INTERNATIONAL EXPERIENCE IN AGRICULTURAL PLASTICS MANAGEMENT

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Commissioned by the Federal Ministry for Economy Cooperation and Development (BMZ) and under the framework of develoPPP.de Programme, Sino-German Project for Upgrading Plastics Management in Agriculture is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, together with Reifenhäuser GmbH & Co. KG Maschinenfabrik, Zhuhai Kinfa Biomaterial Co., Ltd and TÜV Rheinland (Shanghai) Co., Ltd. Commencing in 2020 September, the project aims at tackling "white pollution" caused by inappropriate plastic film recycling and management in China. The project will, for one thing, enhance the recycling efficiency of PE film by digitalized tracking system; for another, promote the utilization of biodegradable mulch film. Five pilots will be implemented in Gansu, Heilongjiang, Inner Mongolia, Hubei and Beijing respectively. According to the best practices of the project, technical specifications and political suggestions will be generated to facilitate the upgrading of agricultural plastic management in China.

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Abbreviations and Acronyms

A.D.I.VALOR	Agriculteurs, Distributeurs, Industriels pour la Valorisation des Dechets Agricoles
ACC	American Chemistry Council
ACRC	Ag Container Recycling Council
ANAIP	Spanish Association of Plastic Converters
APE Europe	Agriculture, Plastic & Environment Europe
APE UK	Agriculture, Plastic & Environment UK
APW	agricultural plastic waste
ASTM	American Society for Testing and Materials
AUA	Agricultural University of Athens
BFP	Birch Farm Plastics
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CEN	European Committee for Standardization
CONAI	Consorzio Nazionale Imballaggi
COREPLA	Consorzio Nazionale per la raccolta, il riciclo e il recupero degli imballaggi in plastica
CPA	Comité français des Plastiques en Agriculture
EOL	End of life
EPR	Extended Producer Responsibility
ERDE	Entekunstoffe Recycling Deutschland
EU	European Union
EuPC	Athens, European Plastics Converters
FAO	Food and Agriculture Organization of the United Nations
FTIR	Fourier Transform Infrared Spectroscopy
GPN	Grønt Punkt Norge
ha	hectare
HDPE	High Density Polyethylene
ICROFS	International Centre for Research in Organic Food Systems
IFFPG	Irish Farm Film Producers Group
IK	Industrievereinigung Kunststoffverpackungen
IRF	Icelandic Recycling Fund
JA	Japan Agricultural Corporative
JIS	Japanese Industrial Standards
JISC	Japanese Industrial Standards Committee
kg	kilogram
KRSAB	Kretslopp & Recycling i Sverige AB

kt	kilo tonnes
LDPE/LLDPE	(Linear) Low Density Polyethylene
MAFF	Ministry of Agriculture, Forestry and Fisheries
MAPLA	Medio Ambiente, Agricultura y Plásticos
MARA	Ministry of Agriculture and Rural Affairs
MD	machine direction
NCS	national collection scheme
NFEP&WM	National Fund for Environmental Protection and Water Management
NWMP	National Waste Management Plan
OWS	Organic Waste Systems
PE	Polyethylene
PO	Polyolefin
POLIECO	Consorzio Nazionale per il Riciclaggio di Rifiuti di beni in Polietilene
PCR	Post-Consumer Recyclates
PPP	Polluter-Pays Principle
PRE	Plastics Recyclers Europe
PRO	Producer Responsibility Organization
PVC	Polyvinyl Chloride
RAFU	Recycling of Used Agricultural Films
RDF	Refuse Derived Fuel
REEA	Rual Energy and Environment Agency
RIGK	Gesellschaft zur Rückführung industrieller und gewerblicher Kunststoffverpackungen mbH
RPF	Refuse Paper and Plastic Fuel
SAC	Suwannee American Cement
SOC	Soil Organic Carbon
SvepRetur	Svensk Ensilageplast Retur
TD	transverse direction
TED-GC/MS	Thermal Extraction Desorption-Gas Chromatography/Mass Spectrometry
UCAN	Cooperativas Agro-alimentarias de Navarra
UIPP	Union des Industries de la Protection des Plantes
UKFPRS	UK Farm Plastic Responsibility Scheme
WFD	Waste Framework Directive

Executive Summary

International Practices in Agricultural Plastics Management

Extensive desk research and interviews have been conducted to understand the status quo of consumption and end-of-life management practices pertaining to agricultural plastics in Europe, Japan and North America. Nevertheless, the amount of available information varies across regions, and it is presented in diverse formats within the text. In order to facilitate the readers with drawing comparison among the practices of different regions, this section provides a consolidated overview of the key findings of the research in a coherent framework. For more details, please refer to the table of contents.

1 Europe

The European Union (EU) has demonstrated significant dedication to the concept of "circular plastics economy", which aims to maintain plastic materials in a close loop system to the greatest extent possible. Several European countries have successfully implemented this model in the agricultural sector. In 2021, the EU published the Status Report on agricultural plastics in Europe (hereinafter referred to as the "EU Report"), which is mainly used as a source for extended (Hann et al., 2021).

1.1 Basic Data

Consumption

In 2019, approximately 722kt of non-packaging agri-plastic products were placed on the European market, which accounted for 1.4% of the total EU plastics demand. Plastic mulch film constituted over 75% of the 722kt, including silage film (267 kt), greenhouse film (176 kt), conventional plastic mulch film (83 kt) and biodegradable mulch film (5 kt).

Greenhouse film and mulch film find primary applications in southern Europe for crop production, while in northern Europe, silage film is predominantly consumed in the livestock sector. In terms of countries that consume the biggest share of mulch film, Spain, Italy, France, and Germany rank top 4.

End of Life Management

Around 63% of the 1175 kt of non-packaging agri-plastic waste generated in Europe in 2019 was collected, weighing 756 kt. The contamination rate of the collected waste was 41% and effective utilization rate was 44%, with a conservative estimate of the recycling rate (calculated by consumption rate) of 24% and 20% being utilized in energy recovery.

As for mulch film, an estimation of 249kt of waste was generated. 199 kt was reported as having been collected, among which 66 kt was mulch film after use and the remainder was soil and other organic matter (i.e., a contamination rate of 67%). Therefore, the collection rate, which is the weight of used mulch film with impurities removed divided by the weight of new mulch film generated from which and put into use, is 80%. The majority of wasted mulch film was incinerated for energy recovery, a small share landfilled, and little recycled.

1.2 Main Characteristics of Mulch Film

· Product Standards ·

The European Standard for "Plastics - Thermoplastic mulch film recoverable after use, for use in agriculture and horticulture" (EN 13655: 2018) is not enforceable at law However, it provides essential guidelines regarding various aspects, including minimum thickness (≥ 0.020 mm), mechanical characteristics (e.g., tensile stress at yield, tensile stress at break ≥ 20 MPa, tensile strain at break (TD) ≥ 350%, and impact resistance), optical characteristics and durability, as well as instructions for installation, use and removal. These specifications aim to ensure quality and reliability in the utilization of mulch film within agricultural practices.

· Common Specifications ·

The common thickness of mulch film on the European market ranges from 0.010 mm to 0.025 mm. Special multi-layer film structure design as well as the addition of UV stabilizers contribute to good recyclability of plastic film. Albeit being a significant factor, thickness is not the only intrinsic characteristic that determines recyclability of mulch film.

1.3 Policy Measures and Practices of EOL Management

1.3.1 EU Legislation

At EU level, the management of agricultural plastic waste (APW) is not currently directly addressed by specific legislation. However, it is acknowledged within the broader waste management framework and plastics strategy to some extent. Furthermore, the EU has taken a significant step towards environmental protection by introducing a ban on oxo-degradable plastics in the EU market since July 2021, in alignment with the Single-Use Plastics Directive.

1.3.2 National Initiatives and Extended Producer Responsibility (EPR)

At the national level, most European countries have established comprehensive legislative systems to govern waste management. These systems prohibit uncontrolled open burning and landfilling of waste, including APW.

Specific national policies and initiatives regarding agri-plastics vary from country to country. Italy, Ireland, and Iceland have enacted legislation to enforce mandatory EPR systems and National Collection Schemes (NCSs) specifically for various agricultural plastic types. In contrast, voluntary EPR alliances have been established in France, Spain, Germany, the United Kingdom, Sweden, and Norway. An overview of tables summarizing various aspects of APW in typical countries is provided here as a quick guide:

- Basic data and information in Table 1
- Policy measures and recycling status in Table 3
- EPR systems and collection schemes in Table 6
- Cost sharing between producers and farmers in EPR schemes in Table 10

The scope of APW categories also varies across schemes. Among the NCSs covering mulch film, significant disparities arise in terms of implementation progress and impact, as summarized below:

The French A.D.I.VALOR alliance is a mature organization. Operating as a voluntary collection and recycling entity, A.D.I.VALOR is a collaborative effort involving 10 associations representing a wide range of stakeholders. A.D.I.VALOR has achieved a remarkable coverage rate of 70% for APW across the country after more than 20 years of practice. Currently, the alliance devotes itself to further enhancing both collection and recycling rates, with the ambitious goal of reaching 100%.

In Andalusia, the region with the largest use of APW in Spain, the previous regional mandatory EPR scheme failed due to unsustainable system design. As a response, a newly established voluntary association called MAPLA (Medio Ambiente, Agricultura y Plásticos) has been initiated and is currently undergoing a pilot phase starting from 2021. The aim is to explore alternative approaches that foster more effective and sustainable management of APW within the region.

Italy has launched a mandatory EPR scheme for discarded PE-based products in 2019 and commissioned POLIECO to operate the collection and recycling system, but some farmers opted to engage private waste contractors who offer free collection services for greenhouse film, as opposed to POLIECO, which charges a participant fee. Now Italy has achieved a recycling rate of 43% for polyethylene (PE) waste.

The German voluntary alliance ERDE has been in operation for nearly a decade and has achieved a collection rate of 51% for silage film, which stands as the most widely consumed agricultural plastic in Germany. Mulch film is planned to be included in the scheme from 2022.

In the UK, the mandatory EPR system was denied, and two coalitions representing different stakeholders were voluntarily established in 2020. However, the effectiveness and outcomes of these voluntary initiatives are still being assessed, and it remains uncertain how well they will function in practice.

In Ireland and Iceland, where mandatory NCSs are implemented, as well as in Sweden and Norway with voluntary NCSs, the focus has always been on the collection of silage film, whereas mulch film collection wasn't emphasized due to rare consumption. These NCSs have achieved exceptional collection rates that exceed 90%, with an average implementation period of 20 years. This demonstrates the effectiveness of the long-term efforts of those countries in ensuring the high collection and recycling rates of silage film within agricultural sectors nationwide.

As for the EOL costs of agri-plastics, they fall mainly on producers under EPR in most NCSs. The burden of these costs is shared by farmers, who pay a collection fee that is lower than that for non-recyclable household waste. However, there are key differences among NCSs in terms of fee structure. Some NCSs require an upfront payment at the time of purchase, known as an "in-price fee," while others collect the fee at the collection point. For mulch film, farmers may need to contribute more due to the higher ratio of EOL costs to retail price. Particularly, the EOL cost to retail price ratio reaches nearly 20% for mulch films in France, whereas for greenhouse films it's only 1%. Drawing from the successful experience of European NCSs, it is recommended that the costs of mulch film at EOL should be shared jointly by producers and farmers.

A modeling policy study from Europe shows that a combination of mandatory EPR and obligatory farmer participation in agri-plastics collection schemes can yield optimal outcomes. While incentivized and non- incentivized voluntary EPR can achieve similar effects, it may require years of implementation.

1.3.3 Other Practices

01 Product Traceability Management

The EU has sponsored a research project LabelAgriWaste, which aims to develop an APW systematic labeling management scheme to facilitate appropriate treatment. Additionally, in 2022, the EU proposed an Eco-design for Sustainable Products Regulation, which highlighted the importance of the “Digital Product Passport” to enhance the transparency of products and enable effective supervision by public authorities. There is speculation that this regulation may also be extended to cover agri-plastics, further emphasizing the significance of traceability and transparency in managing these materials.

02 Farmer Training

It is crucial to provide adequate training to farmers regarding the correct way to utilize, collect, pre-clean (ensuring undesirables are less than 50%), and bale mulch film in the fields. Effective communication channels, including the internet, leaflets, lectures, and on-site guidance, should be utilized to announce the designated collection location and time. Such training initiatives targeted at farmers play a vital role in promoting proper management practices for mulch film within the European agricultural sector.

03 Collection Machine

as part of ongoing efforts in Europe, a recycling solution known as the Recycling of Used Agricultural Film (RAFU) machine, which was implemented on a tractor trailer, has been trialed in France for carrots, melons, potatoes, onions, salads and other crops. This device allows simultaneous operation of collecting, cleaning and rolling mulch film as well as harvesting crops. The contamination rate can be reduced to 30%–50%, depending on crop types in both wet and normal conditions. Currently, this technology is already being utilized by 50% of carrot farms in France, showcasing its feasibility and positive impact in the agricultural sector.

04 Pre-treatment

In pursuit of improving the quality of mulch film recycling, collaborative efforts between French organization A.D.I.VALOR and associated enterprises have resulted in the establishment of a pre-treatment unit with an impressive annual capacity exceeding 10,000 tonnes. This advanced facility enables the production of exceptionally pure recycled low-density polyethylene (LDPE) flakes. Moreover, a Spanish APW recycler has taken proactive measures by installing a pre-cleansing line and expending the recycling capacity of its plant in order to efficiently process all the APW generated in Spain.

1.4 Plastic Recycling

In Europe, mechanical recycling is the dominant method for recycling APW, while chemical recycling is still in the pilot stage.

The end markets for recycled mulch film pellets are mainly garbage bags, construction film and thick plastic profiles (e.g., "plastic wood" for park benches). Additionally, they are utilized in silage films containing 40% recycled materials, as well as in irrigation pipe connectors, and twine.

However, it is important to note that the yield rate of recyclate obtained from mulch film is only half of that from greenhouse film. The profitability of mulch film waste remains a challenge due to high recycling costs and low sales price. Recyclers often face difficulties when finding a market for recycled pellets, especially when the price of virgin resin is competitive.

In Europe, recycled PE resin can be used for mulch films, typically from high-quality commercial and industrial waste plastic film rather than agricultural film. The recycled content in mulch film ranges from 10% to 70%.

1.5 Selected Research Findings on Mulch Film Contamination

01

European experts estimate that for mulch film pieces with a thickness of 0.010 mm, 68% (by mass) remain in or on the soil, while for 0.020 mm film, the retention rate is 25%, and for 0.025 mm film, it is 10%.

02

When considering annual mulching with a fallow period every three years, increasing the removal rate of mulch film from the soil from 75% to 90% (equivalent to reducing the residual rate from 25% to 10%), the time required to reach the threshold of 11% reduction in crop yield increases from 11 years to 26 years. This highlights the importance of increasing the removal rate of mulch film in Europe, as it significantly contributes to reducing plastic pollution, surpassing the effect of banning single-use plastics. More attention should be paid to mulch film pollution in Europe.

03

The iMulch project sponsored by the EU has developed a methodology for detecting soil microplastics and conducted preliminary experiments on the aging, adsorption and ecotoxicological effects of mulch film (IMulch, n.d.).

04

Soil organic carbon (SOC) will decrease during the removal of mulch film, which harms the health of agricultural fields and damages the carbon sequestration capacity of the soil.

1.6 Barriers and Next Steps

Europe encounters various challenges in the recycling of APW, especially regarding mulch film. These challenges include inadequate front-end collection, elevated recycling costs, limited end markets, and incomplete value chain collaboration. Addressing these issues is essential to enhance APW recycling efforts in Europe and promote a sustainable circular economy for agricultural plastics.

The EU considers the next steps:

- to strengthen the collection of statistical data collection on APW;
- to conduct scientific research on the relation between properties of mulch film and soil residues;
- to support technology innovation in the entire value chain;
- to improve management and incentive schemes while clarifying the responsibilities of all stakeholders;
- and eventually streamline the recycling chain and foster the development of a circular economy in agricultural plastics.

2 Asia: Japan

Japan initiated the utilization of agricultural film in the 1950s and has established a relatively complete system for APW management and recycling.

2.1 Basic Data

Consumption

The amount of APW generated in Japan kept declining after its peak at 189 kt in 1993 and leveled out from 2014 onwards.

The annual consumption of mulch film in Japan is around 40 kt, with polyolefin (PO) film constituting over 90% of the total, while totally biodegradable materials make up a mere 2%.

End of Life

In 2018, the total amount of discarded agricultural plastics in Japan amounted to 107 kt, accounting for 1.2% of the total amount of plastic waste. Among the discarded agricultural plastics, PE film constituted 53% (approx. 57 kt), while polyvinyl chloride (PVC) film accounted for 22% (approx. 24 kt).

The volume of discarded mulch film generated in Japan has been decreasing over the years, while the recycling rate has been on the rise. In Japan, material/mechanical recycling, chemical recycling, and thermal recycling (i.e., energy recovery) are all counted as recycling. In 2018, the overall recycling rate of agricultural film in Japan was 74.5%, with all proportions of simple incineration without energy recovery, landfill and other disposal methods being less than 10%. Specifically, around 56 kt of agricultural PE film were discarded, with a commendable recycling rate of 78%.

2.2 Main Characteristics of Mulch Film

· Product Standards ·

In Japan, the current standard for "Polyethylene film for agriculture" (JIS K6781-1994) is adopted, which specifies minimum thickness (≥ 0.020 mm) and mechanical characteristics (e.g., tensile strength, elongation at break, and tearing load). It serves as a reference for ensuring the quality and performance of polyethylene film used in agricultural applications.

· Common Specifications ·

In the Japanese market, the common thickness of mulch film is 0.020 mm and 0.030 mm. The mulch film is designed to remain intact after use, facilitating their collection process.

2.3 Policy Measures and Practices of EOL Management

The promulgation of *Basic Policy on Appropriate Processing of Used Plastics for Horticulture* in 1995 marked a significant step in addressing the management of agricultural film. Subsequent revisions to the Waste Management Law have progressively enhanced the responsibilities of agricultural film producers, farmers, collectors, transporters, recyclers, and the government authorities. These measures have contributed to the strengthening of the overall framework for agricultural film management.

The Japan Agricultural Film Recycling Promotion Association (n.d.) oversees the general management of agricultural film recycling in Japan. It is responsible for the establishment of a recycling levy and processing system, as well as the coordination of its implementation (see Figure18). Additionally, the association engages in developing new technologies, promoting agricultural film recycling, and offering guidance. To support these initiatives, Japanese farmers also are required to pay an appropriate fee either at the collection point or during the purchase process. Opting for the latter option enables farmers to receive additional subsidies from local governments and agricultural cooperatives, with a subsidy ratio normally being 2/3.

The Association actively promotes the adoption of durable film, as well as proper mulching and removal of film. Farmers are obliged to classify and clean mulch film, ensuring that the contamination rate remains below 50%. Additionally, they are required to bale them as required before it is collected.

2.4 Plastic Recycling

In Japan, material recycling and energy recovery are the dominant methods for recycling mulch film, supplemented by chemical recycling. The majority of the recycled mulch film pellets are exported, and the rest are made into pallets, artificial trees, architectural and civil engineering materials, and gardening materials. Energy recovery serves as a viable option for mulch film containing more impurities, such as using them as an alternative fuel in cement plants and paper mills, or incinerating them for power generation. Chemical recycling, although less common, is applied in rare cases where the film can be used as a reducing agent (a hydrogenous material) for blast furnace injection.

3 North America

In North America, characterized by being sparsely populated, the predominant method for solid waste disposal remains sanitary landfills. However, there has been a growing emphasis on recycling and an increasing recognition of recycling agricultural plastics.

3.1 Basic Data

United States The annual output of agricultural plastics is estimated to be 490 kt, encompassing various products such as agricultural film, containers (packaging included), and irrigation pipes. Among these, around 70 kt of mulch film is produced annually. Due to the adverse influence of mulch film residues on farming, used mulch film in the United States is almost fully collected. However, the majority of collected mulch film is disposed of in landfills or incineration power plants, with only a limited amount being recycled.

Canada In 2019, Canada generated 46 kt of non-packaging APW, accounting for 1% of the total plastic waste generated in the country. The waste mainly consists of silage film, netting, twine, and irrigation pipes, with mulch film only accounting for a very small proportion. At present, the recycling rate of non-packaging plastic waste in Canada is only 10%. Most of the non-packaging plastic waste is landfilled, with only a small amount incinerated for power generation.

3.2 Main Characteristics of Mulch Film

· Product Standards ·

The US has established the non-mandatory "Standard Specification for Polyethylene Sheeting for Construction, Industrial, and Agricultural Applications" (ASTM D4397-16) for mulch film. This standard specifies the mechanical characteristics, such as dart drop impact resistance, tensile strength, and elongation at break for PE film with a thickness of 0.025 mm and above.

· Common Specifications ·

The common thickness of mulch film on the US market varies according to the product type and production process. For LDPE/LLDPE mulch film, the common thickness ranges from 0.020 mm to 0.038 mm.

3.3 Policy Measures and Practices of EOL Management

The United States has no mandatory or incentive recycling policies for used agricultural plastics, and currently the market mechanism drives the practices. In certain states, such as Florida, where one-third of the country's mulch film is used, in-situ incineration is still allowed under certain conditions.

While there are voluntary recycling alliances working on agricultural high-density polyethylene (HDPE) packaging and plastic irrigation pipes in the United States, the collection and recycling of agricultural PE film are limited. Few recyclers are dedicated to collecting agricultural PE film, mainly in areas with large usage of mulch film.

