWM Fund to effectively and sustainably mitigate agricultural white pollution. Through access to WeChat, Weibo, Alipay and other applications, the public can make voluntary donations to the fund in a convenient manner. The government and charity organizations will monitor the use of the funds, ensure the effectiveness of APWM, and regularly and truthfully disclose relevant information to society. Little giving, large gains, every coin you donate will help create cleaner farmland.

5)For treatment group targeting combined beliefs:

China is the largest agricultural plastics consumer in the world. Agricultural plastic waste refers to post-consumed mulch film, greenhouse film, pesticide and fertilizer packaging, irrigation pipes and so on. Currently, agricultural plastic waste, especially mulch film waste, is mismanaged, resulting in widespread farmland white pollution.

Robust evidence has shown that APW will damage crop yields and quality in the long term if discarded on farmland. Plastic residues can break down over time into microplastics, spreading in terrestrial, aquatic and atmosphere systems. Microplastic may enter the food chain and thus threaten human health. APW can be disposed of by open burning, landfill and recycling. Among them, recycling is the best management practice for not only solving environmental pollution and health threats but also turning waste into resources.

According to our nationwide survey of different individuals, and groups companies, the majority are willing to make their contributions to APWM for better tackling the problems caused by APW. Managers from government organizations, scientific institutes, media and companies will take the lead to donate and call on everyone who cares about the environment and health to join together. Let’s participate in and donate to APWM together, help keep farmland clean and express our sense of responsibility and mission.

With government permission and regulation, relevant charity organizations are setting up an APWM Fund to effectively and sustainably mitigate agricultural white pollution. Through access to WeChat, Weibo, Alipay and other applications, the public can make voluntary donations to the fund in a convenient manner. The government and charity organizations will monitor the use of the funds, ensure the effectiveness of APWM, and regularly and truthfully disclose relevant information to society. Little giving, large gains, every coin you donate will help create cleaner farmland.

After reading the above information about agricultural plastic waste and its management, please re-answer the following questions:

19. How likely are you to spend a portion of your household income on preventing agricultural plastic pollution? Not at all likely (1) - Very likely (5) □ 1; □ 2; □ 3; □ 4; □ 5

20. On a household basis, the most you would be willing to pay to support agricultural plastic waste management is CNY________/year.

21. Agricultural plastic waste management refers to a series of measures to mitigate agricultural white pollution, such as enhancing mulch film recycling and utilizing biodegradable mulch film. Do you agree with the following views on agricultural plastic waste management? Strongly disagree (1) - Strongly agree (5)

1)Conducting APWM is enjoyable and satisfying for me.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
2)Conducting APWM is good for the society.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
3)Conducting APWM is sensible as the government policy.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
4)Conducting APWM is good for the ecosystem.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
5)Conducting APWM is important and urgent right now.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
6)Everyone should take responsibility for APWM in the future.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
7)My relatives suggest me to pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
8)My friends suggest me to pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
9)Community and government suggest me pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
10)Social media suggests me to pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
11)I would feel morally condemned if I do not pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
12)It is easy for me to pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
13)I know how to pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
14)There is no financial burden for me to pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
15)It is entirely up to me whether to pay for APWM or not.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
16)My efforts will be paid off if I pay for APWM.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
17)Environmental pollution is currently a major problem.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
18)It is important to protect the ecosystem.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
19)Environmental pollution affects human health.
☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5
20)Environmental pollution affects food safety.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

21)Improper disposal of plastic waste can lead to environmental pollution.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

22)Microplastics can enter the food chain and threaten human and animal health.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

23)I aspire to a better living environment.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

24)I am anxious about the current environment state.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

25)I am disgusted by others' environmental damage behaviors.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

26)I am appreciative of others' environmental protection behaviors.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

27)I feel guilty for my environmental damage behaviors.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

28)I am proud of my environmental friendly behaviors.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

29)I am in favour of paying for APWM.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

30)I am willing to pay for APWM.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

31)I intend to pay for APWM.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5

32)The better the management, the more I am willing to pay.

☐ 1; ☐ 2; ☐ 3; ☐ 4; ☐ 5