high-value products from agricultural residues through sustainable chains

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Deliverable D1.2

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Type

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Person in charge of the deliverable (name and organisation): Burkhard Schaer, Ecozept

Author(s): Jan Linck, Diva Fernandez, Alice Charpigny, Burkhard Schaer, Gang Li, Xingyang Lai

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Abbreviations

Abbreviation	
AWCB	Agricultural wastes, co-products and by-products
BtB	Business to Business
B2C	Business to Consumer
BSG	Brewer's spent grains
CO_2	Carbon dioxide
D	Deliverable (report)
DOA	Description of Action
EFSA	European Food Safety Authority
EU	European Union
EUG	End-User Group
MP	Extracted/ microbial proteins
Mt	Mega ton
PE	Polyethylene
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyric acid
PLA	Polylactide
PP	Polypropylene
PPO	Polyphenylenoxid
RQ	Research question
SDGs	Sustainable development goals
SMEs	Small and medium sized enterprises
SSbD	Safe-and sustainable-by-design
WP	Work Package
WR	Stichting Wageningen Research

1. Executive Summary

The main objective of Task 1.1 within WP 1 is to conduct an analysis of the current management of agricultural residues and examine preferences and expectations of different stakeholders in the value chain with regard to innovative circular value chains based on agricultural residues. Objectives are to identify promising residue streams, regional focus areas, relevant applications and business to business (BtB) markets as well as safe and sustainable by design (SSbD) criteria and prioritized pathways.

In preparation of the stakeholder's consultation, promising residue streams have been identified through a desktop study to get an overall understanding of each feedstock's market potential. The analysis followed an analytical approach in which the promising residue streams were identified by the detection of the main processing, followed by an analysis of the production volume in each country. The volumes were then multiplied by the product-to-residue ratio to estimate the volume of residues generated. As a result of the analysis, tomato, apple, potato, wine grapes and brewer's spent grains were identified as promising residue streams in Europe. Furthermore, peanuts, potato, apple, soybean, wine, brewer's spent grains, citrus and corn were identified as promising residue streams in China. Thereafter, the main processing countries/regions for each feedstock had been identified, further processing per country was estimated from the main production made of that feedstock and then multiplied it with the product-to-residue ratio. This means that, for instance, for potatoes residues from frozen potatoes production are considered representative for the whole sector, which overlooks that residue factors for e.g. potato starch industry is quite different from the frozen potatoes industries. The research on residue streams showed that the volumes of agricultural residues targeted within the project are promising. As a result, biopolyester PHA, microbial proteins, plant polymers and plant biochemicals were identified as end products. Based on the identified residue streams and end products, relevant applications and BtB markets as well as safe and SSbD criteria and prioritised pathways were assessed through expert interviews.

In this regard, two rounds of 17 expert interviews were conducted with experts across the value chain (producers, processors, retailers, end users) using the qualitative Delphi research method. The Delphi method, a structured research technique, gathers expert consensus through iterative rounds of questioning, emphasising representativeness of ideas over sample size. In the AgriLoop project, Ecozept carefully selected European stakeholders in a three-step approach. Firstly, the experts in the areas of interest were identified by the consortium partners, as they are experts in their field with excellent networks within the industry. Secondly, the list of experts was supplemented by the results of the desk research. Finally, snowball sampling was used in the Delphi rounds, where experts suggested other experts in their field. The experts were selected according to their area of expertise. Experts were also identified from across Europe in order to identify regional differences in expert judgement. Overall, this approach ensures that all target groups along the value chain are represented, thus achieving representativeness of ideas and consensus for the target stakeholder groups. A third round of data collection will take place in 2025. This deliverable report presents intermediate results.