Cleanfarms, a voluntary EPR alliance engaged in agricultural plastics in **Canada**, was initially devoted to the collection and recycling of plastic containers. Now the alliance has extended its scope of business to include packaging bags, twine, and silage film. Currently, Cleanfarms operates three province-wide regulated programs (i.e., mandatory EPR scheme). Used plastics were mainly exported prior to 2009, but the number of local recyclers has gradually increased, improving Canada's plastic recycling capacity.

3.4 Plastic Recycling

United States Low-value material recycling (conventional pelleting) is still the main method for recycling agricultural film in the United States.

Canada Canada's recycled plastic pellets from silage film is currently used to produce garbage bags, pipes, plastic wood, and more. Canada is experimenting with the production of agricultural film from used grain bags.

4 Recommendations

Drawing on international practices in agricultural plastics management, this report proposes the next step to the management of mulch film in China, in addition to the policy measures given by the state.

4.1 Management Measures

01 The obligation system of the production, use and recycling of mulch film should be scientifically defined for a tailor-made solution in China, together with the responsibilities of producers, collection, transportation and recycling companies, farmers, and the government.

02 A national EPR scheme is recommended to be established, where producers will bear the responsibility and cost of recycling, urging them to improve product quality and therefore providing the basic conditions for recycling. Implementation of such a scheme may lead to the emergence of producer responsibility organizations (PROs) or development of innovative business models to facilitate efficient recycling practices.

03 In addition to the regulatory obligation for farmers to collect used mulch film, it is crucial to explore innovative financial incentives. These could include incorporating the usage of high-strength or biodegradable mulch film and their proper recycling as criteria within the evaluation system for policy-supported guaranteed farm loans and agricultural insurance. Meanwhile, it is vital to consider the convenience for farmers in the collection process, such as ensuring a shorter distance to the collection points and improving farmers' recycling awareness through guidance and training.

04 To strengthen the collaboration among different government departments, it is suggested to establish a dedicated committee, working group, or association focused on promoting, monitoring, and supervising agricultural film recycling. This entity will serve as a central coordinating body, bringing together all relevant authorities and stakeholders along the entire value chain. The management measures devised by this special committee, working group or association can be implemented first in pilot areas and gradually extend to the whole country based on the results.

05 Learning from the idea of "digital product passport", electronic traceability management tools (e.g., product QR code) and a unified information platform based on the established recording system of mulch film use and recycling are highly proposed to strengthen the supervision and evaluation system.

4.2 Research and Innovation

01

Further research on the evaluation indicators of high-strength mulch film is required. More importantly, an improvement in the standard of mechanical characteristics is required. Consequently, the producers shall increase product thickness or use high-quality raw materials/innovative production processes to meet a higher standard. At the same time, the excellent performance of innovative high-strength mulch film should be considered, without adhering to the lower thickness limit of 0.020 mm commonly found in foreign standards.

Technology and equipment along the value chain are supposed to be further innovated, including the product design, various efficient collection machinery, on-site mobile pre-cleaning equipment, the efficient pre-treatment process, and high-value utilization methods, with the purpose of increasing the profitability of recycled materials, which is the key for a market-oriented recycling chain.

02

4.3 Exchange and Cooperation

The mulch film, as one of the most important potential sources of soil microplastics, requires considerable global attention. In terms of the evaluation of soil microplastics, it is vital to establish a unified standard and method worldwide.

01

02

Mulch film management should be one of the measures to cope with global plastic pollution, and experience gained from international exchange can help solve this common concern.

Chapter 1

Introduction

1 Background: Plastic Films in Agriculture

Since the initial adoption of mulch film in agriculture in the United States in 1948, they have gained widespread usage worldwide. However, the extensive use of plastics in agriculture has also given rise to environmental concerns, particularly regarding their recycling and proper management. According to the report published by Food and Agriculture Organization of the United Nations in 2021 (FAO, 2021), the global consumption of agricultural film in 2019 reached 6.1 million tonnes, making it the predominant type of agricultural plastic (with a total consumption of 12.5 million tonnes of plastic in agriculture). Most mulch film is used in Asia, exceeding 4 million tonnes, and most notably in China which alone accounts for 2.4 million tonnes, surpassing Europe and North America. Mulch film usage intensity is also highest in Asia, exceeding 45 kg/ha, followed closely by Europe with approximately 42 kg/ha. By contrast, North America exhibits a comparatively low usage intensity of less than 20 kg/ha.

According to their specific application, agricultural mulch is primarily categorized into greenhouse film, mulch film, and silage film, among others.

- Greenhouse film serves for crop protection without direct contact with soil.
- Mulch film is a plastic film that directly contacts the soil using the mulching technique.
- Silage film (including stretch film) is used as a protective cover for storing silage that feeds animals.

2 Scope of this report

In China, used greenhouse film is frequently entirely collected and recycled due to their durability, low contamination level and high economic value. Silage film is not widely used in China. Mulch film, by contrast, is the major source of agricultural “white pollution” in Chinese agriculture and is thus an urgent issue calling for attention.

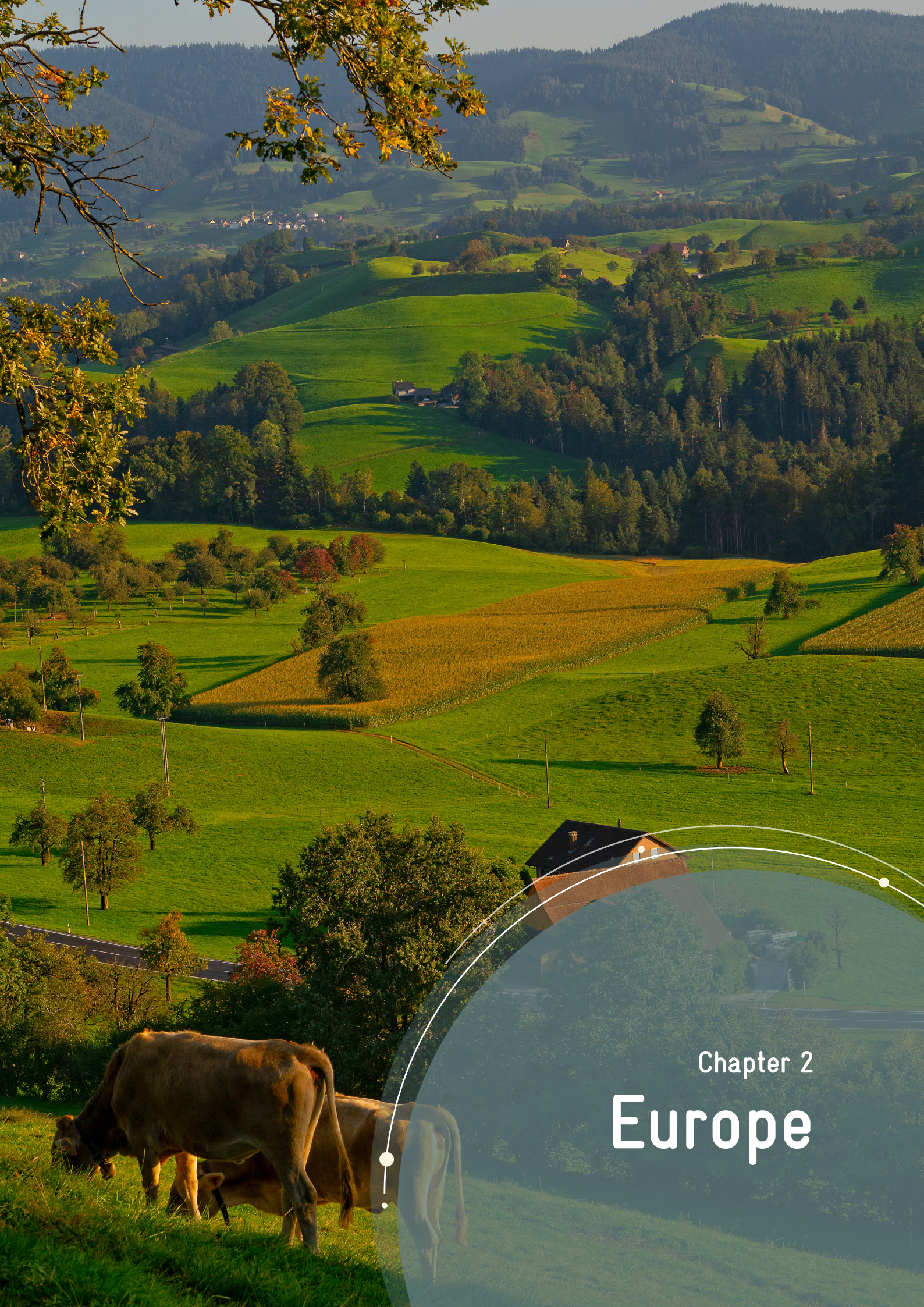
This report aims at providing practitioners in China with policy recommendations from Europe, Japan and North America. The focus of this report is mulch film. It will contribute to the prevention and control of plastic pollution, emission reduction, carbon sequestration, and the promotion of green transformation in rural areas of China, serving as a valuable resource for policymakers, researchers, and industry professionals in the agricultural sector. Ultimately, the goal is to develop effective strategies for agricultural plastics recycling and management, fostering sustainable practices in China’s agricultural industry.

This report provides information on the following:

- Insights into Mulch Film Consumption, EOL Management, and Recycling Practices in Europe (Chapter 2), in Asia-Japan (Chapter 3), in North America-America and Canada (Chapter 4)
- Recommendations: Management Measures, Research and Innovation, Exchange and Cooperation (Chapter 5)

This study also aims to provide guidance on improvements that will assist in the achievement of the United Nations’ 2030 Sustainable Development Goals (SDGs), and in particular:

- SDG1-No poverty
- SDG2-Zero Hunger
- SDG3-Good Health and Well-being
- SDG4-Quality Education
- SDG6-Clean Water and Sanitation
- SDG8-Decent Work and Economic Growth
- SDG9-Industry, Innovation, and Infrastructure
- SDG10-Reduced Inequality
- SDG11-Sustainable Cities and Communities
- SDG12-Responsible Consumption and Production
- SDG13-Climate Action
- SDG14-Life Below Water
- SDG15-Life on Land
- SDG17-Partnerships to Achieve the Goal



Chapter 2

Europe

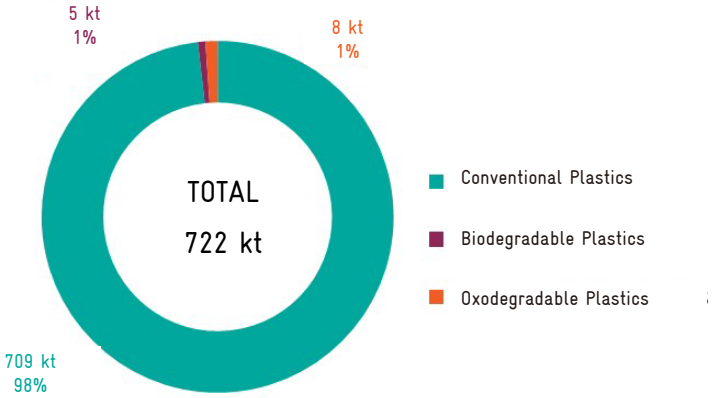
1 Basic Information

1.1 Consumption of Agricultural Plastics

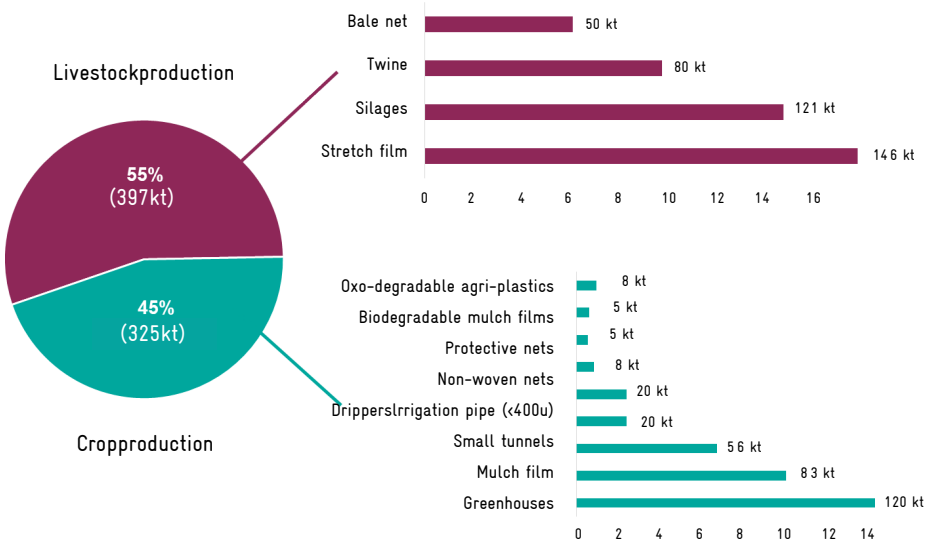
Estimated by Plastics Europe, 3.4% of the plastics consumed in Europe were agricultural plastics (1,700 kt). Around 722 kt of non-packaging agri-plastic products were placed on the European market in 2019, accounting for 1.4% of the total sales of plastic products, as is estimated by APE Europe.

Figure 1 Consumption of non-packaging agricultural plastics by market segment in the EU in 2019

(1) Classified by material



(2) Classified by purpose



Source: APE Europe, EU

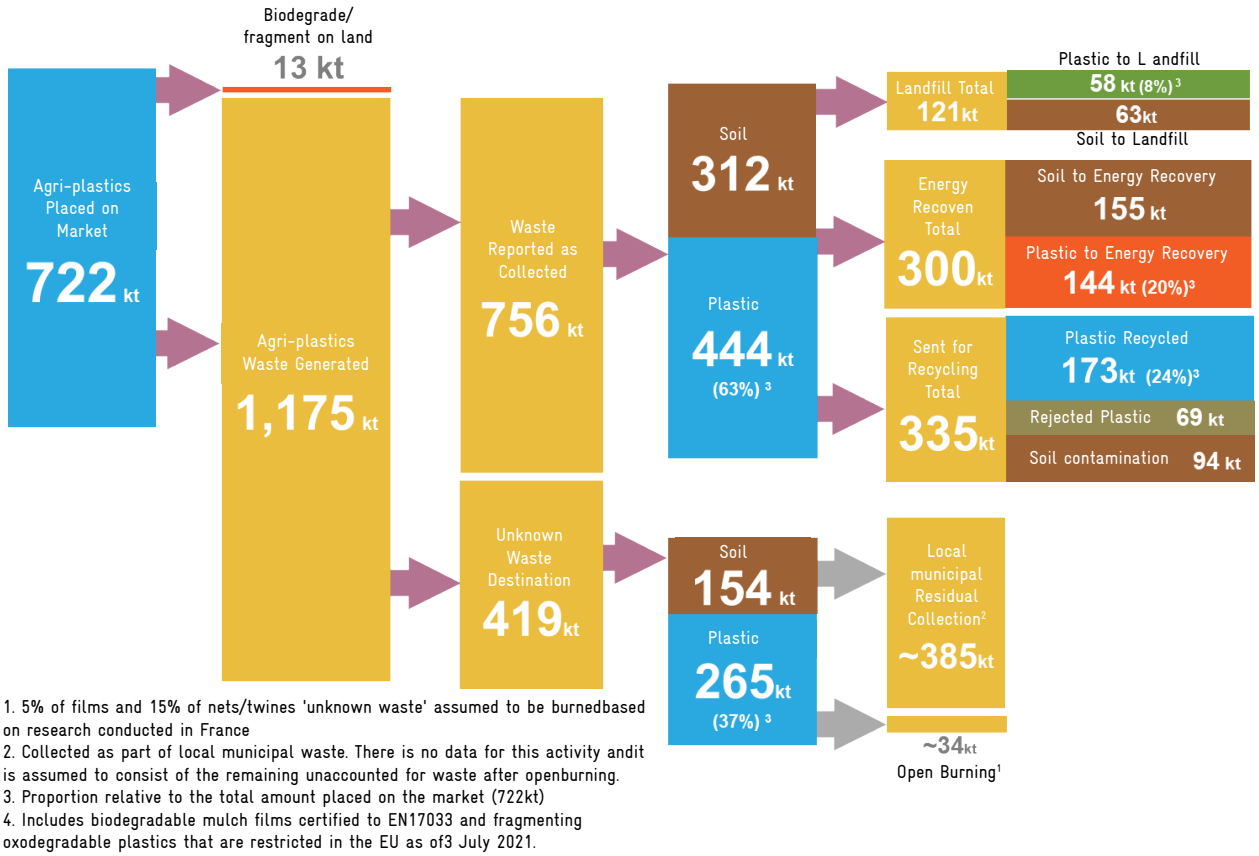
Among all the non-packaging agricultural plastics, 709 kt were conventional plastics, 5 kt were biodegradable plastics (used only in mulch film), and 8 kt were oxo-degradable plastics. It is important to note that the Single-Use Plastics Directive has banned the sale of products made from oxo-degradable plastics on the European market since July 3, 2021. When considering the distribution of non-packaging agricultural plastics, 55% of these materials were applied in the livestock sector, while the remaining 45% were utilized in crop production.

Agricultural film had the largest share (75%) of non-packaging agricultural plastics consumed in Europe, followed by twine (11%), netting (9%), and irrigation pipes and drippers (6%). Agricultural film includes silage film (267 kt of silage and stretch film), greenhouse film (176 kt of film covering greenhouses and small tunnels), and mulch film (83 kt of plastic mulch film and 5 kt of biodegradable mulch film).

1.2 Collection and Recycling of Agricultural Plastics

According to the EU report, findings reveal that in 2019, a total volume of 1,175 kt of waste generated from the 722 kt of non-packaging agri-plastic products was placed on the market (Hann et al., 2021). Among these, 756 kt were collected, consisting of 312 kt of impurities (such as soil, water, and straw, etc.) and 444 kt of products. This data indicates a contamination rate of 41% and a net collection rate of 63%. Out of the total waste collected, a notable proportion of 173 kt was recycled, with a recycling rate of 24%. However, the recycling rate is 39% if calculated on the weight of only products collected. The detailed information is illustrated in Figure 2 below.

Figure 2 Mass flow of non-packaging APW in the EU in 2019



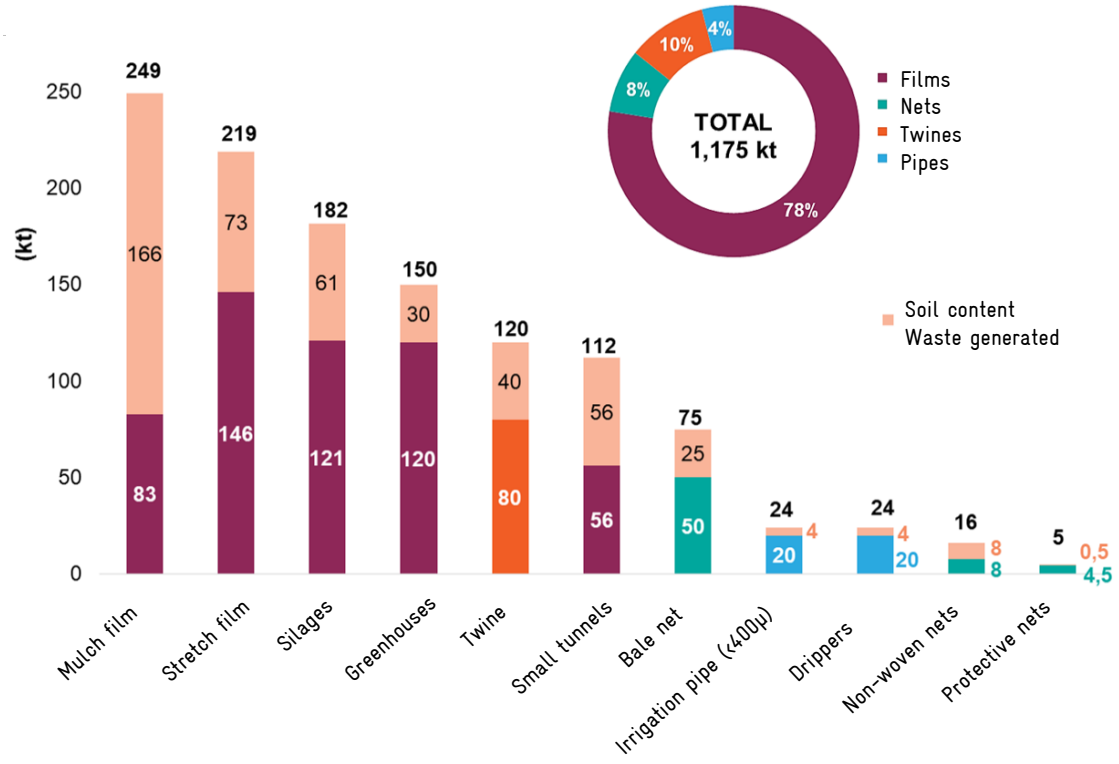
1. 5% of films and 15% of nets/twines 'unknown waste' assumed to be burnedbased on research conducted in France
2. Collected as part of local municipal waste. There is no data for this activity andit is assumed to consist of the remaining unaccounted for waste after openburning.
3. Proportion relative to the total amount placed on the market (722kt)
4. Includes biodegradable mulch films certified to EN17033 and fragmenting oxodegradable plastics that are restricted in the EU as of3 July 2021.

Source: APE Europe, EU
Note: contamination rate = (weight of used film containing impurities - weight of new film put into use) / weight of used film containing impurities

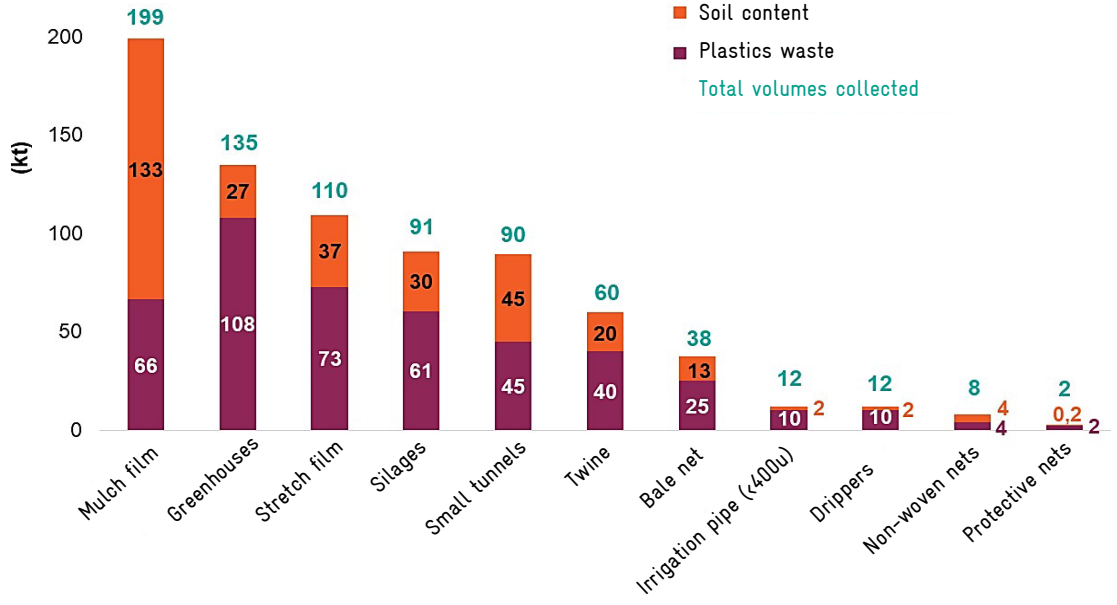
The figure below illustrates the breakdown of non-packaging APW in terms of generation (1,175 kt) and collection (756 kt) by type. Specifically, in 2019, the consumption of mulch film on the EU market was 83 kt, from which 249 kt of waste was generated. Out of this waste, 199 kt was reported to have been collected, among which 66 kt was the products (i.e., a net collection rate of 80%) and 133 kt was impurities (i.e., a contamination rate of 67%).

Figure 3 Quantity of different types of APW generated and collected in the EU in 2019

(1) Quantity of APW generated



(2) Quantity of APW collected



Source: APE Europe, EU

According to the PRE, greenhouse film and silage film are the main types of agricultural film collected in Europe, with a recycling rate ranging from 30% to 70% and an average value of 56%. However, it is worth noting that the recycling of mulch film is relatively limited due to factors like their thinness, high contamination rate, complicated pre-treatment process, and high cost of recycling. Therefore, energy recovery (i.e., incineration) is commonly applied for disposal. Additionally, a small portion of the collected mulch film is sent to landfills, and there have been reports of illegal open burning or dumping by farmers. To address this issue, France, Spain and Germany are taking measures to increase the recycling rate of mulch film. Further details on these measures are elaborated below.

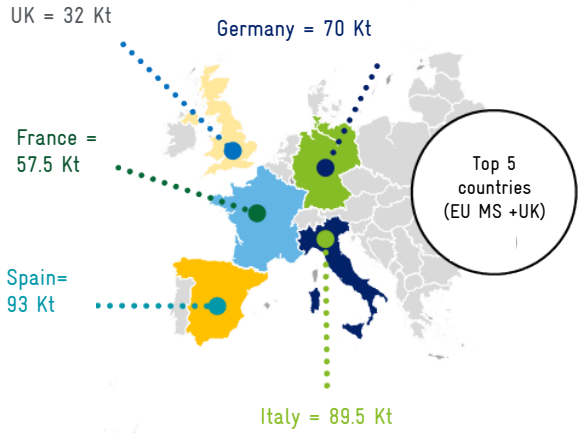
1.3 An Overview of the Application of Agricultural Film in Different Countries

Various types of agricultural film are distributed in Northern and Southern Europe. Southern Europe relies mainly on crop production, so greenhouse film and mulch film are chiefly used. While agriculture in Northern Europe is dominated by animal husbandry, so, silage film is more widely adopted.

According to the APE Europe, in 2018, the top five countries in terms of agricultural film sales were Spain, Italy, Germany, France, and the United Kingdom. These countries collectively occupied 64% of the total market share, but no sales information on mulch film is available. The detailed data of the five countries are illustrated below.

Based on other information found in the EU report (see its Appendix A2.2), the consumption of agricultural plastics, APW generation and end-of-life management in major European countries are summarized in the table below (Hann et al., 2021). It is observed that mulch film is mostly adopted in Spain, Italy, France, and Germany. In Europe, mulch film is mainly used for producing tomatoes, lettuce, zucchini, onions, eggplants, beans, strawberries, watermelons, melons, asparagus and potatoes, etc.

Figure 4 Top five European countries for agricultural film sales in 2018



Source: APE Europe, EU

Table 1 Consumption and end-of-life management of agricultural plastics in major European countries

Country	Annual consumption (kt)	Main types	Annual amount of waste generated (kt)	Main sources of waste	End-of-life management
Spain	182.0* (2017)	Agricultural film (53%): 63% for crop production, mainly greenhouse film; 37% for livestock production, mainly silage film	15.89**	Irrigation pipes (48%); greenhouse film (23%); silage film (11%); mulch film (10%)	Recycling: 57%; landfill; incineration
Italy	176.9* (2018)	Agricultural film (87%): greenhouse film (56%); mulch film (24%, 43 kt); silage film (5%)	–	Agricultural film	Recycling: 56% (nearly half of the waste recycled is agricultural film, consisting of 90% of greenhouse film and 10% of mulch film); landfill; incineration
France	83.4* (2019)	Agricultural film (66%)	9.87*	Agricultural film (71%)	65.7 kt collected by A.D.I.VALOR (67%): 76% recycled (a recycling rate of 99% for agricultural film), 22% landfilled, and 2% incinerated; municipal waste treatment centres (25%); private companies (5%); open burning
Germany	67.8* (2019)	Silage film (63%); mulch film (18%, 12 kt)	8.3*	Silage film	ERDE: recycling; incineration
Finland	14.3* (2019)	Mulch film (49%, 7 kt); silage film (49%)	1.2**	Silage film; mulch film; packaging	Incineration: 90%–95%; open burning/dumping: 3%; recycling: 2%
The UK	50*	Silage film (major type); mulch film (8%, 4 kt)	1.5*	Silage film (major source); mulch film (16 kt)	Overall collection rate: 30%
Ireland	41*	Silage film (major type); mulch film (a very few, 0.4 kt)	3.7*	Silage film; netting; twine	Recycling rate: 90%
Sweden	18.8*	Silage film (72%); netting (8%); twine (3%)	1.75*	Silage film	Collection rate: 93%; recycling rate: 90%
Norway	13.6**	Silage film; packaging	1.22**	Silage film	Collection rate > 90%; recycling rate: 86%
Iceland	1.8*	Silage film; packaging	0.16*	Silage film	Collection rate: 90%

*Note: * packaging excluded; ** packaging included; – no data.*
Source: EU

2 Research Results on Mulch Film Pollution

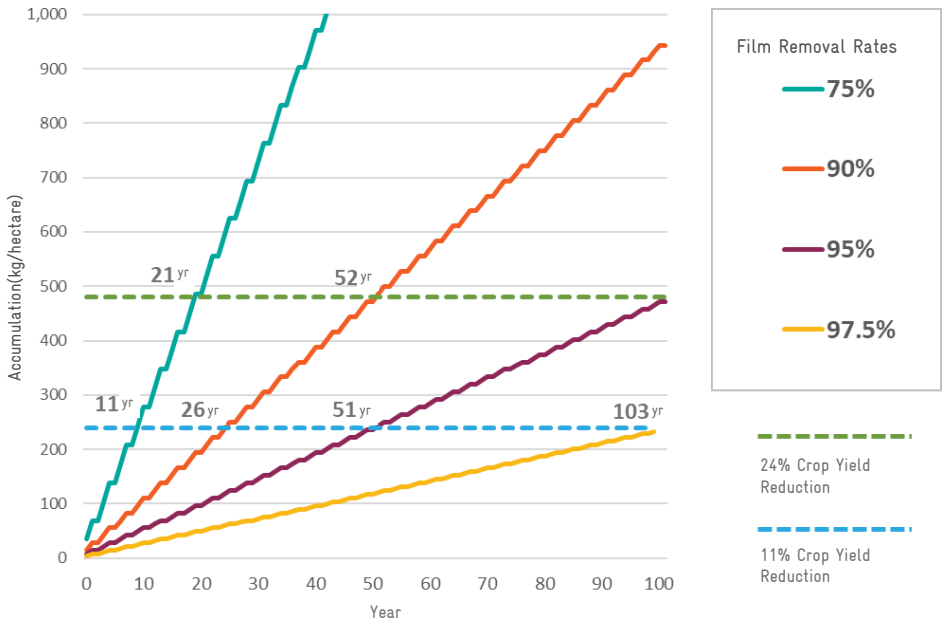
2.1 Relationship between Film Thickness and the Residual Rate

Generally, the thicker mulch film is easier to collect from the soil, which leads to a higher removal rate and a lower residual rate. Regarding the quantitative relationship between film thickness and the residual rate, it is estimated by the APE Europe that the residual rates of mulch film with a thickness of 0.010 mm, 0.020 mm, and 0.025 mm (these mulch films only differ in thickness with no special structural design) are 68%, 25%, and 10% (by mass), respectively. The OWS, an independent testing agency in Belgium, also presented similar results.

2.2 Linear Relationship between the Film Removal Rate and Crop Yield Reduction

No reliable data has been provided by the percentage of mulch film that remains in the soil after collection in Europe, according to the EU report (Hann et al., 2021). A model calculation is conducted on the accumulation of mulch film in the soil of annual mulching with a fallow period every three years, and the modeled calculations are shown in the figure below.

Figure 5 Linear relationship between the film removal rate and crop yield reduction



Source: EU

When the film removal rate is 75% (i.e., a residual rate of 25%), the threshold of 11% reduction in crop yield, where the accumulation of mulch film is 240 kg/ha, is reached in the 11th year of mulching. When the film removal rate is 90%, 95% and 97.5%, the number of years required to reach the threshold doubles. Figure 5 shows that when the film removal rate exceeds 90%, every percentage point increase in the removal rate will have a significant impact on the pollution level.

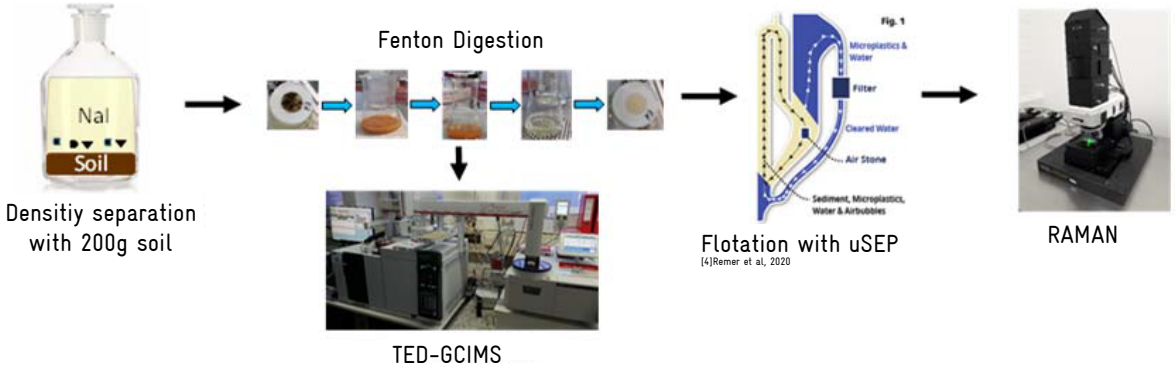
At present, the annual consumption of mulch film stands at 83 kt. When the average film removal rate is 75%–95% (i.e., a residual rate of 5%–25%, which is based on facts according to European experts), each year there will be 4.75–20.75 kt of film residues in the soil; this figure can be reduced to 0.83 kt with a recycling rate of 99%. Considering that the Single-Use Plastics Directive is estimated to reduce marine plastic waste by 2.75 kt–12 kt per year, increasing the film removal rate is more effective than banning the use of single-use plastics in reducing plastic pollution, and thus further attention should be paid to mulch film residues.

2.3 Microplastics

Mulch film that is not removed from the soil in time can fragment over time, forming plastic residues of various sizes. Fragments smaller than 5 mm in length are called microplastics. Microplastics are of great concern to the EU. The iMulch project has conducted research on mulch film and microplastics in the soil, and the main results are as follows (IMulch, n.d.):

- **developed a detection method for microplastics in the soil:** collected soil samples diagonally with Pürkhauer, and used thermal extraction desorption-gas chromatography/mass spectrometry (TED-GC/MS) and Raman spectroscopy for analysis after sample preparation;

Figure 6 Schematic diagram of the detection of microplastics content in the soil



Source: iMulch project summary poster

- **concentration of microplastics in mulched soil:** no increase was detected in the microplastics content in the soil after the use of conventional mulch film for three months; the concentration of microplastics in the soil was not significantly related to crop types (strawberries and asparagus);

Figure 7 Microplastic content in the soil before and after mulching in different fields

Tab. 1: TED-GC/MS results of different field sample.

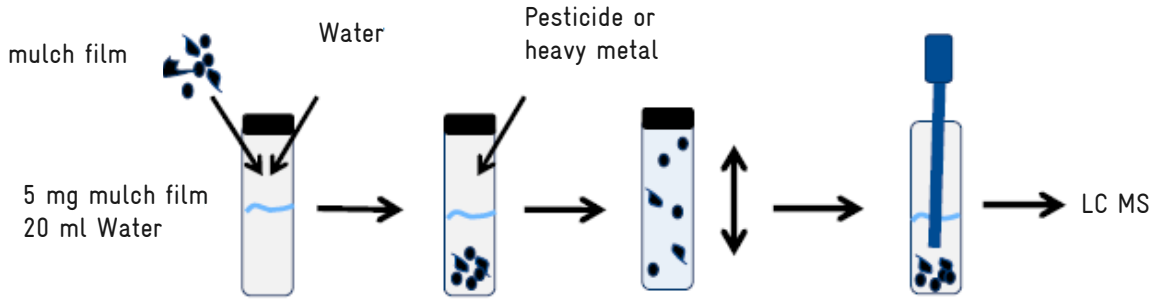
Results	µg PE /g Soil	µg PS /g Soil	µg PLA / PBAT / g Soil
Field with Biodegradable film_A	0.2	LOQ	0.1
Field with Biodegradable film_A2	4.4	LOQ	0.3
Field with Biodegradable film_B	5.2	LOQ	0.5
Field without film_A	0.8	LOQ	0.1
Field without film_A2	1.4	0.9	0.3
Field without film_B	LOQ	LOQ	0.5
Field with mulchfilm / strawbeeries_A	LOQ	LOQ	0.1
Field with mulchfilm / strawbeeries_B	0.5	LOQ	2.2
Field close to motorway service station_A	LOQ	LOQ	0.1
Field with Asparagus film_A	LOQ	LOQ	0.2
Field with Asparagus film_B	0.8	LOQ	0.4
Reference soil RefesolA01	8.2	LOQ	0.4
A = sampling March 2021, B = Sampling June 2021, A2 = sampling shiped with plastic bag			

LOQ PE: 8.4 µg absolute, LOQ PS: 0.3 µg absolute.
Source: iMulch Project

- **aging of mulch film:** Aging of mulch film fragments was observed after 8 weeks in a laboratory simulation of a sewage treatment facility, that is, the density of water drained from the equipment increased, causing Fourier transform infrared spectroscopy (FTIR) changes with the highest record of 70%;

- **adsorption of substances on mulch film:** there was no obvious adsorption of the heavy metal (copper) and pesticides (tebuconazole and thiacloprid) on PE mulch film fragments of 0.030 mm (the test result is consistent with that of the comparison test involving glass beads and glass bottles);

Figure 8 Schematic diagram of the adsorption test for mulch film



Source: iMulch Project

- **ecotoxicological effects of mulch film fragments:** no ecotoxicological effects of mulch film fragments on fleas and earthworms were observed; however, the mulch film eluate had an endocrine disrupting effect on soil organisms, and aging mulch film had smaller effects.

2.4 Loss of SOC

Used agricultural plastics are mixed with a large amount of soil when being collected. The EU report focuses on the issue of organic carbon loss in relation to this. Soil organic carbon represents the largest active carbon reservoir in terrestrial systems, and its content reflects the carbon sequestration capacity of the topsoil. Even minor changes can have an impact on greenhouse gas concentrations in the atmosphere. Additionally, soil organic carbon is a crucial component of soil organic matter, directly influencing soil structure stability, fertility, and water-holding capacity. According to the data presented in Figure 2, at least 312 kt of soil is estimated to be lost each year in the EU when agricultural plastics are collected, with 43% (133 kt) coming from mulch film collection. The organic carbon content of most European soils ranges between 2% and 6%, although the average SOC content of Southern Europe (most parts of Spain and Italy) is less than 2% with the rapid mineralization of SOC as a result of high summer temperature. It means that 6 kt to 19 kt of SOC is removed from EU soil every year when collecting agricultural plastics.

3 Full Life Cycle Management Practices for Agricultural Plastics

3.1 Policies and Regulations

3.1.1 At EU Level

Due to the relatively small contribution of agricultural plastics consumption to the overall plastic consumption in the EU, the management of APW is not currently directly addressed by specific legislation at EU level but acknowledged in the following policies.

Table 2 EU policies and regulations on APW management

Policy	Content
Waste Framework Directive (WFD)	The overall goal is to reduce the environmental impact of waste and increase resource efficiency through reuse, recycling, and recovery. It offers the general guiding principles for solid waste management at EU level, such as the waste hierarchy, the Polluter-Pays Principle (PPP), and EPR.
EU Plastics Strategy	The overall goal is for all plastic packaging placed on the EU market to be recyclable or reusable in a cost-effective manner by 2030, with a concurrent focus on reducing plastic waste at its source. As for agricultural plastics, the objective of the EU is to increase the market share held by products made from recycled materials; play a leading role in developing sorting and recycling technologies to meet the global demand for more sustainable ways of processing plastic waste; and encourage the industry to make voluntary commitments. Meanwhile, efforts are being directed towards formulating measures that increase rates of plastic recycling and reuse, including the implementation of EPR across the EU.
Single-Use Plastics Directive	The EU countries are prohibited from putting oxo-degradable plastic products on the market.
Incineration Directive (Directive 2000/76/EC)	Uncontrolled incineration of waste, including bio-waste, is prohibited.
Landfill Directive (Directive 99/31/EC)	Uncontrolled landfill of waste is prohibited.

3.1.2 At National Level

Most European countries have enacted relatively complete legislation regarding waste management, including regulations prohibiting open burning/in-situ landfill, which is applicable to APW management. Countries with a large consumption of agricultural film pay more attention to the management of used agricultural film. They have formulated regulations on the recycling options, including energy recovery, for agricultural plastics. Additionally, these countries have mandated that producers and distributors are obliged to collect and dispose of the waste generated, as outlined in their EPR schemes.

Table 3 Policies and regulations on APW management in major European countries

Country	Policies and regulations	Current situation
Spain	In Andalusia, EPR regulations on APW were adopted in 2012, but the scheme failed in March 2018 due to insufficient funding from Cicloagro.	A voluntary EPR alliance was formed in 2020, aiming to collect greenhouse film and mulch film in Andalusia and eventually all non-packaging APW at national level.
Italy	Mandatory EPR: Legislative Decree 152/2006 stipulates that the producers, importers, users, distributors and recyclers of PE products shall participate in either POLIECO or an independent organization (e.g., a private company).	Greenhouse film and mulch film are both covered by POLIECO, but not all farmers choose to join the program.
France	Encouraging plastic recycling.	A.D.I.VALOR, a French voluntary EPR alliance with nationwide coverage, set the goal of achieving collection and recycling rates of 100% in 2023 together with the French CPA.
Greece	The NWMP contains specific provisions for agricultural waste management and a mandatory EPR scheme is being developed.	A pilot program for the collection of agrochemical plastic packaging waste and greenhouse film is underway.