By the first round of expert interviews, valuable insights from experts of the End-User Group (EUG) and the main value-chains were collected. The implementation of the methods was successful, and the intermediate results confirm the pertinence of the research strategy. The expert interviews showed that the challenges addressed by the project are well known, such as the need for promising valorisation pathways. They also provided some inspiration on possible valorisation pathways and opportunities, polyhydroxyalkanoates (PHA), PHA applications and extracted/microbial proteins (MP) have been confirmed as promising target end products. The market potential of these products is generally considered to be very high. However, several limitations and potential barriers need to be considered.

The second round of expert interviews validated the results of the previous round and yielded crucial insight into the industry's perception of AgriLoop's targeted residue streams and end products. The expert interviews provide critical insights into stakeholder expectations and market potential for valorisation, both for PHA and MP. Stakeholders emphasise the need for innovative applications of agricultural residues to increase economic benefits and profitability, as well as the need for supportive legislation to harmonise regulations. In the PHA sector, there are calls for improvements in material properties and reductions in production costs to compete effectively with traditional plastics, as well as calls for a clearer regulatory framework to facilitate market entry. The potential for MP in animal feed as a sustainable alternative to conventional proteins depends on competitive pricing and increasing consumer acceptance, particularly among younger generations. In addition, the current under-utilisation of agricultural residues offers significant economic opportunities. Overall, effective valorisation strategies and cooperation are essential to unlock the full potential of these sectors, while addressing challenges such as high production costs and regulatory barriers.

The preliminary report on the market assessment in China highlights key challenges in the use of organic agricultural by-products, such as crop straw, livestock manure and processing residues, due to low recycling rates and inefficient waste treatment methods. The report emphasises the importance of adopting sustainable practices such as the development of bioenergy solutions, organic fertilisers and animal feed from agricultural by-products. It concludes by recommending strategic improvements in policy support, technological innovation and infrastructure to facilitate a circular economy in agriculture, thereby contributing to environmental sustainability and economic growth.

2. Introduction

2.1 Description of Work Package 1

The tasks and results that are the object of this Deliverable Report are embedded in Work Package 1 “Foundational circular & strategic flows” that is led by partner **WR**. In the framework of this Work Package, the following objectives will be achieved:

(1) Estimate the potential; set up SSbD criteria; analyse stakeholders’ preferences; assess B2B market of valorisation pathways,
(2) Estimate EU agricultural residue volumes and potential yields for extraction and microbial fermentation chains based on compositional characteristics and processing yields heuristics,
(3) Identify, quantify potential circularised hazards
(4) Develop a framework for assessing sustainability impacts of the cascading pathways.

In order to achieve these goals, Task 1.1 led by Ecozept, provides a market analysis and research on stakeholders’ expectations. This deliverable report describes the methodology that we applied, provides first results as well as an outlook (roadmap and agenda) for the next steps.

2.2 Background of the deliverable and description of the associated task

The objectives of task 1.1 are to conduct a market analysis and to identify experts’ preferences, acceptances and expectations. In this regard we refer to “experts, this includes stakeholders and business deciders (B2B domain).

According to the DOA, Ecozept will identify potential market opportunities for the AgriLoop innovations by investigating the B2B demand building on the dialogue with stakeholders together with the partners of the consortium. We identified two innovations that we focus our research on: PHA and MP from agricultural residues. We conducted interviews with experts and will continue with this process throughout the project. We will iteratively include stakeholders’ feedback in the development of the projects’ innovations. Furthermore, AgriLoop project partner dss+ will identify promising residue streams, regional focus areas, relevant applications.

Ecozept carries out the tasks and analyses the results, but input of all project partners is necessary at several stages of the work. The results of the market analysis will, for instance, be incorporated in exploitation plans and business modelling, thus data exchange with other tasks and work packages is necessary and takes place. SMEs and industry partners should also provide technical input on the project innovations in preparation for the interviews.

Major experts of the EUG and the main targeted value-chains were interviewed using qualitative research methods to investigate the market potential. The preliminary results lead to this progress report (D1.1). Final results on stakeholder’s assessment of the market and business potential will be included in the report (D1.2) of Task 1.1.