Country	Policies and regulations	Current situation
Poland	There is no ban on the landfill of plastic waste. In 2019, the NFEP&WM launched the Removal of Agricultural Foils and Other Agricultural Waste program to facilitate the collection of APW.	Local collection schemes for APW (e.g., used mulch film and greenhouse film) are available in some areas, but there is no regional/national collection scheme.
Germany	In February 2022, the German Bundesrat passed a regulation, urging the German government to promote the mechanical recycling of mulch film (ERDE-Recycling, 2022).	Most of the producers in Germany have joined the voluntary EPR alliance ERDE. The target collection rate for silage film for 2022 is 65%, and mulch film is included in the system.
Finland	The Plastics Roadmap for Finland was launched in 2018 to optimize collection services and encourage innovation, in a bid to improve the plastic recycling rate.	Material recycling of sorted silage film, supplemented by chemical recycling, has been sanctioned since 2020.
The UK	Mandatory EPR for agricultural plastics was considered in 2005 but was rejected by stakeholders. The Plastic Packaging Tax, which came into effect in April 2022, does not include silage film.	The APE UK, a voluntary EPR alliance, and the UKFPRS, an alliance for farm plastic collectors, were formed in 2019 and officially formed in 2021, and their effectiveness is unknown.
Ireland	Mandatory EPR: the Farm Plastics Regulations place an obligation on producers to support the recycling of agricultural plastic film, either by offering a deposit-refund scheme or by participating in the IFFPG.	Almost all stakeholders such as producers and farmers have joined the IFFPG scheme.
Sweden	Encouraging plastic recycling.	Almost all stakeholders such as producers and farmers have joined the voluntary EPR alliance SvepRetur.
Norway	Encouraging plastic recycling.	The voluntary EPR alliance GPN is engaged in agricultural packaging and silage film management. Almost all stakeholders such as producers and farmers have joined the GPN.
Iceland	Mandatory EPR for silage film, run by the state fund IRF.	Almost all stakeholders such as producers and farmers have joined the scheme.

3.2 Product Design: Product Standards and Innovation

3.2.1 European Standards for Mulch Film

The European Standard for "Plastics - Thermoplastic mulch film recoverable after use, for use in agriculture and horticulture" (EN 13655: 2018) is not mandatory. It was developed by the CEN and has been adopted as a national standard by 33 CEN members.

EN 13655 differs from China's national standard (GB13735-2017) in the following notable aspects:

- more granular classification: the classification by purpose in addition to the classification by mulching time, with different specifications;
- higher standards for some indicators: minimum thickness (≥ 0.020 mm), mechanical characteristics (e.g., tensile strength ≥ 20 MPa and nominal tensile strain at break (TD) ≥ 350%), and weather resistance (longer life span of A, B, C and D);
- additional requirements: tensile stress, impact resistance, optical performance, conditions of use, recycling guidance, etc. (EN 13655 not only specifies product standards, sales and after-sales requirements—recycling responsibility, but also provides guidance for consumers.)

Table 4 Comparison of Chinese and European standards for mulch film

Country/Region	China	Europe
Classification	Classified into two groups by mulching time: Class I and Class II	Classified into four groups by purpose: transparent film, black film, reflective film, and colored film for weed control; classified into five groups by mulching time: N, A, B, C and D
Thickness	Class I anti-aging mulch film: 0.010 mm–0.025 mm; Class II regular mulch film: 0.010 mm–0.030 mm; thickened high-strength mulch film: ≥ 0.015 mm	Transparent film: 0.020 mm–0.035 mm; black film: 0.020 mm–0.100 mm; reflective film: 0.025 mm–0.060 mm; colored film for weed control: 0.025 mm
Mulching time/Weather resistance	Class I anti-aging mulch film: ≥ 180 days (The nominal tensile strain at break (MD) should be no less than 50% of the original value after the mulch film ages.) Class II regular mulch film: ≥ 60 days	N: ≥ 65 days A: ≥ 330 days B: ≥ 585 days C: ≥ 975 days D: ≥ 1,340 days (The life span before aging is converted to its equivalent in China. The definition of aging is the same as that in China.)
Nominal tensile strain at break	0.010 mm–0.015 mm: ≥ 260% 0.015 mm–0.020 mm: ≥ 300% 0.020 mm–0.030 mm: ≥ 320%	MD ≥ 250% TD ≥ 350%
Tensile strength	0.010 mm–0.015 mm: ≥ 1.6 N 0.015 mm–0.020 mm: ≥ 2.2 N 0.020 mm–0.030 mm: ≥ 3.0 N (10 MPa–16 MPa)	≥20 MPa

In addition, EN 13655 notes that used mulch film is always mixed with soil and plants, resulting in a contamination rate of 70% to 90%. Film thickness is a key factor affecting the contamination rate. The film with a thickness of less than 0.025 mm is the most contaminated, which means a challenging cleaning, collection and recycling process and high costs.

3.2.2 Product Innovation Featuring Ultra-Thinness and High Mechanical Strength

While maintaining ultra-thinness (less than 0.015 mm), special product design and raw materials are employed to greatly enhance the mechanical strength of mulch film. For example, Reifenhäuser applies the technique of multi-layer film extrusion in structure design, so that the mechanical strength of mulch film with a thickness of 0.012 mm is well above the national standard, even above the standard for mulch film with a thickness of 0.030 mm. It also shows that thickness is not the only determinant of mechanical strength, and thus not the only factor affecting collection. It is advisable to strike a balance between thickness, mechanical strength and the collection rate by improving the technical level, in a bid to reduce adverse environmental effects while ensuring economy. The table below provides a clear illustration of the superior mechanical performance of the thin mulch film compared to the standards:

Table 5 Indicators of Reifenhäuser mulch film and Chinese Standards

Indicator	Chinese standards	Reifenhäuser mulch film	
		Black film	Transparent film
Thickness	≥ 0.010 mm	0.012 mm	0.012 mm
Nominal tensile strain at break (MD/TD)	0.010 mm–0.015 mm: ≥ 260% 0.015 mm–0.020 mm: ≥ 300% 0.020 mm–0.030 mm: ≥ 320%	MD 339% TD 882%	MD 359% TD 846%
Tensile strength (MD/TD)	0.010 mm–0.015 mm: ≥ 1.6 N 0.015 mm–0.020 mm: ≥ 2.2 N 0.020 mm–0.030 mm: ≥ 3.0 N	MD 4.1 N TD 4.3 N	MD 4.5 N TD 4.1 N
Right-angle tearing load (MD/TD)	0.010 mm–0.015 mm: ≥ 0.8 N 0.015 mm–0.020 mm: ≥ 1.2 N 0.020 mm–0.030 mm: ≥ 1.5 N	MD 1.6 N TD 1.6 N	MD 1.4 N TD 1.6 N

Source: Reifenhäuser

The addition of UV stabilizers in raw materials is also one of the major ways to enhance mechanical strength. Briassoulis et al. (2013) selected relatively thin agricultural film products on the European market, including mulch film with a thickness of 0.010 mm to 0.014 mm (the common thickness on the European market is 0.010 mm to 0.025 mm) and asparagus film with a thickness of 0.030 mm to 0.050 mm (the common thickness on the European market is 0.040 mm to 0.060 mm), and tested the changes in their mechanical characteristics such as tensile strength during the life cycle. The test results show that after five months of field use in Greece, the mechanical strength of most products reached 87% of the original value, and these films could be fully collected; however, the mechanical strength of an Italian mulch film dropped to 15% of the original value after use, affecting subsequent collection. The EU report highlights that practical experience has revealed a concerning issue in areas with intense UV exposure, such as Italy and Spain, that some mulch film may fragment when being collected due to the lack of UV stabilizers, which will adversely affect recycling.

3.2.3 Use of Recycled Materials in Mulch Film

According to the APE Europe, mulch film can use high-quality recycled PE plastics from industrial and commercial sectors as one of their raw materials, but recycled pellets from agricultural film are rarely used. In 2018, 43 kt of recycled plastics were used to produce mulch film, equivalent to 52% of the quantity of virgin plastics required for the same purpose, and 6 kt were used to produce greenhouse films.

Grupo Armando Alvarez, a traditional agricultural film processor in Spain, uses 10%–50% recycled plastics in mulch film production. The thicker the mulch film, the higher the content of recycled plastics. CEDO, Europe's largest recycler of plastic film, pointed out that a maximum of 70% recycled materials can be used in mulch film production (Mulch film is not required to be of high quality and is only used for one growing season).

3.3 Sales and Utilization: Product Labeling and User Guide

3.3.1 Product Traceability Management

3.3.1.1 LableAgriWaste Project

Digital traceability management can be an effective tool for enhancing the transparency and supervision of agricultural plastic products. Its acceptability and effectiveness still require pilot tests. A research project LabelAgriWaste sponsored by the EU (Dangis,

2006; EU, n.d.) was conducted to develop and test an economically viable APW labeling scheme from 2006 to 2009 by 18 partners from EU countries, including the AUA, EuPC, PRE, agricultural associations, universities, and research institutions.

There is no open access to the actual application of the project, but the operation mode and logic basis involved will provide a basis for policy making in the future.

3.3.1.2 Digital Product Passport

On March 30, 2022, the EU unveiled a new Eco-design for Sustainable Products Regulation which builds on the existing Eco-design Directive, aiming to improve the energy performance, circularity and other environmental sustainability aspects of EU products. The new regulation covers almost all categories of products on the EU market, requiring extension of the product life cycle, reduction of carbon and environmental footprints, promotion of material recycling, and disclosure of product information, including the use of a Digital Product Passport. The Digital Product Passport will provide information about products' environmental sustainability and enable consumers to make informed choices when purchasing products. It will facilitate product recycling and improve product transparency during its life cycle and is also conducive to product supervision. The working plans are being enriched, which will extend to agricultural plastics.

3.3.2 Guide on the Selection and Utilization of Mulch Film

Great importance is attached to user training in Europe, as the pollution caused by mulch film can be effectively reduced by properly cutting the use of mulch film, choosing alternatives, and using correct mulching methods to avoid tearing the mulch film when removing it. For example, the UCAN in Northern Italy has issued a guide on the selection and utilization of mulch film, offering advice on each type of crop and conducting training on a regular basis. The Organic Farm Knowledge platform, funded by the EU and set up by the ICROFS, provides all kinds of information about organic farming and training on mulch film such as proper mulching methods (Organic Farm knowledge, n.d.).

3.4 Collection: EPR and Efficient Collection Methods

3.4.1 Farmers Lacking Motivation for Voluntarily Collecting APW in the Free Market

In a free market, collectors will collect waste with a high recycling value at a more preferential price than usual, and they may even buy the waste, motivating farmers to collect the waste. It explains why greenhouse film in some areas is very popular.

In fact, many types of agricultural plastics are unattractive to recyclers and collectors can hardly benefit from them. With no other economical options, farmers tend to mix them directly with household waste, or even secretly incinerate them on the spot to avoid paying high waste disposal fees.

Some collectors, such as the BFP, have to suspend agricultural plastics collection due to losses. The BFP is the only collector of APW in Wales, UK. In 2019, as China and Southeast Asian nations imposed an all-out ban on the import of used plastics, a massive amount of plastic waste accumulated in Europe. Recyclers of agricultural plastics have turned to used plastics of higher quality from commercial and industrial sectors for more profit. Recyclers no longer pay the collectors for the transportation of APW as they used to; instead, they charge a waste disposal fee. The BFP has to increase the collection fees for agricultural plastics to recover its costs, and as a result, farmers no longer contract with the BFP.

3.4.2 National EPR/Collection Schemes Promoting Recycling of Agricultural Plastics

EPR extends the responsibility of producers for their products beyond production and sales to the entire life cycle, including collection, recycling and end-of-life management. The EU report explores different approaches to EPR, including:

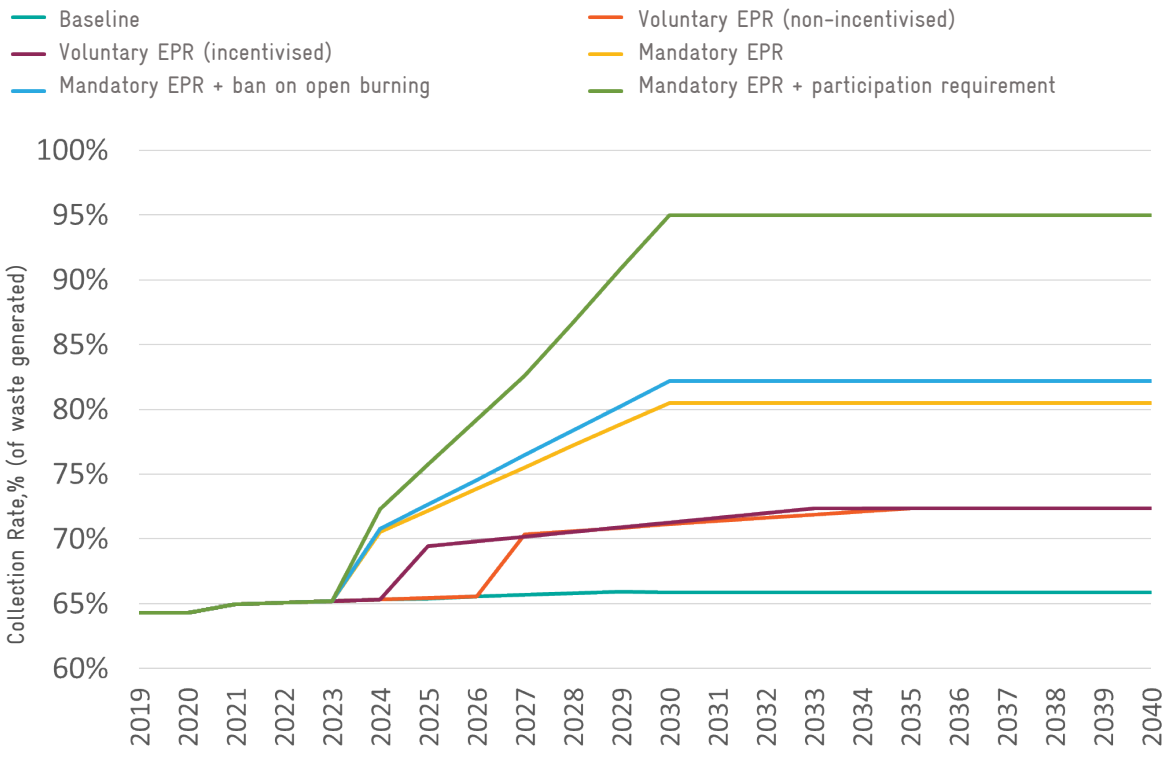
- mandatory EPR: Legislative enforcement;
- incentivized voluntary EPR: providing funding (e.g., subsidies and rewards) for producers and distributors who voluntarily set up alliances;
- non-incentivized voluntary EPR: encouraging producers and distributors to voluntarily set up alliances without material incentives;

and supporting policies targeting farmers:

- prohibition of open burning;
- mandatory participation in collection schemes for farmers.

The impact of the above EPR policies (including a combination of EPR policies and supporting policies) on the collection and recycling rates of agricultural plastics is modeled. The results (as shown in the figure below) show that the EPR scheme can effectively increase the collection and recycling rates of agricultural plastics, with the combination of mandatory EPR and the participation requirement being the most effective approach. It is worth noting that incentivized voluntary EPR and non-incentivized voluntary EPR will not have a significant impact on the final collection rate, which will reach approximately 72% in both scenarios. The advantage of incentivized voluntary EPR lies in the fact that a significant improvement in the collection rate can be achieved earlier in this way.

Figure 9 Modeling of the collection rate of agricultural plastics under different policy scenarios in the EU (similar results for the recycling rate)



Source: Eunomia

In fact, some European countries have applied EPR to agricultural plastics, mainly through the implementation of national collection/recycling schemes. Normally, the producer pays an environmental fee for the products it places on the market, which is run by an intermediary agency. The agency provides waste collection services to all farmers in the area and is responsible for subsequent recycling and disposal. In countries with complete national collection schemes (see the table below), the average collection rate of APW reaches up to 75%, higher than the average collection rate of 63% in the EU.

Table 6 Existing collection schemes for APW in Europe

Country	Scheme	Start date	Type	APW streams collected	Collection rate*	Recycling rate**
France	A.D.I.VALOR	2001	Voluntary	All agricultural film, twine, netting, irrigation pipes and packaging	70% (2020)	76% (2019)
Italy	POLIECO	2019	Mandatory	Greenhouse film and mulch film (PE)	-	56% (packaging included)
	COREPLA/ CONAI	2016	Voluntary → Mandatory	Packaging	-	
Spain***	MAPLA	2020	Voluntary	Greenhouse film and mulch film	-	-
Germany	ERDE	2013	Voluntary	Silage film, netting, twine and mulch film (the collection of mulch film started from 2022)	51% (2021)	100% (2021)
The UK	APE UK	2020	Voluntary	Film, twine and netting	-	-
	UKFPRS	2020	Voluntary	-	-	-
Ireland	IFFPG	1998	Mandatory	Silage film, netting and twine	90% (2021)	-
Sweden	SvepRetur	2001	Voluntary	Silage film, horticultural film and packaging	93%	90%
Norway	GPN	1997	Voluntary	Packaging and agricultural film	>90% (2021)	86% (2021)
Iceland	IRF	2005	Mandatory	Silage film	90% (2020)	-

*Note: * the collection rate of particular APW in the scheme; ** calculated based on the amount of waste collected; *** mainly implemented in Andalusia.*
Source: Eunomia, NCSs' websites

The national collection schemes in Italy, Ireland and Iceland are mandatory, and those in the other six countries are voluntary. The collection schemes implemented in France, Italy, Spain and Germany cover mulch film (they are the major users of mulch film in Europe, and the collection scheme in the UK may cover mulch film), and much can be gained from other countries' measures. A detailed introduction to each collection scheme is listed in Annex 1.。

3.4.3 Major Problems Facing Mulch Film Collection

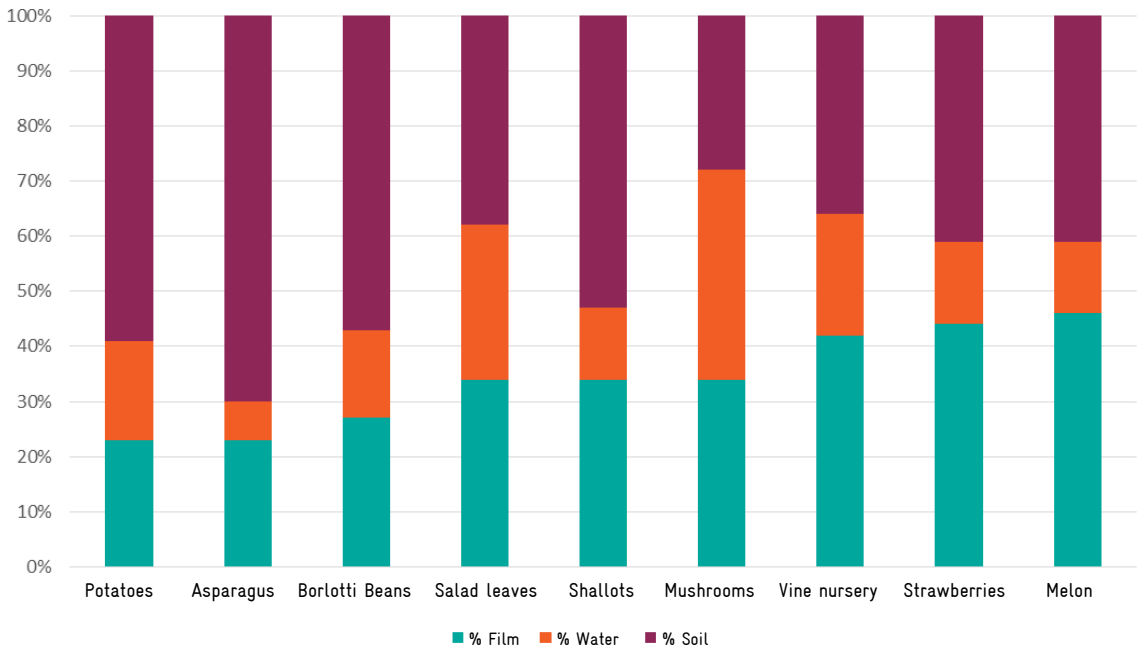
Like in China, even in countries/regions with collection schemes, the collection rate of APW is 93% or below. Due to their sheer thinness and high contamination rate, the collection rate of mulch film is even lower. The following is an introduction to major problems facing mulch film collection mentioned in the EU report.

3.4.3.1 High Contamination Rate of Mulch Film

The content of impurities such as soil, straw and water in used mulch film is high and inevitable. In light of experience, the contamination rate can still be as high as 30%–40%, even when best practices are followed.

The figure below shows the empirical contamination rate of mulch film for typical crops in Europe. The contamination rate of mulch film for potatoes and asparagus is higher than that for strawberries and melons, and the quantity of recyclable plastics of the latter is twice that of the former.

Figure 10 Contamination rate of mulch film for typical crops in Europe



Source: APE Europe

3.4.3.2 Insufficient Participation of Farmers

The factors affecting farmers' participation in the collection scheme include the incentive mechanism, accessibility, the distance to collection points, farmers' awareness, and the quantity of used mulch film.

- **Incentive mechanism:** APW collection schemes in various countries tend to introduce an economically feasible mode of operation. The greater the economic incentive for farmers, the more motivated they are to join the collection scheme. Making farmers pay a collection fee lower than the general waste disposal fee is a common practice in European countries, while other operating costs of collection schemes are partly borne by producers and partly covered by revenues from recycling.
- **Accessibility:** mulch film collection is time-consuming (16–18 hours/ha). In addition, collection schemes often require farmers to do the preliminary cleaning of used agricultural film. Therefore, more convenient collection methods (e.g., mechanical collection) and guidance & training will reduce the burden on farmers.
- **Distance to collection points:** most collection schemes set up collection points in places frequented by farmers (e.g., farmers markets and agricultural cooperatives). Agricultural cooperatives in France decided, after discussion, that the nearest collection point to farmers should not exceed 20 km, and the average distance in Ireland is 10 km. Generally, this is not the primary factor dampening farmers' participation, but farmers who produce less waste tend to mingle mulch film with other garbage (higher costs) or even incinerate them on the spot.
- **Farmers' awareness:** while some collection schemes have established an intensive collection network and offered the most economical option, the collection rate remains low. Such is the case with the ERDE scheme in Germany. The ERDE believes that farmers' lack of understanding of the scheme is the main reason for the low collection rate. In response to this, the ERDE has ratcheted up its publicity efforts, informed farmers of the collection conditions when they purchase products, promoted its services at agricultural exhibitions with a large number of farmers participating, and developed an app to provide all sorts of collection-related information (e.g., operations guide, collection date, and collection point). In so doing, the collection rate has been increasing year by year.