3. Applied methods

In the course of the AgriLoop project, Ecozept's task is to conduct several multi-stage surveys with experts at the beginning, half and after two thirds of the project.

More detailed information about the methods for data collection are described in the following chapters. We describe methods that were already applied and give a short overview about the steps that will be carried out next.

3.1 Desk research

As the conduction of the first stage survey is aspired at the beginning of the project, the research is based on the project description and was extracted from the grant agreement and the description of action.

The first step was the identification of key challenges that would be the focus of the project. From the challenges, key words were derived. These were the following:

- "Cascading agricultural residues biorefineries etc."
- "valorisation"
- "Agricultural by-products"
- "Polyhydroxyalkanoate (PHA) from renewable sources"
- "extracted/ microbial proteins (MP)"

Based on these key words we identified information that was useful for preparing the expert interviews like descriptions of the market for agricultural residues, challenges of promising end-products like PHA and MP, current structure of valorisation of agricultural residues.

3.2 Identification of practical opportunities: promising residue streams, regional focus areas, relevant applications and BtB markets assessment in Europe

The promising residue streams, regional focus areas, relevant applications and assessment of BtB markets in Europe were assessed in the course of D1.1, chapter 2.2 and are therefore not included in the latest Deliverable Report 1.2. In Europe, tomato, apple, potato, wine grapes and brewer's spent grains (BSG) were identified as promising residue streams. In addition, peanut, potato, apple, soybean, wine, BSG, citrus and maize were identified as promising residue streams in China. Finally, updated estimates of residue levels, including for China, are presented in Agriloop D1.5. As the exact data are not critical for the work reported in D1.2, they are not included in D1.2.

3.2.1 Examined end-products

Based on the desk research and the analysis of promising residue streams in chapter 3.2.2 promising end products were identified. Due to the aim to demonstrate the possibility to produce at integrated pilot scale, PHAs, plant extracted polyesters (cutin and suberin), proteins/peptides and polyphenols/carotenoids, as well as MP are examined in pilot plants. The high-value agricultural residue-based end-products resulting on the utilization of the feedstocks via biorefinery and extraction are:

- **Biopolyester PHA**
  - PHA-based materials
    - Blends, composites, multilayers
    - Flexible films and rigid materials
    - textile farming materials
- **Microbial proteins**
  - Microbial protein-based feed (or potentially food)
- **Plant polymers**
- **Plant biochemicals**
  - PPO, carotenoids and cutin

With the help of the stakeholder interviews the industry's expectations and needs, as well as their assessments on the examined end-products will be identified. The interviews will also help to identify bottlenecks.

3.3 Research and surveys on expert level

In the following chapter the methodology of the Delphi survey is described in detail. We describe the general methodology of Delphi and the process of Delphi surveys in AgriLoop, as well as the development of research questions, hypotheses and questionnaires. We also discuss the selection of the Delphi panel and describe its representativeness. Finally, the collaboration with INRAE to optimise the synergies and interaction between the iterative interviews and the innovative computational methods is described.

3.3.1 General methodology: the Delphi method

After having conducted the desk research, experts of the EUG and the main targeted value-chains were interviewed by using qualitative research methods to investigate the market readiness of the innovations of AgriLoop for the B2B sector. In order to do so, we made use of the "Delphi" method. This approach is a systematic, multi-stage and iterative process of several "rounds" (or "waves") of interviews, mainly used to explore the "intuitive" (=non-documented, unwritten) expert knowledge namely in innovative and confidential domains which are complex to investigate (Haber & Schärli, 2021; Bui, Tsai, Tseng, & Ali, 2020; Conchin & Carey, 2018).

A first round of interviews ("Delphi I"), characterized by mainly open question and a semi-structured guideline explored the field of research. The results of this first round are expected to produce hypotheses for further refining and validation in the next round of expert interviewing.

The main principle of our Delphi-approach is a "2 steps forward, one step back movement", the interview (=data collection) rounds alternate with feedback to the experts on individual opinions, experiences, information and knowledge and assessing group judgements. The objectives of Delphi are, thus,

(1) to steer an indirect group communication process

(2) to enable each expert to understand his/her own position with regards to the group's opinion, and to revise or confirm his/her position in the next round of interviews

(3) to obtain, after a certain number of rounds, a reliable consensus of an expert group.

There is a double core benefit of the Delphi technique, it (1) verifies hypotheses and at the same time (2) opens new communication within the expert group (Padel & Midmore, 2005; Okoli & Pawlowski, 2004).

The Delphi approach that we applied for the expert research in AgriLoop consists of 3 rounds in total. This is shown in Table 1.

Table 1: Overview of the framework for Delphi expert survey (own compilation of Ecozept).

Round	Time frame	Type of analysis	Objectives/content	Data collection method	Status
Delphi I	Jun-Aug 2023	Qualitative	Establishment of first insights about identification of market opportunities for the AgriLoop innovations	Phone interview	Data collection finished
Delphi II	Jun-Aug 2024	Qualitative	Validation, consolidation and supplementing of results	Phone interview	Data collection finished
Delphi III	May-Sept 2024	Quantitative	Validation, consolidation and supplementing of results	Phone interview	In planning (not included in this report)

3.3.2 Development of research questions hypotheses

In order to develop the hypotheses for Delphi, we have compiled research questions based on the desired results in the description of action, desk research on the latest scientific publications and taking into account the target stakeholder groups. The research questions (RQ) formulated are listed below:

RQ1. What are the general market opportunities for PHA, PHA-applications and extracted/microbial proteins?

RQ2. What are stakeholders' expectations regarding the valorisation/the function of PHA, PHA-applications and extracted/microbial proteins?

RQ3. What are the actual and potential limits/barriers for PHA, PHA-applications and extracted/microbial proteins?

Once we had identified the main research questions, we used them to formulate hypotheses. The hypotheses relate directly to the research questions and operationalize and concertize them. The answer to the hypotheses is given by the answer to the questions within the questionnaire and the answer to the hypotheses in turn answers the overall research question. The formulated research questions are listed below:

RQ1 What are the general market opportunities for PHA, PHA-applications and extracted/microbial proteins?

PHA

- Due to their biodegradability and biocompatibility, PHA applications are better suitable for agriculture than existing conventional products from petrochemicals.
- The production of PHA is a better valorisation of agricultural by-products than today's standard valorisation.
- Market potential of PHA from agricultural by-products is higher than for conventional agricultural applications from petrochemicals.
- The best applications of PHA in agriculture are mulch films.

MP

- MP from agricultural residues are an equivalent alternative to conventional products regarding its functionalities.
- It is more appropriate to use MP from agricultural by-products in non-feed applications than as feed products
- MP only have market potential for niche applications.

RQ2 What are stakeholders' expectations regarding the valorisation/the function of PHA, PHA-applications and extracted/microbial proteins?

PHA

- PHA for agricultural applications fulfils the same functions as conventional alternatives.
- PHA from agricultural residues must not be more expensive than conventional materials in order to be accepted on the market.

MP

- Extracted/ microbial protein must have the same properties when compared to conventional alternatives (for fish feed, e.g., soybeans or fishmeal).
- Extracted/ microbial protein from agricultural residues cannot be more expensive than conventional feedstuff.

RQ3 What are the actual and potential limits/barriers for PHA, PHA-applications and extracted/microbial proteins?

PHA

- Logistical challenges are the biggest barrier for market potential of PHA for agricultural applications.
- Missing scalability of PHA production is the biggest barrier for market potential of PHA.

MP

- Regional availability of feedstock in Europe is the biggest barrier for processing of extracted/microbial proteins.
- Extracted/microbial proteins make good economic sense compared to conventional proteins.
- Current legislation for the approval of extracted/microbial proteins as feed is the biggest barrier for their market potential.
- Missing scalability of MP is the biggest barrier for their market potential.