3.4.4 Measures to Lower the Contamination Rate of Mulch Film

3.4.4.1 Preliminary Cleanup and Rolling by Farmers

The instruction manual for farmers provided by A.D.I.VALOR has achieved the most remarkable results. Best practices for mulch film cleanup include:

- **removal:** irrigate the mulch film a few days in advance to soften the soil attached to the film and make it easy to clean;
- **cleanup:** manually (throw away soil and straw)/mechanically;
- **rolling:** hang the film overnight before rolling to make it drier; manually/mechanically (roll the film into two cones using a double-cone device with a winder);
- **storage:** store it in a clean area and keep it dry to prevent the adsorption of sediment on the mulch film.

Table 7 Collection requirements for mulch film by A.D.I.VALOR in France

Mulch film typ	Colorless	Colored	Black
Highest contamination rate	50%	50%	20%
Rolling requirement (illustration)			

Source: A.D.I.VALOR

3.4.4.2 Mechanical Collection

Compared with manual collection, mechanical collection significantly lowers the contamination rate of mulch film. A new technology—RAFU—has been piloted in France. As a tractor trailer, RAFU (RAFU, n.d.) can remove, clean (upper and lower surfaces) and roll the film when harvesting crops, and only one driver is needed for the entire process. The film rolling rate can automatically adapt to the vehicle speed to ensure proper tension on the mulch film so that the film will not break. The pilot results indicate that with this technology, the weight of impurities can be reduced from 3 to 4 times the original weight of mulch film (a contamination rate of 75%–80%) to 1.4 to 1.7 times the original weight of mulch film (a contamination rate of 37%–42%) in both wet and normal conditions. Currently, eight hectares of film can be removed per day using this technology. The following are examples of applicable crop types and equipment.

Table 8 Film removal effect of RAFU on different crops

Crop type	Carrot	Melon	Salad (outdoor cultivation)	Salad (greenhouse cultivation)	Potato	Onion
Number of film layers	3					
Film thickness	0.028mm	0.028mm	0.025/0.028mm	0.022/0.030mm	0.025mm	0.035mm
Mulching method	Mechanical					
Removal method	Mainly mechanical					
Removal steps	Cleaning and rolling	Rubbing and dry brushing → rolling	Dry brushing → rolling	Dry brushing → rolling	Dry brushing → rolling	Cleaning and rolling
Contamination rate (common)	70%	60%	72%	75%	70-80%	67%
Contamination rate (RAFU)	30%	30%	50%	40%	45%	30%/50%

Source: APE Europe

Figure 11 RAFU apparatus for different crops

(1) Carrots -1

(1) Carrots -2

(2) Salad

(3) Onions

Source: APE Europe

The price of RAFU apparatus hovers around EUR 25,000–30,000 (equivalent to RMB 180,000–210,000). The reduction in the weight of used mulch film can slash the corresponding collection fee, so large growers participating in A.D.I.VALOR are able to recover the investment within three years.

There is no official data on the proportion of agricultural film collected manually and mechanically in the EU. Given the costs, it can be inferred that mechanical collection is limited to large farms. About 50% of carrot farms in France (by area) are using the RAFU technology. A Spanish agricultural machinery dealer estimated from experience that at least 90% of agricultural film is manually collected.

3.4.4.3 Pre-treatment Plants/Production Lines

A.D.I.VALOR announced the launch of the CLEANFILM project in early 2022, aiming to provide pre-treatment (i.e., grinding and cleaning) for agricultural film, so as to encourage recyclers to collect agricultural film and increase the recycling rate. To be more specific, A.D.I.VALOR entered into a cooperation agreement with Plasticclean (FreshPlaza, 2022), a subsidiary of Calvet, and invested EUR 4.3 million (approx. RMB 30.8 million) in the construction of a pre-treatment plant with a capacity of 10, 000 tonnes (RAFU, n.d.). The plant adopts an innovative technique developed by Plasticclean for efficiently cleaning agricultural LDPE film (including mulch film), shredding, cleaning, drying and eventually baling the flaked agricultural film. Thanks to the single-material agricultural film and the efficient technique, the plant can provide particularly pure used LDPE fragments to the market, which can be directly used by plastic producers to produce new film products. The plant is set to launch production in February 2023 and ten jobs will be created.

Green World Compounding is a plastic recycler in Spain (Green World Compounding, n.d.). Being the largest recycling plant for agricultural film in Europe and a benchmark for the industry, its agricultural film recycling plant in Murcia has a capacity of 100,000 tonnes per year and can process all used agricultural film in Spain (mainly greenhouse film and mulch film). It introduces a pre-treatment line for cleaning mulch film, where it recovers and processes the soil on mulch film to make concrete.

3.5 Recycling: Markets and Economic Performance

3.5.1 Current Recycling Methods and End Markets

Material recycling is the main method for recycling agricultural plastics in Europe. The process is as follows: bundles of agricultural film are sent to the recycling plant. As they are composed of one single material, no further sorting is needed. Yet conspicuous impurities will be manually removed. Plastics are made into plastic sheeting after shredding, cleaning and drying according to their type, and the degree of intricacy depends on the quality requirements of the final product. The plastic sheeting is fed into the extruder and processed into plastic pellets, and additives are added according to the required properties of the final product.

Low-value recycled pellets made from poor-quality agricultural plastics (except greenhouse film) have limited end markets. In addition, buyers of recycled plastics tend to be more mindful of pesticide residues, odors and other problems when it comes to materials from the agricultural sector. According to POLIECO, nearly half of the recycled agricultural plastic pellets are made from agricultural film, including 90% from greenhouse film and 10% from mulch film. The APE estimated that about 93 kt of recycled agricultural plastic pellets were consumed in Europe in 2019. The end markets are mainly garbage bags (e.g., CEDO in the Netherlands and Berry BPI in the UK), construction film, and thick plastic profiles (e.g., "plastic wood" for park benches), as well as silage film (containing 40% recycled materials), irrigation pipe connectors, and twine reused in agriculture.

Figure 12 Park bench made of 90% recycled agricultural film pellets

Source: A.D.I.VALOR

The chemical recycling of agricultural plastics is still in the pilot stage in Europe and has not yet entered commercial operation.

3.5.2 Economic Performance of Recycling

3.5.2.1 High Costs, Low Prices, and Limited Profit

Technically speaking, recycling plants can process agricultural film with a contamination rate of 60% or above, but it will incur a host of additional costs, including:

- processing costs of intensive cleaning; sewage and garbage treatment fees generated during this process;
- maintenance costs arising from damage to equipment blades by impurities (e.g., sand);
- a low yield rate (i.e., the ratio of recycled plastic pellets obtained per tonne of material input). The common yield rate of used industrial and commercial film, greenhouse film, and mulch film with a thickness of 0.015 mm to 0.020 mm is 75%–85%, 60%–70%, and 33%–35%, respectively.

Compared with high-quality industrial and commercial plastic film, agricultural film is characterized by high processing costs, low selling prices, and even no profit at all. This disparity in profitability is highlighted in Table 9, illustrating the economic challenges faced by the agricultural film sector.

Table 9 Costs and Selling Prices of Various Used plastic film

Unit: euros/tonne	Used agricultural film	Used industrial and commercial plastic film
Total costs	470–635	330–360
Processing costs	380–480	280–300
Sewage treatment costs	20–25	-
Garbage treatment costs	70–130	50–60
Selling prices of recycled plastics	Silage film sheeting: 550 Stretch film: 600–620	550–670
Profits	-85–150	190–340

Source: CEDO in the Netherlands

The price of virgin plastics exerts a tremendous impact on the demand for recycled plastic pellets. All other things being equal, virgin plastics are a more convenient choice than recycled materials for producers—the former is of higher quality and has better consistency, showing no differences between batches. Normally, if the price of virgin plastics is higher than EUR 1,200/tonne, producers will opt for recycled materials, but when the price of virgin plastics is lower than EUR 1,000/tonne, recycled pellets will not sell.

3.5.2.2 Proportion of Recycling Costs under the EPR Scheme

The core principle underpinning the EPR scheme is that producers bear the full net cost of waste collection, transportation, and recycling. Yet this is not always the case for current collection schemes in Europe, as farmers are usually required to pay a collection fee, as indicated in Table 10.

The main reason is that the collection and processing costs of used mulch film account for a large proportion of the selling price. The average selling price of mulch film in Europe is EUR 2,055/tonne, and the processing cost in France is EUR 395/tonne, nearly 20% of the selling price (12% borne by producers). By contrast, the average selling price of greenhouse film is EUR 2,955/tonne, and the processing cost in France is EUR 30/tonne, only 1% of the selling price. The voluntary collection scheme aims to avoid excessive fees that discourage the participation of producers. The scheme can encourage farmers to improve the cleanliness of used mulch film, thus reducing processing costs. However, even a nominal collection fee can be a hindrance to some farmers. Furthermore, cases of secret in-situ incineration/landfill have been observed, further compounding the issue.

Table 10 Cost sharing arrangements under current APW collection schemes in Europe

National scheme	Proportion borne by producers	Proportion borne by farmers	Details
A.D.I.VALOR in France	Most APW: 100%; mulch film: 60%	Mulch film: 40%	Producers bear the full net cost of collection and processing of most APW, and the costs vary from type to type, except for mulch film: farmers have to pay a collection fee of EUR 155/tonne at the collection point, and part of the fee can be waived if there is a test report issued by a certification body proving that the contamination rate is lower than 50%, while producers shall pay EUR 240/tonne.
POLIECO in Italy	A certain proportion	A certain proportion	Participating producers are required to pay a fixed annual fee and share the costs equally with all stakeholders (EUR 15–31/tonne per year). Farmers also have to pay an additional collection fee of EUR 14/tonne when purchasing products.
MAPLA in Spain	Unknown	Unknown	There is insufficient information on the scheme at its initial stage.
ERDE in Germany	30%–40%	60%–70%	The proportion borne by producers is used to incentivize ERDE-certified collection points, which will receive a reward for each tonne of qualified agricultural plastics collected and recycled. The amount of the collection fee paid by farmers is decided by the collection point, which is lower than that of other disposal methods. The costs borne by each party vary among different types of agricultural plastics.
APE UK in the UK	Unknown	Unknown	There is insufficient information on the scheme at its initial stage.
IFFPG in Ireland	70%	30%	Producers pay EUR 140/tonne (regardless of the type of agricultural plastics), and farmers pay a disposal fee at the collection point (EUR 50–170/tonne depending on the collection form).
SvepRetur in Sweden	Unknown	Presumably 100%	Producers charge farmers an additional collection fee when selling products, which is handed over to SvepRetur every half a year to cover management and collector costs of SvepRetur. Farmers do not have to pay at the collection point. The collector is in charge of the treatment and disposal of APW. The costs borne by each party vary among different types of agricultural plastics.
GPN in Norway	A larger proportion	A smaller proportion	The environmental fee paid by producers is partially included in the price.
IRF in Iceland	A larger proportion	A smaller proportion	Producers and farmers together pay EUR 190/tonne, and the environmental fee paid by producers is partially included in the price.

Source: The EU, NCSs' websites

An alternative approach to involve farmers in the collection scheme is to charge first and refund them later, that is, farmers pay an additional collection fee when purchasing mulch film. If the contamination rate of mulch film brought to the collection point is lower than a certain value, farmers can get a refund without having to pay any fees. However, the problem is that it is hard to visually evaluate the contamination rate of mulch film. A.D.I.VALOR chooses to ask farmers to test the contamination rate. If farmers assume that it is lower than the specified value, they need to present a test report issued by a certification body. If the test result is indeed lower than the specified value, they will get a refund; otherwise, they will bear the testing fee.

This approach allows for a more objective assessment of the contamination rate and promotes accountability among farmers, fostering adherence to quality standards in agricultural plastic waste management.

4 Major Challenges and Next Steps

4.1 Major Challenges

4.1.1 Collection Rate and Quality of APW Need to Be Improved

Collection serves as the initial step in the recycling process. In European countries, there is a lack of collection points dedicated to agricultural plastics, resulting in a small amount of waste being collected and uncertainty of supply. A robust and reliable supply of waste is an essential prerequisite for the operation of the recycling sector.

The collection and recycling of mulch film poses specific challenges. Used mulch film has poor quality, a high contamination rate, and high costs of pre-treatment and equipment maintenance, leading to a low profit margin and making them unattractive to recyclers. Therefore, improving the quality of collected mulch film (e.g., preliminary sorting and pre-cleaning) can directly lower the overall recycling cost, thus enhancing recycling efficiency and attracting more recyclers.

4.1.2 Low-Value Recycling of Agricultural Plastics

Low-value material recycling is still the primary approach for recycling agricultural plastics in Europe, with limited end markets. To encourage the growth of the recycled plastics market, it is important to address two key aspects. For one thing, deciding the proportion of recycled materials for agricultural plastic products and ensuring the traceability of recycled materials can stimulate the recycled plastics market. For another, considering the limited types of recycled materials applicable to agriculture, it is imperative to explore new application fields with higher added value.

4.1.3 Insufficient Investment in Technology and Infrastructure for Collection and Recycling

There is an urge to intensify research and development of advanced technology and further improve the quality of recycled materials so that they can be used in higher-end markets. In addition, pre-treatment steps, such as on-farm pre-cleaning to reduce transportation costs, need to be introduced to minimize impurities in the materials to be recycled.

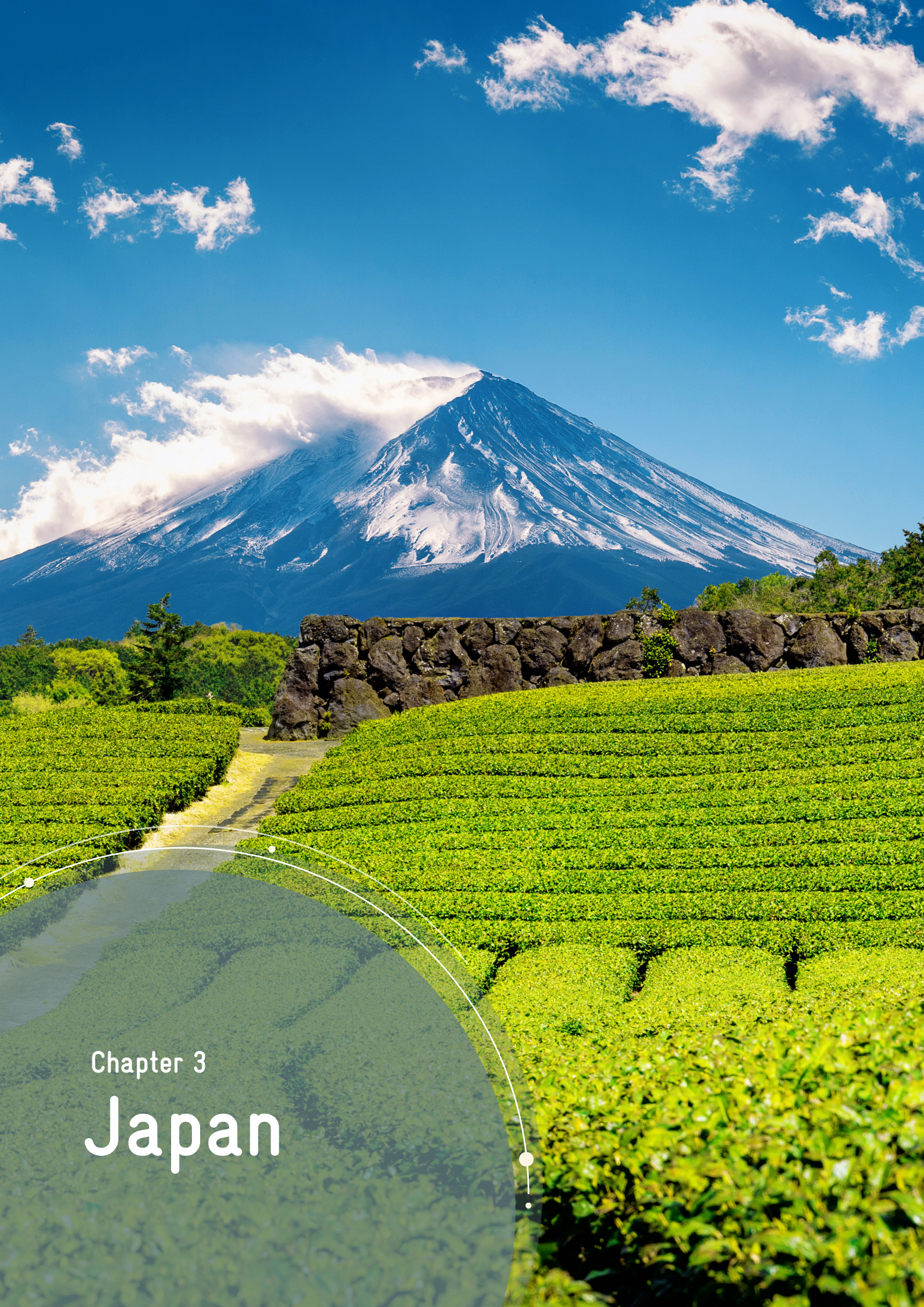
4.1.4 Incomplete Value Chain Collaboration

The recycling of agricultural plastics encompasses the whole value chain, involving producers, distributors, farmers, collectors, and recyclers. The principle of joint liability is key to the success of the recycling model. The key to establishing a well-functioning recycling chain for agriculture film lies in the design of an EPR scheme which balances the responsibilities of all parties based on actual conditions .

4.2 Next Steps

With the increasing emphasis on APW management, the focus will be on research and management. The next steps include:

- collecting basic statistics on the consumption, collection, recycling, and other disposal methods of agricultural plastics;
- studying the accumulation of conventional mulch film for different crops in the soil after collection and their transfer from soil to other environments under different climate conditions, as well as the effect of plastic residues on humanity;
- conducting field research on factors that affect the collection rate, including the physical properties of mulch film such as thickness and strength, the crop type, and climate; establishing clearer criteria for the physical properties of mulch film to enhance collection efficiency and improve the quality of film collected;
- strengthening research and development and innovating in the production and design of high-strength mulch film, collection machinery, pre-treatment techniques, and recycling processes to further improve the quality of recycled materials; exploring high-value recycling methods to expand end markets and attract recyclers;
- further optimizing financial, regulatory, reputation, and other incentive mechanisms, applying traceability tools such as the Digital Product Passport, and establishing an EPR scheme clearly defining the responsibilities of producers, distributors, users, collectors, and recyclers to facilitate value chain collaboration.



Chapter 3

Japan

1 Basic Information

1.1 Consumption and Recycling of Agricultural Plastics

Japan has emerged as an early adopter of agricultural film, with initial research in this field dating back to 1948. In 1955, agricultural film was successfully applied to strawberry production. At present, plastics are widely used in Japan's agricultural sector, mainly for the manufacture of greenhouse film (covering greenhouses and small tunnels), mulch film, silage film, seedling trays and flowerpots.

According to public information published by Japan's MAFF, Japan's domestic consumption of resin products reached 10.29 million tonnes in 2018, among which 130,000 tonnes went to the agriculture, forestry and fisheries sectors (MAFF, 2021). In the same year, the amount of plastic waste was 8.91 million tonnes, among which 120,000 tonnes were generated in the agriculture, forestry and fishery sectors, and 106,500 tonnes were APW, accounting for 1.2% of all plastic waste in Japan.

Japan achieved an impressive utilization rate of 84% for plastic waste. A total of 7.5 million tonnes of plastic waste were recycled, including 2.08 million tonnes by material recycling (of which 0.91 million tonnes were exported), 0.39 million tonnes by chemical recycling, and 5.03 million tonnes by energy recovery. Despite the commendable recycling and recovery efforts, there remains a quantity of 1.42 million tonnes of plastic waste that was not effectively utilized. Instead, they were incinerated without energy recovery or landfilled.