3.3.3 Development of the questionnaires

Subsequently to the creation of the research questions and hypotheses, Ecozept drafted a questionnaire with corresponding topics for the experts' assessment of the market potential of the innovations, the experts' expectations regarding the AgriLoop innovations and the experts' needs regarding implementing innovations. In the following the main thematic fields that were explored in the questionnaires are presented. The final version of the guidelines and questionnaires are attached in the Annex of this deliverable deport:

Delphi I:

Valorisation:

Current valorisation of agricultural by-products, strengths and advantages in the current valorisation, challenges regarding the valorisation, payment for current valorisation pathway, satisfaction with valorisation, alternative valorisation pathways, ideal solution for the valorisation, support for valorisation, expectations regarding the valorisation.

PHA:

Assessment of the market opportunities, determining factors of market potential, best applications, not suitable applications, comparison of bio-based and bio-degradable with petrochemical products. advantages of bio-based and bio-degradable PHA applications, disadvantages, other bio-based and bio-degradable applications, not suitable applications; expectations on function, quality, contamination, composite products, purity, price, willingness to pay; challenges regarding the application, solutions, scalability of PHA.

Extracted/ microbial proteins:

Comparison with conventional proteins regarding purpose and function, the best use, other applications, inappropriate applications, promising markets, market potential; expectations regarding quality, compared to conventional proteins, expectations regarding the qualities of agricultural residues as feedstock for processing of MP, willingness to pay; influence of geographical distribution agricultural residues, logistical challenges, other factors limit the market potential, assessment of the costs compared to conventional proteins, price, future development of prices, legislation regarding approval of microbial proteins as feed, scalability.

The final version of the questionnaire is attached in annex I of this deliverable report.

Delphi II

Valorisation:

Current valorisation of agricultural by-products, financial compensation for providing your agricultural by-products, importance of agricultural by-products to the current value chains, satisfaction with the current valorisation, assessment on PHA as an alternative pathway, assessment on positive effects through valorisation, benefits of PHA and MP as an alternative pathway, validation of identified challenges, solutions to existing challenges, expectations on ideal valorisation, assessment on valorisation of residues to PHA as an ideal valorisation process, assessment on crucial factors for ideal valorisation, specification of financial support, expectations in terms of input and output generated, assessment on PHA applications for agriculture, willingness to pay, promising valorisation pathways.

PHA:

Assessment on market potential, validation of previously identified determining factors for market potential, validation of best applications for PHA in agriculture, Perception on competitiveness of PHA compared to conventional alternatives, further attractive applications for PHA, inappropriate applications for PHA, expectations on functional requirements, expectations on specific features for practical usability, Assessment on issue of contamination, validation of previous assessment on supplementation of PHA, Assessment on price development, identification of price factors, validation of previously identified main challenges to the market potential, solutions to current challenges, assessment on scalability.

Extracted/ microbial proteins:

Validation of previous assessment on market potential of MP, assessment on suitable markets, identification of specific functionalities or characteristics of MP, identification of not-existent functionalities, best practical usage of MP, identification of promising applications for MP, expectations on quality and functional requirements of MP, qualities of MP compared to conventional proteins for feed / food, expectations on the qualities of agricultural residues as feedstock for processing of MP, assessment on influence of geographical distribution of agricultural residues on the production of MP, validation of previously identified challenges to the market potential of MP, Identification of factors influencing the price of MP, willingness to pay, assessment on price development, assessment on legislation regarding MP, assessment on scalability of MP, Identification of factors influencing the scalability of MP.

The final version of the questionnaire is attached in annex II of this deliverable report.