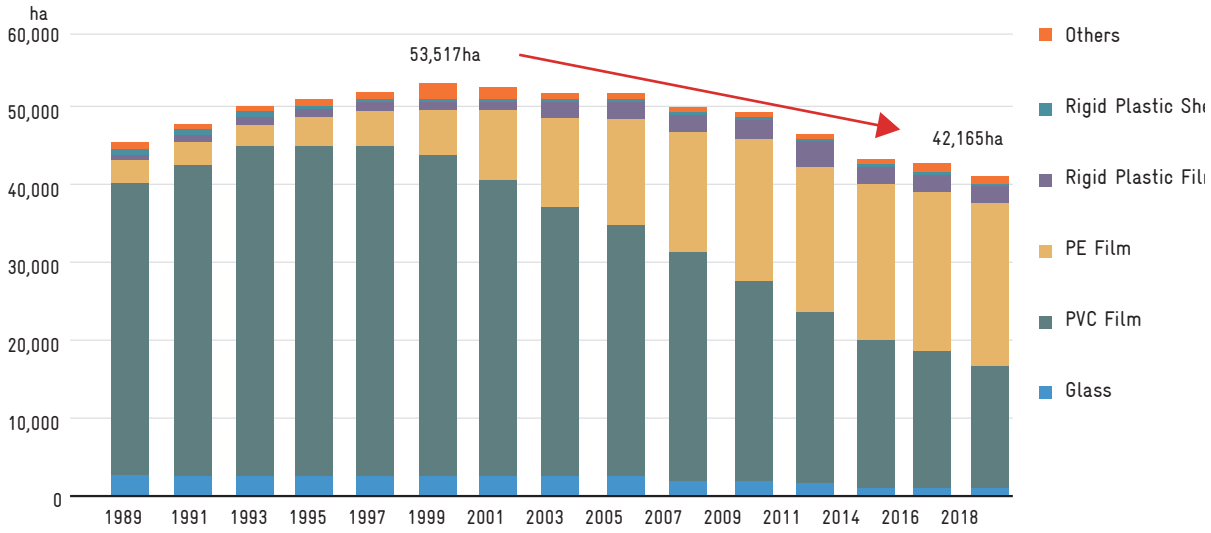
As for used agricultural film, the effective utilization rate was 74.5%, and the proportions of incineration without energy recovery, landfill and other treatment methods were all less than 10%.

1.2 Changes in the Consumption and Waste Generation of Agricultural Plastics

Figure 13 shows the changes in the application area of greenhouse film of different materials in Japan (by material) since 1989. In general, the application area peaked at about 53,500 ha in 2000 and then gradually decreased to around 42,000 ha till now. The application area of PVC film more than halved, and that of PE film increased, making PE film the most used greenhouse film. There are also a small number of rigid plastics, glass, etc.

Mulch film is extensively applied in the cultivation of onions, potatoes, tomatoes, konjac, bok choy, sweet corn and other vegetables and fruits of high economic value. Different mulch film is used in different seasons according to the variety of crops. Black mulch film accounts for about 70%, while the rest are colorless or in other colors. At present, the overall consumption of mulch film in Japan is about 40,000 tonnes, covering an area of about 130,000–140,000 ha. Due to the high price of biodegradable mulch film, PE mulch film occupy a large proportion of the overall market in Japan. Despite less than 2% of the market share, biodegradable mulch film witnessed an increasing trend in the amount and application area over the years.

Figure 13 Application area of greenhouse film in Japan (by material), 1989-2018

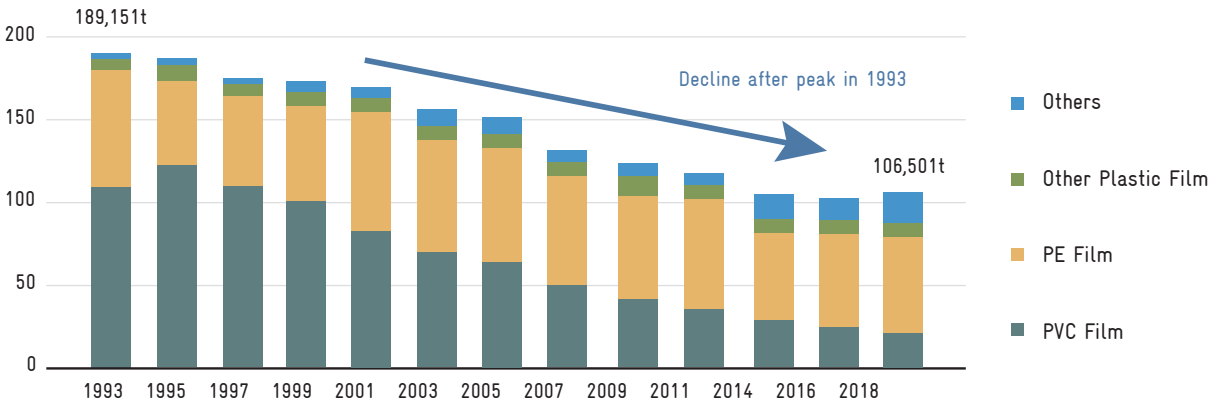


Source: MAFF

The quantity of APW generated in Japan had been declining after reaching a peak of 189,000 tonnes in 1993 and leveled off after 2014 (Figure 14). 53% of the 107,000 tonnes of APW in 2018 were PE film (mainly greenhouse film and mulch film) and 22% were PVC film (mainly greenhouse film).

There is no public data on the changes in mulch film waste generation, but it can be inferred that the amount of PE film waste attributed to PE film, primarily greenhouse film and mulch film has remained relatively stable over time, ranging between 50,000 and 60,000 tonnes per year. Meantime, the application area of PE greenhouse film increased year by year (Figure 13) and no decreasing trend was observed in the film thickness. Even considering the factor of reuse, the PE greenhouse film waste did not witness a significant decrease over time. Based on this speculation, the waste generation of mulch film in Japan either remained stable or potentially decreased year by year. The observed trend of stable or potentially decreasing waste generation of mulch film in Japan can be attributed to two primary factors. Firstly, the development of product standards in 1994 has led to improvements in film production technology, enhancing both the quality and durability of the film. Secondly, advances in cultivation and farm machinery technology have reduced the rate of film breakage and extend the service life of mulch film, which in turn has reduced waste generated in Japan.

Figure 14 Quantity of APW generated in Japan (by material), 1993-20

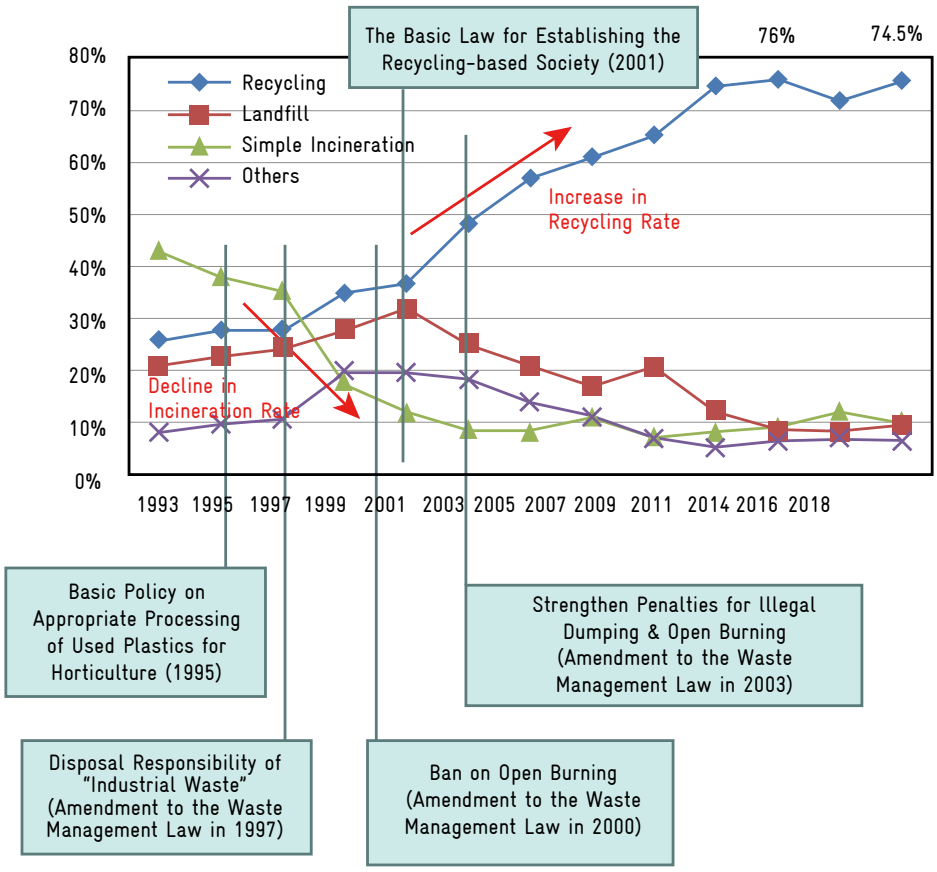


Source: MAFF

1.3 Changes in the Treatment Methods of Agricultural Plastics

In the past 30 years, the treatment methods of APW in Japan have changed significantly with policy guidance (Figure 15). In 1993, incineration without energy recovery was the dominant treatment method, accounting for more than 40%; and recycling accounted for only 27%. Since the release of Basic Policy on Appropriate Processing of Used Plastics for Horticulture in 1995, APW recycling has been given priority over disposal. Then in The Amendment to Waste Management Law issued in 1997, agricultural plastics were classified as industrial waste, followed by a significant drop in simple incineration and a sharp rise in the recycling rate. In 2001, The Basic Law for Establishing the Recycling-based Society was officially implemented. After that, landfill and other disposal methods of APW reached a peak and then continued to decline. By 2014, the recycling rate reached 76% and has remained above 72% since then, while other disposal methods have dropped to below 10%. In 2018, agricultural film waste in Japan totaled 106,500 tonnes, with a recycling rate of 74.5%, including 24,000 tonnes of PVC film and 56,000 tonnes of PE film, with a recycling rate of 80% and 78% respectively.

Figure 15 Changes in the treatment methods of APW in Japan



Source: MAFF

2 Practices in Life Cycle Management of Agricultural Plastics

2.1 Major Policies and Regulations

Since the 1990s, agricultural film waste has been incorporated into the Japanese waste-related policy system, and relevant regulations have been introduced and improved, forming a sound life-cycle management policy system. Regulations and amendments related to agri-film waste are summarized in Table 11.

Table 11 Laws and regulations on agricultural film waste in Japan

Date of issue	Regulations	Content
1991	Law for Promotion of Utilization of Recycled Resources	The product design and manufacturing process should incorporate the concept of environmental protection, and producers and operators are obliged to recycle, pack and send the wasted mulch film to the specified location for further sorting and classification, and pay corresponding treatment fees, but it is not mandatory.
1995	Basic Policy on Appropriate Processing of Used Plastics for Horticulture	Administrative agencies and agricultural groups should improve the organization of recycling and disposal activities, carry out necessary publicity and education, and require farmers to classify, clean and return agri-film to the recycling centre; priority should be given to material recycling, and if it is difficult to achieve, thermal energy recovery should be considered.
1997	Amendment to Waste Management Law	APW is listed as "industrial waste", which means that the discharger (farmer) is responsible for the proper disposal of APW, and entrusting APW disposal involves no responsibility transfer; those who collect, transport, and process APW should obtain a permit from the prefectural governor.
2000	Amendment to Waste Management Law	Prohibit illegal burning of agri-film waste and determine related penalties
2000	The Basic Law for Establishing the Recycling-based Society	Clarify the responsibilities and obligations of all members of society, and promote the transformation to a sustainable, recycling-oriented society featuring waste reduction and resource recycling
2000	Law for Promotion of Effective Utilization of Resources (Amendment to Law for Promotion of Utilization of Recycled Resources)	Ensure the use of recycled resources while suppressing waste generation (resource conservation, life extension, reuse, etc.)
2003	Amendment to Waste Management Law	Prohibit illegal dumping of agri-film waste and strengthen penalties for open burning: imprisonment of up to 5 years / fines of up to JPY 10 million (RMB 0.5 million) for individuals and up to JPY 300 million (RMB 15 million) for companies
2004	Amendment to Waste Management Law	Mandatory provisions for functional facilities of agri-film waste transport vehicles
2005	Amendment to Waste Management Law	Increase the penalties for false reporting of agri-film waste treatment
2008	Amendment to Waste Management Law	Mandatory requirement for county governments to recycle agri-film waste
2011	Amendment to Waste Management Law	Clarify the obligations of agri-film producers to recycle their products
2020	Circular Economy Vision 2020	Further increase the recycling rate and reduce waste

The Waste Management Law promulgated in 1970 has undergone multiple amendments over the years to clearly define the management obligations for the collection, storage, treatment and disposal of agricultural film waste. The responsibilities for all parties, including producers, farmers, collection, transportation and recycling enterprises, and the government, have also been gradually strengthened. Particularly, agricultural film manufacturers are responsible for the quality of their products and bear the responsibility for the difficulties in collection and recycling due to poor product quality. Farmers, as users of agri-film, must properly dispose of agri-film waste in accordance with regulations; those who dump, burn and bury the wasted film shall be subject to high fines or even imprisonment. Recycling and processing organizations, including collection stations, transportation service providers, recycling enterprises, are required to apply for licenses from relevant authorities and comply with certain administrative regulations, such as the "transferring table system". More responsibilities and obligations are devolved to lower-level local governments, who bear responsibility for developing recycling plans, providing financial subsidies and supervising recycling systems.

Basic Policy on Appropriate Processing of Used Plastics for Horticulture, put into force in 1995, gave full consideration to a series of difficulties in agri-waste management, such as the scattered distribution of farmers and plastic waste emissions. The policy requires the national government, prefectural and municipal administrations, and relevant agricultural associations to promote the establishment of a comprehensive collection and recycling system. They are also required to facilitate the sharing of information and conduct educational lectures to ensure that farmers are provided with scientific collection methods and recycling routes. Also, the policy actively promotes the use of durable film and clarifies the impact of this investment on the short- and long-term economic benefits to farmers.

2.2 Product Standards and Common Specifications

The JISC released the national standard for "Polyethylene film for agriculture" (JIS K6781-1994 Polyethylene Films for Agriculture, n.d.) in 1994 and it has been used since then. This standard specifies five product thicknesses between 0.02 mm and 0.1 mm and the corresponding mechanical strength (Table 12), which cannot be compared directly with the Chinese standard because of the difference in testing methods.

Table 12 Main mechanical characteristics of agricultural film in the Japanese standard (JIS K6781-1994)

Thickness	Tensile strength	Elongation at break	Tearing load
[mm]	[N]	[%]	[N]
0.10	≥ 9.807	≥ 250	≥ 4.90
0.07	≥ 6.86		≥ 3.43
0.05	≥ 4.90		≥ 2.45
0.03	≥ 2.45	≥ 150	≥ 1.18
0.02	≥ 1.47		≥ 0.78

Japanese mulch film is known for their quality, commonly marketed in thicknesses of 0.02 mm and 0.03 mm, with no breakage after use. They remain intact when being removed and can be collected easily by hand (Figure 16). Quality problems with Japanese mulch products can be traced, and according to the relevant regulations, farmers can complain directly to sellers and agricultural associations and demand compensation in case of massive rupture and difficult recovery after use.

2.3 Collection and Recycling Mechanism

The JA, together with seven agricultural film companies, established the Agricultural Film Recycling Promotion Association in July 1999 (Japan Agricultural Film Recycling Promotion Association, n.d.). Initiated formed as a voluntary EPR alliance, it later evolved into the primary organization responsible for the implementation and coordination of national agricultural film recycling efforts in 2009, following The Amendment to Waste Management Law that mandated prefectural governments to recycle waste agricultural film. The alliance has now established divisions in all 47 prefectures to provide comprehensive management of used agricultural film, including the establishment of recycling systems, the development of recycled products, the research and development of new technologies, promotion and guidance.

Farmers are obliged to sort and collect used mulch film and then carry out pre-treatment. They are supposed to remove impurities (a contamination rate of less than 50%), and to bale mulch film as required (tearing parts from the mulch film as the tie, 10 kg–15 kg per bundle). Farmers take on the task of mulch film collection, utilizing either a small film recycling machine or collecting by hand. The resilience of the mulch film allows for its easy removal, simplifying the collection process. This is depicted in Figure 16, which illustrates the straightforward and uncomplicated nature of mulch film collection.

Figure 16 Mulch film collection and piling in Japan

Source: Key Laboratory of Agricultural Film Pollution Prevention and Control, MARA

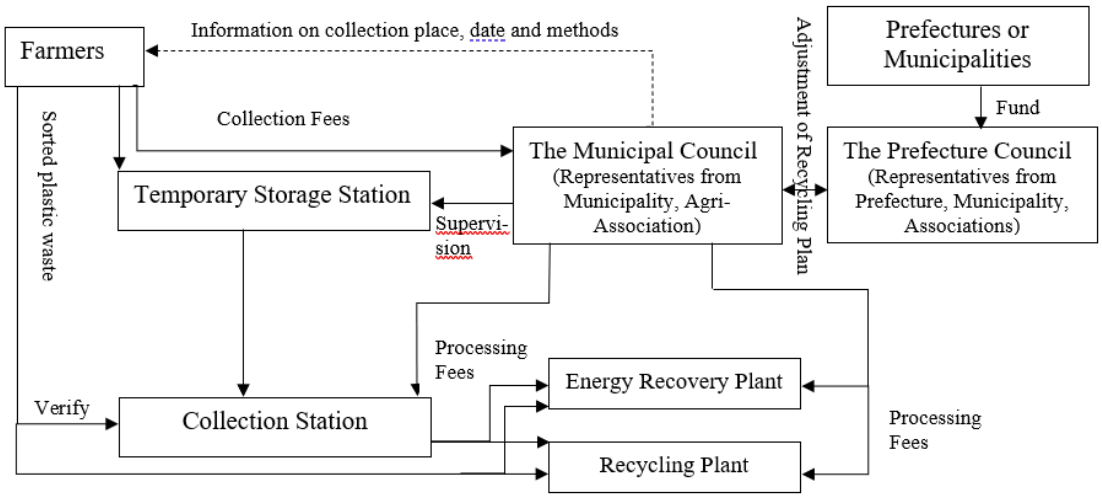
For farmers, two approaches to collect used agricultural film are possible (HU et al., 2019). One is to send used but clean and properly sorted film to a dedicated collection point and pay a recycling fee of JPY 30,000–50,000 (approx. RMB 1,500 to 2,500) per tonne. The other involves mandated collection of mulch film under the unified management of the Agricultural Film Recycling Promotion Association by authorized agricultural cooperatives, dealers or other institutions. Farmers are informed in advance of the collection date (generally 2–3 times per year) and the modus operandi through flyers. The organization that transports and disposes of the collected mulch film is required to strictly follow the "transferring table system" to record the disposal process, including briquetting and block cutting as required, before handing them over to the recycling company for disposal. Farmers are legally obligated to use (electronic/paper) tables to keep track of the disposal of waste agricultural film until final disposal is completed.

Figure 17 Transfer of used mulch film in Japan

Source: Key Laboratory of Agricultural Film Pollution Prevention and Control, MARA

Under the second approach, a portion of the collection and recycling cost is added directly to the sale price of the film, so farmers do not have to pay an additional recycling fee; the rest of the cost is subsidized by local governments and agricultural cooperatives, generally in the range of JPY 10,000 to 30,000 per tonne (approx. RMB 500 to 1,500) , as shown in Figure 18. Each prefectural council will determine the specific amount and sharing ratio of collection and recycling fees depending on the local situation. Typically, the cost of the recycling system is shared among farmers, farmers' associations, and local governments, with each party bearing one-third of the total expenses. This cost-sharing mechanism ensures the sustainable operation of the recycling system. This method can also effectively avoid careless disposal of agricultural film waste due to farmers' unwillingness to pay the recycling fee.

Figure 18 Levy system for agricultural film recycling in Japan



Source: Japan Agricultural Film Recycling Promotion Association

2.4 Recycling Methods

In Japan, there are three main types of plastic recycling methods: mechanical recycling (material recycling), energy recovery and chemical recycling. Material recycling and energy recovery are employed for most PE agri-film, and only a small quantity of PE film is recycled chemically. Most of recycled PE pellets are exported to foreign countries, and a few are made into pallets, artificial trees, architectural and civil engineering materials, and gardening materials in Japan. PE agricultural film with a high contamination rate generally undergo energy recovery, such as being sent to cement plants and paper mills as alternative fuels, with the ashes left being used as cement material; and they can also be incinerated for power generation or made into refuse derived fuel (RDF). Only a small fraction of agriculture film is chemically recycled as a reducing agent (a hydrogenous material) for blast furnace injection. All PVC film is physically recycled at present, with half being exported and the other half being used as construction and industrial materials in Japan. When it comes to PVC plastic waste, chemical recycling of PVC is technically immature in China. With the poor quality of physically recycled materials and the unsustainable business model, the recycling of PVC waste plastics in China is another problem to be solved.

Table 13 Recycling methods for PVC and PE agricultural film in Japan

Method of recycling			PVC agri-film	PE agri-film
Mechanical recycling	Material recycling	Domestic use	●	●
		Export	●	●
Chemical recycling	As a blast furnace reductant		No longer accepted by JFE Steel Corporation from December 2012	●
	Gasification and liquefaction			Not for APW
Energy recovery	alternative fuels for cement plants and paper mills; power generation; refuse paper and plastic fuel (RPF); RDF			●

Note: The size of the circle represents the quantity.

Source: MAFF, Japan Agricultural Film Recycling Promotion Association

Chapter 4

North America

1 The United States

1.1 Consumption of Agricultural Plastics

The annual output of agricultural plastics in the United States amounts to 490 kt according to estimates, which mainly includes agricultural film, containers (e.g., packaging barrels and pots), and irrigation pipes. Around 70 kt of mulch film is produced annually (Jones, 2018)

In the United States, agricultural film is mainly used for producing high-value cash crops such as vegetables, berries, and hemp. According to a practitioner in the field of agricultural film from ExxonMobil, the United States, as the third largest producer of cotton in the world, does not rely much on mulch film in cotton growing.

1.2 Product Standards and Common Specifications for Mulch Film

There is no mandatory, unified standard for agricultural PE film in the United States, but the "Standard Specification for Polyethylene Sheeting for Construction, Industrial, and Agricultural Applications" (ASTM D4397-16) formulated by the ASTM is in place (ASTM D4397-16, 2016). The mechanical characteristics of film stipulated in this standard, including impact resistance, tensile strength, and elongation at break, are shown in Table 14.

Table 14 Product standards for PE film in ASTM D4397-16

Thickness		Dart drop impact resistance	Tensile strength	Elongation at break
[mils]	[mm]	[g]	[MPa]	[%]
1.0	0.025	40	MD≥11.7 TD≥8.3	MD≥200 TD≥325
1.5	0.038	65		
2.0	0.050	85		MD≥225 TD≥350
3.0	0.075	125		
4.0	0.100	165		
5.0	0.125	205		
6.0	0.150	260		
7.0	0.175	315		
8.0	0.200	370		
9.0	0.225	420		
10.0	0.250	475		

A mil is a unit of measurement commonly used in the United States to measure mulch film thickness in thousands of an inch. According to the Intergro, a distributor of agricultural film, Table 15 provides information on the common thicknesses of different types of film products on the market (Intergro, n.d.). According to an industry insider, a large portion of mulch film sold in the United States is imported from Mexico, while domestically produced mulch film consists solely of embossed variants manufactured using tape casting techniques. The common thickness ranges from 0.8 mils to 1.0 mils (i.e., 0.020 mm to 0.025 mm).

Table 15 Thickness of common agricultural film in the United States

Film	Production process	Common thickness	
		[mils]	[mm]
LDPE/LLDPE film	Blow molding/tape casting	0.8-1.5	0.020-0.038
HDPE film	Blow molding	0.5-1.0	0.012-0.025
Aluminized film	Blow molding/tape casting	1.0-1.25	0.025-0.031
Five-layer co-extrusion VIF film	Blow molding	0.9-1.25	0.022-0.031
	Tape casting	1.0-1.25	0.025-0.031
Five-layer co-extrusion TIF film	Blow molding	1.1-1.25	0.027-0.031
	Tape casting	1.25	0.031

Source: Intergro

1.3 Collection and Recycling of Agricultural Plastics

The U.S. Environmental Protection Agency has developed a national strategy to increase the waste recycling rate to 50% by 2030, and most states have introduced regulations on resource recycling (Office of the Spokesperson, n.d.). However, there is no mandatory or incentivized policy on the recycling of used agricultural plastics, and the market mechanism still plays a vital role in the recycling practices within this sector (Mancl, K., 2020).

In terms of agricultural plastic containers and packaging, the ACRC, a voluntary EPR alliance initiated by 11 producers, has been organizing the recycling of agricultural HDPE plastics since 1992 (ACRC, n.d.). The ACRC focuses primarily on recycling chemical containers such as those for pesticides and herbicides across the United States. Over the past three decades, the ACRC has recycled 100 kt of plastics for the production of drain tiles, fences, plastic baskets and flowerpots rather than delivering them to landfills. Currently, the ACRC boasts a membership of 50. The Missouri Botanical Garden in St. Louis has also voluntarily initiated a collection scheme, recycling horticultural plastics such as plastic flowerpots from gardens and households.

Plastic irrigation pipes exhibit favorable characteristics in terms of cleanliness and recyclability. A producer in California has managed to keep its products in a closed loop system during the entire life cycle. After the collected used irrigation pipes are shredded, cleaned, and pelletized, they are directly made into new products for sale (Office of the Spokesperson, n.d.). Since 1999, the non-profit clearinghouse Southern Waste Information eXchange, Inc. has been promoting recycling in Florida, where irrigation pipes are widely used. In this region, farmers roll up plastic pipes and return them to the producer. In doing so, they are eligible for discounts when purchasing new products.

Voluntary recycling projects for agricultural film were implemented in many regions, but none of them have been able to sustain long-term operation. The Plastic Film Recycling project funded by the ACC's Plastics Division currently only targets plastic film packaging and is committed to achieving collection and recycling rates of 100% (including energy recovery) by 2040.

Figure 19 Irrigation pipe collection in Florida, USA

Source: Waste Advantage

American farmers almost fully collect mulch film, as they recognize the adverse impact that residual mulch film will adversely affect farming. Also, mulch film is relatively thick, further emphasizing the importance of its proper collection and disposal by farmers. In areas with a small amount of mulch film waste, waste disposal agents collect and deliver it to landfills/incineration power plants, where no other options are available (McDaniel, D., 2022). It is mainly due to the high contamination rate in the United States, which is generally 60% to 70%. The SAC tried to use mulch film waste instead of coal as a fuel in cement plants, for mulch film has a high calorific value and this process is cleaner than coal burning. However, mulch film with high sediment content could cause a lot of damage to crusher blades during the pre-treatment (shredding) stage, so the blades needed to be changed every week. The huge economic costs (USD 16,000) prompted the SAC to stop collecting mulch film.

Collectors can always be found in areas with a large quantity of used mulch film. Most of used mulch film was mainly exported to China, Vietnam, and Malaysia. As these three countries banned the import of plastic waste, used agricultural film could only be disposed of within the country. Due to a lack of recycling facilities, they were eventually sent for incineration/landfill, or directly incinerated on the spot. It is worth noting that one-third of all mulch film in the United States is used in Florida, where in-situ incineration is allowed by law (Florida Administrative Code 403.707 (2)(e)) under certain conditions (Jones, G., 2018) . Despite appeals from environmental groups and experts to revise the regulations, the practice of in-situ incineration has not yet been prohibited.

There are not many recyclers in the United States who can process agricultural PE film with a high contamination rate, mainly due to low profitability. In many cases, agricultural plastic producers can find a suitable business model for investing in recycling. For instance, Delta Plastics, a leading company in the manufacture of plastic irrigation pipes in the United States, made a significant investment in 1998. They established a recycling plant with an annual processing capacity of 67 kt of waste in Arkansas in the southern region of the United States. This plant is capable of cleaning and recycling agricultural plastics with a high soil content such as greenhouse film, mulch film, and irrigation pipes (Delta Plastics, n.d.). Conventional pelleting is used in the United States for recycling agricultural film.

2 Canada

2.1 Consumption of Agricultural Plastics

In Canada, agricultural plastics are mainly used in livestock farming. Key applications include silage film, netting, twine, irrigation pipes, and packaging bags and barrels, but mulch film only accounts for a small proportion. There is insufficient data on the consumption of each type of plastics.

2.2 Collection and Recycling of Agricultural Plastics

According to the Economic Study of the Canadian Plastic Industry, Markets and Waste released by Environment and Climate Change Canada in 2019 , 46 kt of non-packaging APW was generated in Canada (Environment and Climate Change Canada, 2019). This represents around 1% of the total amount of plastic waste generated. Most of the non-packaging plastic waste was landfilled, while only a small portion was incinerated for power generation. The recycling rate is about 10%.

As early as 1989, the voluntary EPR alliance Crop Life started to collect used pesticide and fertilizer containers in Alberta, and it was renamed Cleanfarms in 2010 (McConnell, B., 2019) . It serves as the only non-profit organization in Canada that collects and recycles agricultural plastics. With the emphasis by state governments on APW management and the support of companies and farmers from all over the country, the alliance has now covered 10 provinces in Southern Canada and five types of agricultural plastics as shown in Table 16 and Figure 20. This extensive coverage has garnered the participation of 80 producers, distributors and retailers. Cleanfarms operates three province-wide regulated programs (i.e., mandatory EPR), including the collection of grain bags in Saskatchewan and the collection of agricultural plastic containers in Manitoba and Quebec. In 2021, 80% of Canada's agricultural plastic containers were collected through the scheme.

Figure 20 Regions implementing the Cleanfarms scheme in Canada

(See Table 16 for province details)

Source: Cleanfarms

Table 16 Development of Canada's Cleanfarms scheme in 2021

No.	Provinces	Fertilizer/Pesticide containers (≤ 23 L)	Pesticide drums/ tanks (>23L)	Used pesticides & animal medications	Bags	Agricultural film & twine
1	British Columbia	X	X	X	P	P
2	Alberta	X	X	X	P	P
3	Saskatchewan	X	X	X	X	P
4	Manitoba	X	X	X	X	P
5	Ontario	X	X	X	X	P
6	Quebec	X	X	X	X	P
7	New Brunswick	X	X	X	X	
8	Nova Scotia	X	X	X	X	
9	Prince Edward Island	X	X	X	X	P
10	Newfoundland			X		
Amount of waste collected in 2021		143 million	318,000	3,958 tonnes	13,000 tonnes	

Note: "X" stands for long-term implementation of the Cleanfarms scheme, and "P" stands for pilot tests.

As China banned the import of plastic waste, the disposal of agricultural film, packaging bags and other plastics has drawn public attention. Many provinces have provided subsidies for the Cleanfarms scheme to carry out pilot tests. An increasing number of local recyclers have expanded the end market. Compressors are employed on pilot farms to compress silage film, which allows for the compression of approximately 200 to 250 silage bags into a single bale weighing 450 kg), in order to reduce transportation costs. The recycling method is physical granulation. The film is processed through pelleting, and recycled pellets are used to make garbage bags, pipes, plastic wood, and so on. Meanwhile, Canada is experimenting with the production of agricultural film from used grain bags.

Chapter 5

Recommendations

Mulch film is one of the most important production materials in China’ s agricultural sector. In the past decade, China's annual consumption of mulch film has exceeded 1.3 million tonnes, ranking first in the world. Mulch film is irreplaceable for efficient farming and farmers' income growth, also for the effective supply of agricultural products and food security. Despite their benefits, the pollution caused by mulch film residue can hardly be ignored. To tackle this problem, the scientific use of mulch film is highly recommended, along with improving their recycling and replacement. China pays great attention to the pollution caused by mulch film, taking a number of actions in terms of issuing quality standards, strengthen supervision and recycling mechanisms, and has made enormous progress in addressing this issue. In fact, regarding mulch residue, many developed countries also face similar challenges, caused by film insufficient collection, high recycling costs, limited end markets and incomplete value chain collaboration. Countries with a huge consumption of mulch film are paying more attention to the topic and are exploring better tailor-made solutions. Meanwhile, lessons can also be learned from countries with limited use of agricultural plastics. Drawing on international practices in agricultural plastics management, this report proposes the next steps for managing mulch film residues in China from three aspects, including policy management, scientific research, cooperation and exchange.

1 Innovative recycling mechanism to strengthen life cycle management

1.1 Defining the Obligations along the Value Chain

Regarding various responsibilities of all parties in the value chain, scientific clarification and supervision is a key factor in achieving a high recycling rate of agricultural film. In Japan, policies on agricultural film recycling mainly focus on value chain management, where the obligations of farmers, producers, collectors, recyclers and governments have also been clarified. A robust policy scheme and well-developed recycling network lead to high recycling rate of mulch residues in Japan. In Europe, among several mulch film recycling models, the French voluntary collection scheme currently performs best, as it connects all stakeholders in the chain while clarifying the responsibilities of each party. The results of the EU’s policy modeling also show that a mandatory EPR system with compulsory farmers' participation, that is, to define the obligations of producers and users, is the most effective policy combination.

According to Article 30 of Soil Pollution Prevention Law and Article 88 of Circular Economy Promotion Law, producers, sellers and consumers of mulch film in China are all required to collect, recycle and dispose the mulch film in a timely manner but the responsibilities of the above-mentioned parties, collection and recycling enterprises, and governments are not clearly defined. The need to further clarify the responsibilities of all parties has placed greater demands on policy makers. Taking the local condition and other factors into consideration, as a result, piloting the policy practice in a small scope can contribute to a suitable responsibility framework, which can be further stimulated using legislation. This will be an important prerequisite for a breakthrough in this area.

1.2 EPR Schemes

The core principle of EPR is that producers bear the full net cost of waste collection, transportation and recycling. However, recycled material of mulch film has low profitability, jointly with the cheap new mulches lead to producers’ reluctance to bear relatively high disposal and recycling costs, creating obstacles for the design of EPR. Therefore, in all the mandatory and voluntary EPR schemes studied in this paper, farmers as consumers will bear part of the costs to share the burden.

China has also experimented with various mulch film recycling mechanisms: (1) incentivized EPR, where producers take the responsibility of recycling, and they will be shortlisted in the government procurement catalogue when the government purchase new mulch film as incentives for producers; (2) agri-processing enterprises who voluntarily perform ecological compensation (e.g., tobacco companies that subsidize farmers and cooperatives encouraging them to collect mulch film residues and recycle them into tobacco seedling trays or other products); (3) a model where the government incentivizes farmers and recycling companies with rewards or subsidies; (4) and a mechanism based on the payment of a recycling deposit in advance, mainly for large-scale farmland. The main bearer of the net cost of mulch film collection and recycling in China is still the government, who provides different forms of subsidies or incentives to producers, farmers or recycling and processing enterprises. However, this model is only a temporary solution. Establishing a scientific EPR scheme that allows market players to play an active role is the long-term goal of policy makers.

Transferring payment responsibility from users to producers is an attempt at EPR for mulch film in China. Commonly, in developed countries, the cost of recycling used mulch film is partly borne by farmers. But considering the significant income gap between Chinese and European farmers, most of the recycling responsibility will be borne by producers in China. A shift in the responsible party can force producers to improve the quality of their products and provide the basis enabling mulch film recycling. According to international experience, under the EPR scheme, producers tend to affiliate with professional associations for collection and recycling. Farmers are encouraged to collect used agricultural film and collected film will be sold to recycling processors. New business models may be stimulated in this process if producers take the responsibility. Large farms perhaps can directly purchase the full life-cycle service for mulch film, rather than just the product itself.

1.3 Awareness of Farmers

The clarification of user' responsibility for collection is also one of the key factors in mulch film recycling. After studying different countries here with NCS for agricultural plastics, one thing that they have in common is the practice that farmers are paying fee for waste collection and disposal. When the fee for mulch film collection and recycling is lower than the general waste disposal fee, farmers will be incentivized to do so and willing to share some of the costs for collection and recycling. Some countries even force farmers to pay when the waste is collected or when they are purchasing products. Japan has introduced an extremely harsh penalty system for farmers who burn or illegally dump waste agricultural film. In contrast, Cicloagro in Spain did not charge farmers any fee or provide any reward, leaving farmers with no incentive to participate and collect film as required. That is one of the reasons why the collection scheme in Spain is not sustainable. Therefore, motivating farmers using various approaches must be considered.

The user-pays model in international practices and harsh penalties may not be suitable for China. Incentives for farmers on recycling issue are already in place in China, including offering financial rewards, discounts while purchasing new mulches, exchange mulch residues for groceries, and deposit return schemes. These are all internationally accepted practices.

Incentives should be chosen according to the local context. Innovative incentives for agricultural production should be considered, such as adding the selection of mulch film properties and its collection performance as an evaluation criteria for political agricultural guarantee loans and agricultural insurance.

In addition to the economic measures, easy operation and proximity to collection points are also vital for farmers to decide on their participation. Awareness raising activities are also commonly used to mobilize their actions. In Japan, the scattered distribution of farmers and waste mulch film make it difficult to merely rely on farmers' self-motivation. Instead, governments and institutions at all levels are required to establish a better collection system. Meanwhile, farmers should have access to scientific collection methods and recycling routes. This reminds us that strengthening farmers' awareness on scientific use, proper mulching, collection and cleaning, dangers of film residues are essential. Thus, related communication and knowledge sharing should also be a priority in the future.

1.4 Cooperation between Government Departments

Globally, establishing NCSs is the most commonly used approach to monitoring and managing agricultural plastics recycling. There will be a national implementation body that is responsible for coordinating collection, transportation and recycling, usually in the form of association or alliance. Generally, it can cover the entire or large part of the country through different forms of organization. It will involve almost all the main players in the value chain, including manufacturers, distributors, farmers, collectors, and recyclers, who are subject to government supervision. In some countries such NCS is mandatory endorsed by national policies and regulations, while in other countries it is voluntary.

Administrative Measures for Agricultural Film, released and implemented by China in 2020, also follows the idea of life cycle management. It clarifies the main responsibility of local governments and establishes a management mechanism characterized by multi-departmental collaboration. The Ministry of Industry and Information Technology is in charge of the production and selling process, and the State Administration for Market Regulation is responsible for product quality supervision. The Ministry of Agriculture and Rural Affairs is responsible for the supervision, management and guidance of the use and recycling of mulch film, and the Ministry of Ecology and Environment is responsible for the supervision and management of environmental pollution prevention during

the recycling and reuse process. And in the Notice on Solid Promotion of Plastic Pollution Control in 2020 issued by the National Development and Reform Commission jointly with eight ministries, it has mentioned that the Ministry of Agriculture and Rural Affairs, in conjunction with supply and marketing cooperatives, should organize professional collection and recycling. In 2021, the Action Plan for Plastic Pollution Control of the 14th Five-Year Plan proposed to integrate the agricultural film disposal into the rural waste collection and transportation system. The sanitation department under the Ministry of Housing and Urban-Rural Development will carry out agricultural film disposal, but no specific policy has been introduced for the follow-up process (recycling or incineration).

Unlike other countries, there is no specialized department or organization in China dedicated to coordinating the collection and recycling of mulch residues film. Constant overlap of responsibilities between different departments is perceived in the mulch film collection and recycling process. Therefore, it is suggested to set up a special committee/working group/association, which can monitor and supervise the mulch film collection and recycling and coordinate all relevant authorities and stakeholders along the value chain. After the pilot implementation in smaller scope, extension to the whole country can be then considered.

1.5 Electronic Traceability Tools

Electronic traceability tools have been applied in many fields. Their application to trace agricultural products has started in countries and regions such as the EU, Japan and North America since the early 2000s. Full coverage of digital traceability has been achieved in the EU's fisheries sector. Now the EU is considering promoting digital supervision in the field of electronic products such as power batteries. With the constant development of the Green Deal for Europe, more information on the environmental/carbon footprint of products will be disclosed in the "digital product passport". Digitalization has become inevitable, and information on the usage of pesticides and agricultural film as well as carbon emissions of agricultural products may be included in their digital product labels.

China has established a management ledger system for the usage and collection of mulch film, recording the whole process of mulch film production, use and collection. Some municipalities have gradually incorporated the use and recycling of agricultural film into the existing pesticide management information platform and accept public supervision. Drawing on the EU's "digital product passport", it is recommended that electronic traceability management tools, such as product QR codes, can be used. The QR code and the digital traceability tool can upgrade the existing management ledger to a unified national or regional information platform. This tool can prevent information tampering and facilitate scientific evaluation and supervision. Subsequently, all APW including packaging waste can be integrated for systematic management. It can also provide the necessary basis for traceability information that may be required for China's agricultural exports in the future.

2 Research and Innovation

2.1 Evaluation Indicators for High-strength Mulch Film

Mechanical strength (including tensile stress at break and tensile strain at break), as an important factor, directly affects the collection rate of mulch film. The higher the integrity of the mulch residue during collection, the less mulch debris remains. This also leads to a lower impurity rate, which is easier to be transported and recycled with lower cost. Moreover, high-strength mulch film can effectively prevent tearing during use, thus better ensuring their effectiveness.

Thickness does not appear to be the only factor that affects mechanical strength. Innovative designs (e.g., raw materials with high quality, special additives, and multi-layer film structure) will greatly enhance the strength of mulch film. Using the innovative design, even the thickness of film is below 0.015 mm, its mechanical strength can even exceed the national standard requested on the film with a thickness of 0.030 mm. In response to chaotic market in China with a number of ultra-thin mulch film, Technical Guidance for Scientific Use and Recycling of Mulch Film on Pilot (REEA of MARA, 2022), increases the nominal thickness of high-strength mulch film to 0.015 mm. This can serve as a benchmark and can be easily monitored and supervised. However, in comparison to European standards for mulch film, China's request on the mechanical strength indicator is lower. Therefore, this report recommends a more ambitious national standard for mechanical strength, encouraging producers to improve the quality of their products using innovative

approaches, in order to realize a higher collection rate. Though international standards can be seen as a benchmark, it is also necessary to take our local crop types and climate conditions into consideration while determining the values for mechanical strength and product thickness in China. Only in this way, the agricultural production and film collection/recycling can be guaranteed in parallel. In addition, it is recommended to consider the excellent performance of innovative high-strength mulch film, instead of sticking to parameter commonly used in international standards, such as limit the thickness to above 0.020 mm.

2.2 Technological Innovation in the Value Chain

The innovation of high-strength mulch film (e.g., special structure and optimized recipes) should be highlighted to reduce the whole life cycle costs of the product and increase the economic efficiency of agricultural production. During the collection process, it is also necessary to develop various types of machinery, which are efficient, economical and adaptable to different working conditions. Such as the RAFU technology in France, it can roll up and clean the mulch film while harvesting the crops.

In addition, development of mobile pre-cleaning equipment for mulch film can be seen as a solution as well. For areas that are not suitable for mechanical collection, a high impurity rate can be foreseen. Thus, using pre-cleaning equipment to pretreat the mulch film residues can significantly reduce the contamination rate and transportation costs. A more efficient pre-treatment process of recycling is also required to optimize the quality of post-consumer recyclates (PCR) and increase the profitability of recycled materials. Moreover, innovative techniques should be applied to further improve the quality of recycled materials. Using the PCR in a high-value way within large and stable end markets is significant for the recycling process. While bringing higher profits to the recycling part, the entire value chain can be stimulated and linked tightly in a sustainable model.