3.3.4 Selection of Delphi panel and representativeness of the stakeholder group

The Delphi method is a research technique used to obtain a consensus from a panel of experts in the relevant field through several rounds of questioning. One of the most important phases of the Delphi technique is constituting a Delphi panel by identifying individuals who have the knowledge and expertise on the subject of the study. This phase is essential because the validity of the results depends on the competence and knowledge of the panel members. (Brady, 2015; Habibi et al., 2014; Sablatzky, 2022). In other terms, the Delphi method seeks representativeness less through quantities or size of the sample than through the method that helps to achieve 'representativeness of ideas'. One of the greatest qualities of the Delphi method is its iterative nature, which allows new issues to be raised and for participants to evaluate and compare their own knowledge, opinions and responses with those of others. Consequently, the Delphi methodology itself allows the results of the previous round to be verified. The experts check and verify the statements of their colleagues in the same stakeholder group (Lilja et al., 2011). This principle is applied within the stakeholder interviews of the AgriLoop project. Through iteration and the type of questions asked, the survey goes beyond the group of respondents and thus allows a representative assessment of the real market needs. Indicators for achieving representativeness are:

(1) The statements start to repeat themselves.

(2) Consensus is reached in the iteration.

Within AgriLoop, the target group of stakeholders is clearly defined in the Grant Agreement, more precisely in the Description of Activities: farmers, residue traders, feed, food, biochemical and material producers and users, investors, legislators, policy makers, consumers. The experts in the fields of interest were identified by the consortium partners, as they are experts in their field, have excellent networks within the industry and have targeted contacts. The list of experts was supplemented by the results of the desk research. The experts were selected according to their area of expertise. Experts were also identified from across Europe in order to identify regional differences in expert judgements. Finally, the snowball sampling technique was used during the Delphi rounds. Snowball sampling is one of the most common approaches to sequential sampling. This type of sampling is a non-probability method that is also randomly selected. This method is suitable when the members of a group or community cannot be easily identified. In this method, the researcher first identifies some people and after receiving the information, he/she wants them to introduce other people (Habibi et al., 2014).

The research questions and hypotheses were formulated according to the Delphi method and taking into account the identified target stakeholders. In order to best address the target stakeholders, the questions to answer the research questions and hypotheses were divided into 5 questionnaires. Each questionnaire is aimed at specific target groups:

Table 2: Overview on Questionnaires and their specific target groups (own compilation of Ecozept).

Questionnaire	Target group	Stakeholders of target group
Questionnaire 1:	Suppliers of residual streams	Farmers, residue traders, plant production, food processors
Questionnaire 2	PHA industry	Traders, processors, converters of the end-product PHA, investors
Questionnaire 3	Users of the end-product PHA	Arable farmers/ horticulture businesses as users of the end-product PHA applications
Questionnaire 4	Feed and Food industry	Feed traders and processors of the end-product extracted and microbial proteins & food producers
Questionnaire 5	Potential users of the end-product extracted/ microbial proteins	Livestock farmers and aquaculture, protein producers

The first round of Delphi interviews focused on farmers and end users of PHA applications. The second round will therefore focus on producers, traders and processors of PHA, as well as producers of extracted and microbial proteins. The reason for this, as described above, is that the overall aim of the Delphi method is to ensure that all target groups are adequately and equally represented, thus achieving representativeness of ideas and consensus for the targeted stakeholder groups.

3.3.5 Conduction and analysis of the stakeholder interviews

The conduction of the Delphi method can be divided into three phases.

The **first phase** is the preparation of the interviews. In this phase, the research questions described in 3.4.2 were formulated on the basis of the research objectives in the description of the action, desk research of recent scientific publications and consideration of the target stakeholder groups. On this basis, hypotheses were formulated, and questionnaires were designed to evaluate the hypotheses. The Delphi I and II guidelines contain the questionnaires presented in annex I and annex II. The Delphi II guideline was adapted on the basis of the Delphi I results and aimed at validating these results. In addition, the format of the survey was determined in preparation for the Delphi survey. For Delphi I and II, a qualitative survey format was defined in the form of open questions within a semi-directive questionnaire. The questionnaires were tested in two staged pre-tests. The first test was carried out internally with the research team. The second test was carried out with an external expert. Phase 1 did not end until the questionnaires had been validated twice.