3 International Exchange and Cooperation

Plastic pollution is a topic of global importance. In March 2022, Draft Resolution to End Plastic Pollution was adopted in the fifth session of the United Nations Environment Assembly. 175 countries committed to develop an international legally binding agreement by 2024. The FAO has also called attention to the issue of microplastic pollution in the soil, indicating that microplastics in the soil, compared with the ones in ocean, are a greater threat to human health and the environment. Agricultural film, as a major potential source of microplastics in the soil, will also be a topic worthy of exploration by all countries. The report believes that the establishment of uniform standards and testing methods is of great importance in the evaluation of microplastics in the soil.

The EU report on Conventional and Biodegradable Plastics in Agriculture mentions that 4,750–20,750 tonnes of mulch film will be left on farmland in Europe each year (i.e., a residual rate of 75%–95%). If the mulch film collection rate can increase to 99%, 3,920 to 19,920 tonnes of plastic residues in the soil will be reduced annually. Compared with the goal to reduce 2,750–12,000 tonnes of marine plastic waste per year, which is required in Single-Use Plastics Directive by the EU, a decrease in the mulch film residual rate and an increase of the mulch film collection rate will have a greater effect on tackling plastic pollution. In terms of mulch film use and its end-of-life management, despite the different challenges faced by countries around the world, exchanges on experience and collaboration for innovations still remain one of the best options to address global challenges together.

Annex

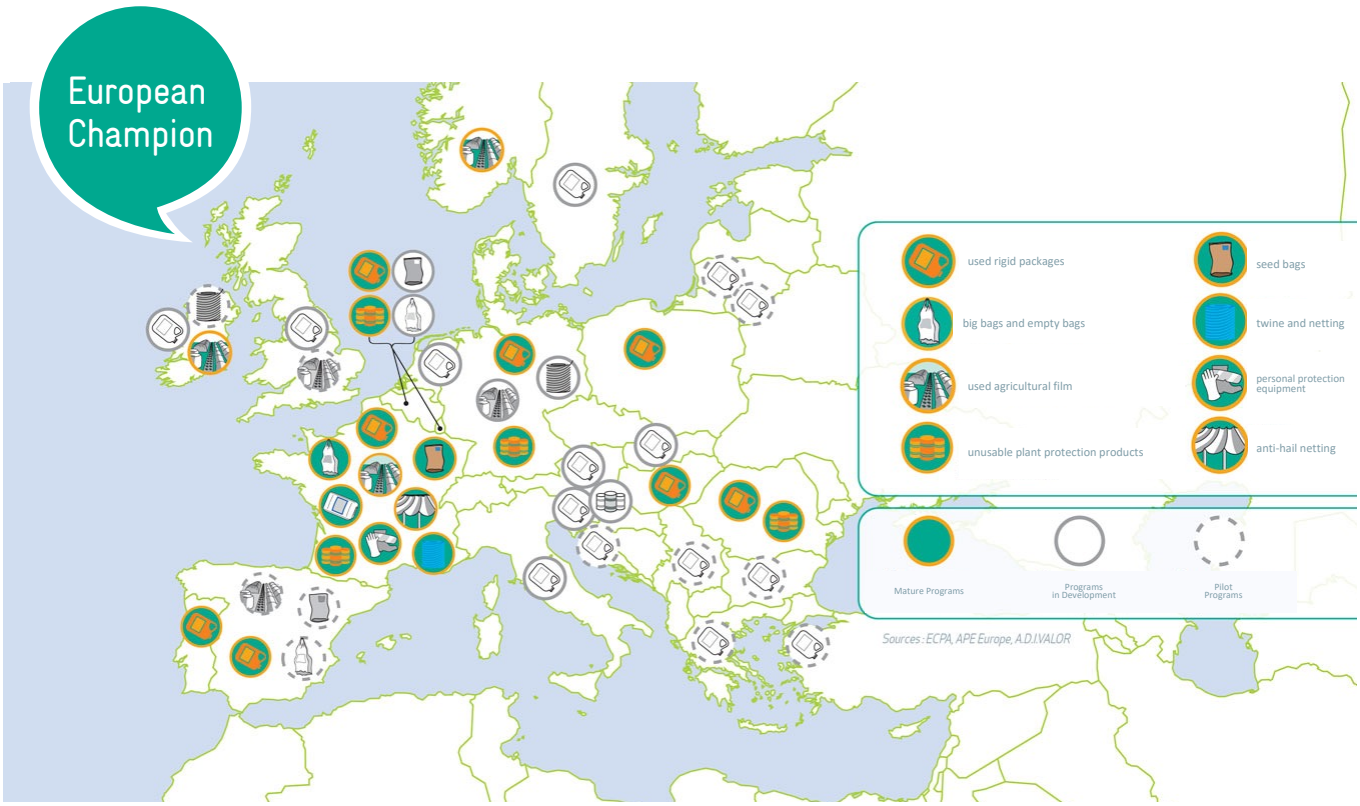
National EPR/Collection Schemes Promoting Recycling of Agricultural Plastics

1. A.D.I.VALOR in France

A.D.I.VALOR was established in 2001 under the initiative of the UIPP (A.D.I.VALOR, n.d.). As a voluntary national alliance in France engaged in agricultural waste recycling, A.D.I.VALOR achieved a coverage rate of 98%, a collection rate of 70%, and a recycling rate of 76% in 2020. A.D.I.VALOR's notable achievements position them as a frontrunner in the field of agricultural waste recycling within Europe.

A.D.I.VALOR is jointly operated by 10 organizations representing companies, distributors and farmers. Based on the principle of joint liability and voluntary commitments, it ensures safe disposal and effective recycling of various used crop protection products. At present, it has covered more than 20 types of waste in four categories: packaging waste, expired/ineffective crop protection products, agricultural film, and twine and netting.

Figure 21 Types and distribution of agricultural waste recycled by A.D.I.VALOR in France

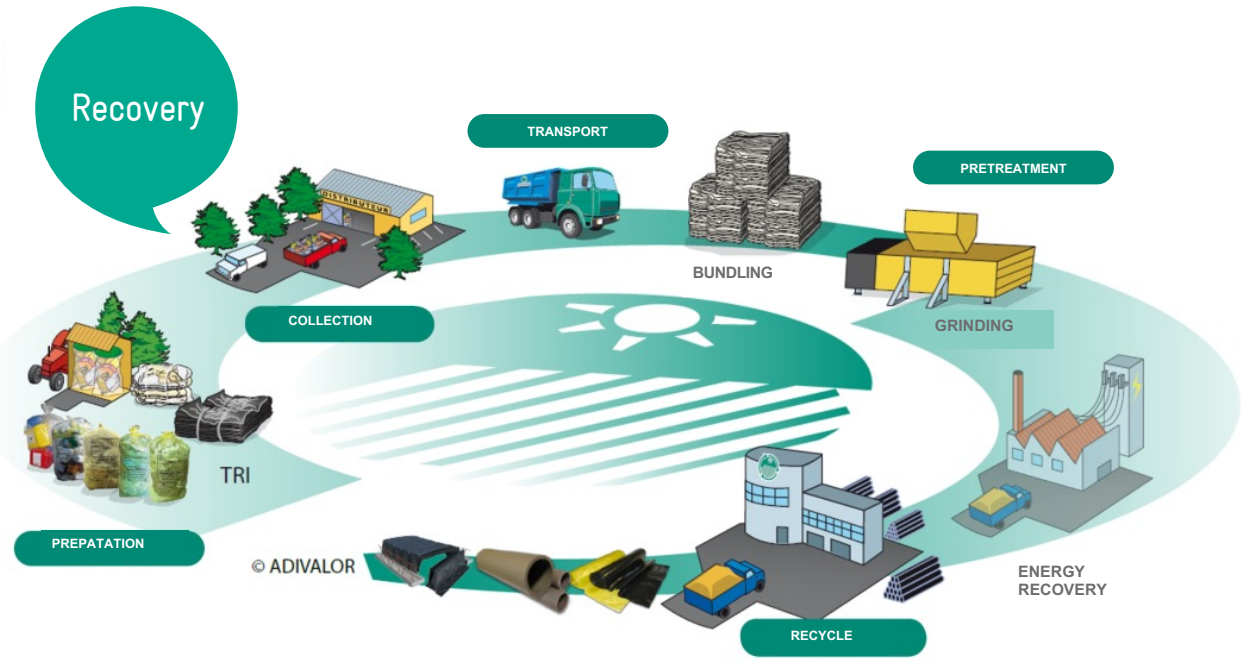


Source: A.D.I.VALOR

Under the A.D.I.VALOR scheme, the responsibilities of each role along the value chain are as follows:

- producers and importers: fulfilling their responsibilities for their products during the life cycle by paying funds or taxes as an ecological contribution and funding A.D.I.VALOR's recycling system. Producers can also include an A.D.I.VALOR logo or an APE Europe certificate on the packaging, which is conducive to the sales and promotion of products;
- farmers: sorting, cleaning and storing agricultural waste according to recycling requirements and delivering it to designated locations on dates set by operators of waste collection stations;
- local chambers of agriculture and other organizations: providing support and guidance to farmers;
- operators of waste collection stations: registering with A.D.I.VALOR for the franchise, of which more than 90% are agricultural cooperatives or distributors;
- distributors: organizing and managing recycling activities, sorting and storing agricultural waste at waste collection stations, and sending it to recycling companies for subsequent processing;
- recyclers: turning used agricultural plastics into recycled products such as pipes, suitcases, urban public facilities (e.g., benches), drywall, pipe fittings, garbage bags, etc.

Figure 22 Agricultural waste recycling system of A.D.I.VALOR in France



Source: A.D.I.VALOR

As France has limited recycling infrastructure in place, 30% of agricultural film are exported to Spain, Poland and the Netherlands for recycling and processing. To tackle this problem, A.D.I.VALOR will re-build four agricultural plastic recycling plants in France in 2022 and 2023. The plants will be located at the junction of two major agricultural areas in Southern France to reduce transportation distance. Meanwhile, A.D.I.VALOR will establish storage points in remote agricultural areas for the collection and transfer of agricultural plastics, to ensure sufficient supply of plastic waste for plastic recycling plants throughout the year.

Up to now, more than 350 producers and importers, 1,300 operators of waste collection stations and 300,000 farmers have joined A.D.I.VALOR. There are more than 7,000 collection stations, and more than 7.9 tonnes of agricultural plastics and packaging were recycled in 2020, equivalent to 70% of the national consumption. A.D.I.VALOR has signed a framework agreement with the French Ministry of the Environment and the French Ministry of Agriculture and Food, and has set an ambitious goal of achieving collection and recycling rates of 100% for agricultural film in 2023. Since its inclusion in the scheme in 2008, a recycling rate of 99% has been achieved for used agricultural film.

2. POLIECO in Italy

In 2019, Italy launched a PE collection scheme covering greenhouse film and mulch film in the agricultural sector, which is operated by POLIECO, a national PRO founded by the government (Polieco, n.d.). Legislative Decree 152/2006 stipulates that the producers, importers, users, distributors and recyclers of PE products shall participate in either POLIECO or an independent organization (e.g., a private company), and that farmers can temporarily store a maximum of 30 cubic metres of agricultural waste on the farm up to one year.

A fixed annual fee (e.g., EUR 500, equal to RMB 3,580, for farmers associations) is required for joining POLIECO to receive technical, economic, legal advice and regular training services, as well as a sliding scale fee (EUR 15–31/tonne, equal to RMB 105–220/tonne) charged every year for the collection and reuse of PE waste. In addition, an environmental fee of EUR 14 (approx. RMB 100), borne by farmers, is included in the purchasing price of PE products per tonne. However, some farmers turn to private waste collectors instead of joining the program. According to local farmers, private companies will collect used greenhouse film for free or buy them at a certain price, but will charge a collection fee of around EUR 96–250/tonne (approx. RMB 688–1,790/tonne) for mulch film.

At end-2020, POLIECO had approximately 5,000 members, and 351 kt of PE waste was collected for manufacturing 312 kt of recycled products, with a recycling rate of 43%.

3. MAPLA in Spain

The consumption of agricultural film in Spain, especially in Andalusia, is among the top in Europe. As early as 2012, Andalusia formulated EPR policies on APW and authorized Cicloagro, a non-profit organization in the field of agricultural plastics established by Cicloplast, to operate the scheme. The scheme was developed to establish a waste collection and recycling system and work towards an agreement on collection fees by all parties. As of 2016, Cicloagro achieved a collection rate of 80.5%. However, it did not charge farmers any fees, nor did it have any incentives (e.g., subsidies) or additional requirements (e.g., removing impurities from agricultural film). It only charged producers a fixed annual fee, which might drive up product prices. The scheme mainly used the sales revenue from recycled materials, and the price of recycled materials relied heavily on the virgin-plastics market. When the price of oil fell, the revenue from recycled materials might not cover the fixed operation costs. The scheme ended in March 2018, but a collection and recycling network for used agricultural film has come into being in the region, laying the foundation for the recovery of the collection scheme.

With the concerted efforts of ANAIP, Cicloplast and APE Europe, the collection scheme resumed in 2020 and a voluntary alliance MAPLA was thus formed (MAPLA, n.d.). MAPLA has reached 90% of agricultural film producers and distributors in Spain, aiming to collect greenhouse film and mulch film in Andalusia and eventually all non-packaging APW at national level.

4. ERDE in Germany

The ERDE, initiated by six agricultural film producers from the IK in 2013, is the only agricultural plastic recycling alliance in Germany (ERDE-Recycling, 2022). It mainly recycles six categories of agricultural plastics, including silage film, netting, twine, non-woven fabric, asparagus film and perforated film. From 2022, mulch film has also been included in the recycling system.

Producers and distributors fund this voluntary EPR alliance in proportion to their market share. Users, such as contractors and farmers, have the obligation to collect, sort, pack, and clean APW as required, deliver it to designated collection stations, and pay a collection fee (30%–50% lower than the general waste disposal fee). In return, they will receive a CO2 emission reduction certificate. Collection stations are operated by the ERDE's system operator RIGK. Distributors, agricultural cooperatives, contractors, and waste disposal companies can all run a collection station franchise. RIGK will assist them by providing collection specifications and subsidize them considering the amount of waste collected, to encourage collection stations to offer services at competitive rates. The collected plastic waste will be further processed into recycled film or garbage bags by partner recyclers of the ERDE.

Figure 23 Agricultural plastic recycling system of ERDE in Germany

Source: ERDE-recycling

At end-2021, the ERDE system reached 50 producers and 85% of silage film producers joined the system. A total of 581 fixed collection stations and 2,895 mobile collection stations were established to recycle more than 32 kt of agricultural plastics, and the collection rate of silage film reached 51%. The ERDE made a voluntary commitment to the BMU in 2019 to achieve a collection rate of 65% for silage film in 2022.

5. APE UK and UKFPRS in the UK

The UK is one of the countries in Europe with the largest consumption of agricultural plastics. As early as 2005, the British government considered applying EPR to agricultural plastics. After years of attempts and discussions, mandatory EPR was eventually rejected at the public hearing session in 2010, because most stakeholders believed that there was no need for excessive government intervention (Doherty, 2019).

In 2019, with the efforts of APE Europe, a voluntary EPR alliance for non-packaging agricultural plastics, APE UK (APE-UK, n.d.), was set up in the UK, reaching 80% of producers and distributors (ERDE-Recycling, n.d.). In collaboration with a waste management company, it strives to build a collection network covering every corner of the UK to make it easier for farmers to collect APW. However, the operating costs of the alliance are borne by farmers who purchase products in the APE UK scheme (they pay an additional collection fee of GBP 20/tonne when purchasing products). Drawing on the successful experience of other European countries, the APE UK aims to increase the collection rate of non-packaging agricultural plastics in the UK from 30% to over 70% by 2025.

A week after the establishment of the APE UK, agricultural plastic collectors in the UK established the UKFPRS to maintain their market position, which was initiated by several large businesses (Farm XS and Agri-cycle in England, Emerald Isle Recycle in Northern Ireland, and Birch Plastics in Wales). Different from the APE UK, the UKFPRS does not charge farmers any additional fees; instead, it guides farmers in sorting and cleaning used agricultural plastics while offering collection services, which vary from place to place, to increase collection and recycling rates. The UKFPRS has been renamed Green Tractor Scheme (The Green Tractor Scheme, n.d.). It has 17 recycling partners and can collect almost all types of APW, including packaging. The objective of the scheme is to have all farms in the UK equipped to recycle all types of agricultural plastics by 2030.

Both alliances were officially launched in 2021, and it remains unknown how the two competing schemes will affect each other.

The Plastic Packaging Tax, which came into effect in April 2022, covers agricultural plastic packaging. However, Silage film, which functions as a container for the anaerobic fermentation of silage, is not included in the current waste management scheme for agricultural film.

6. IFFPG in Ireland

Ireland is one of the few countries in Europe to have passed legislation to promote the recycling of agricultural plastics. Farm Plastics Regulations, promulgated in 1997, place an obligation on agricultural film producers to recycle used agricultural film, either by offering a deposit-refund scheme or by participating in the IFFPG (Irish Farm Film Producers Group) (IFFPG, n.d.), an EPR scheme authorized by the government. Currently, all companies choose to join the IFFPG instead of offering a deposit-refund scheme.

The IFFPG recycles all APW generated by farmers. Animal husbandry is an important sector of Ireland's economy, so silage film, netting, twine, and packaging are chiefly used, and the consumption of mulch film is very small (0.4 kt).

The IFFPG operates in the following manner. Producers provide about 70% of the operating funds for the recycling scheme by paying a recycling fee of EUR 140 (approx. RMB 1,000) per tonne of plastic products to the IFFPG; and the remaining 30% of costs are borne by farmers. Compared with the general waste collection fee (EUR 70–80 for half a tonne), the IFFPG is a more economical and convenient choice for farmers to dispose of used agricultural plastics (as shown in the figure below). When purchasing products for which producers have paid a recycling fee, farmers can obtain a six-digit tag code (as shown in the figure below) from the distributor and use this code to get a collection fee discount. Farmers need to sort, clean, dry, and pack agricultural waste as required. They can either deliver used agricultural plastics to designated collection stations on a specified date on their own, or book door-to-door recycling services and pay recycling fees depending on the waste type and weight.

Figure 24 Collection fee for half a tonne of used silage film charged by IFFPG in Ireland

Recyle Serivice Type	With Tag Code (500kg)	Without Tag Code (500kg)
Collection Stations	€25 (¥ 190)	€50 (¥ 380)
Door-to-Door Recycling Services	€85 (¥ 650)	€100 (¥ 760)

Source: IFFPG

Figure 25 Recycling tag code of IFFPG in Ireland

Source: IFFPG

Recycling service providers deliver the collected used agricultural plastics to recycling companies, where they are eventually made into garbage bags, pipes, damp-proof roofing, park benches, and more. The IFFPG has reached 40 manufacturing companies and set up 235 collection points. In 2021, 37 kt of agricultural plastics were collected, with a collection rate of 90%.

7. SvepRetur in Sweden

Based on voluntary EPR, agri-plastic waste management in Sweden started as early as 2001, and a relatively stable and mature system has been in place. It is operated by the non-profit alliance SvepRetur (SvepRetur, n.d.) and supervised by the SEPA. Almost all stakeholders in the agricultural sector of Sweden have joined the SvepRetur system.

The actual cost of the collection and recycling system, which varies according to the price of recycled materials and other factors, is directly included in the product price, that is, farmers pay the collection fee when purchasing products. When discarding such products, they only need to sort them as required and put them in the collection point. When purchasing products from producers who have not joined the SvepRetur system, farmers do not need to pay an additional processing fee, but they need to dispose of the waste by themselves. In this case, the used products are disposed of as general waste, and the general waste disposal fee is higher.

The collector KRSAB is appointed by SvepRetur to collect silage film, horticultural film, agricultural plastic packaging, pesticide containers, and other used agricultural plastic products in the system directly from 340 on-farm collection points across Sweden. It is responsible for delivering them to dedicated facilities in Sweden for recycling (mechanical cleaning and pelleting). A small proportion are sent to other countries for recycling, and a very small amount of waste that cannot be recycled (e.g., heavily soiled plastic containers) is sent for incineration/energy recovery. The performance of the SvepRetur system has remained relatively steady since 2014, with an average annual collection rate of 93% and an average annual recycling rate of 90% (based on the total amount of waste collected).

8. GPN in Norway

The GPN, a voluntary EPR alliance for plastic packaging in Norway, was established in 1997 (Grønt Punkt Norge, n.d.). It covers agricultural packaging (e.g., fertilizer and seed bags) and agricultural film (e.g., silage film). Plastic producers and importers bear the cost of waste collection and recycling by paying an environmental fee, and they can place a specific logo on the product packaging. Users no longer need to pay any collection fee.

In 2021, the GPN submitted a report to the Norwegian Environment Agency, pointing out that the collection rate of APW exceeded 90% and that the recycling rate reached 86%.

9. IRF in Iceland

In 2003, Iceland implemented a mandatory EPR scheme for silage film, operated by the state-owned fund IRF. Producers and importers pay a recycling fee as per waste management (including collection, transportation, and recycling) costs. The recycling fee is partially included in the product price and borne by farmers. The cost in 2020 is ISK 28,000/tonne (equivalent to EUR 190/tonne, RMB 1,360/tonne). In addition to setting up fixed collection points, the IRF visits farms to collect used film at least twice a year. As a main plastic recycler in Iceland, Pure North Recycling recycles used film, turns them into plastic sheeting, and sells them to other European countries.

The collection rate of silage film of the IRF is estimated to be around 90% in 2020 (a contamination rate of about 30%).

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SINO-EUROPEAN SUSTAINABLE TRANSITION TOWARDS CIRCULAR ECONOMY

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