As a first step in the **second phase**, 'Conduction', the experts for the panel were then identified as described in 3.3.4. The experts in the areas of interest were identified by the consortium partners as experts in their field, with excellent networks within the industry and targeted contacts. The list of experts was supplemented by the results of the desk research. The next step was to make initial contact with each expert by telephone. They were briefly informed of the aim of the project and asked if they would be willing to participate in an interview. We decided to motivate the experts non-monetarily by promising them early access to the results. If they agreed, further information about the project was provided in a short email. Participants had to agree to take part in the interviews by completing a consent form on a self-administered online form. The interviews were conducted using a phone/visio conferencing tool and the interview language was English, French, German and Spanish. The interviewees' answers to the interviewers' questions were transcribed directly into a Microsoft Word document and served as the basis for the analysis.

Finally, in the **third phase** 'Analysis', the results of the qualitative interviews were analysed by Ecozept using the MAXQDA software. The approach is a thematic qualitative text analysis to reduce the large amount of qualitative data. The analysis is based on a defined code system, which structures the data according to codes derived from existing literature (deductive codes) and codes derived directly from the interviews (inductive codes). In Delphi I, a code system was created by one researcher and then validated internally by a second researcher. After this, each interview transcript was encoded using the code system. The codes were then combined into summaries. In the main analysis step, the individual codes and summaries were used to compare the assessments, expectations and needs of each expert for each question. The aim of the analysis is to identify consensus, analyse disagreement and sentiment, interpret the results and draw conclusions for recommendations for action in preparation for the second round of stakeholder interviews. Table 3 gives an overview of the Delphi approach used in AgriLoop.

Table 3: Overview of the Delphi Approach carried out in AgriLoop (own compilation of Ecozept based on Beiderbeck et al (2021)).

Preparation *(Phase One)*	Conduction *(Phase Two)*	Analysis *(Phase Three)*

Desk research
• *Screening and analysing scientific papers*
	Software selection
	• *Technical Delphi requirement*
	• *Selection of MAXQDA software*
		Descriptive statistics
		• Qualitative analyses
		  • *Definition of code system*
		  • *Validation of code system*
		  • *Syntax and content analysis*
		• Quantitative analyses (planned for third round)

Initial conceptualization • *Research goal: practical contribution* • *Research setting: future based* • *Delphi questionnaire: context-related*	***Expert selection*** • *Expert selection: Expert nomination, desk research and snowball sampling* • *Selection criteria: Areas of expertise* • *Expert motivation: non-monetary*	**Sentiment analyses** • *Experience and expertise* • *Level of confidence* • *Level of optimism* • *Positive and negative affect*
Formulation sessions • Formulation of research questions, hypothesis, questions based on research • Iterative refinement • Question formats (e.g. flexible, fixed, multiple dates), related information, and additional questions	**Conduction of survey** • *Survey format: Qualitative, context related survey* • *Format of questions: Open questions within a semi-directive questionnaire* • *Survey conduction: time-related, consensus-related*	
Project pre-test • *Pre-test with research team* • *Pre-test with external experts*	**Expert follow-up** • *Appreciation for participation* • *Invitation for follow-up discussion, meetings*	

The interviews in the first round of Delphi with an overall number of 17 experts were conducted from June until August 2023. The interviews of the second round of Delphi with an overall number of 17 experts were conducted from May to September 2024. The survey sample comprised a large spectrum of different kinds of experts. The different characteristics of the participants are depicted in **Fehler! Verweisquelle konnte nicht gefunden werden.**4.

Table 4: Study sample for Delphi I (own compilation of Ecozept).

Expertise	**First round of Delphj interviews (Delphi I)**	**Second round of Delphj interviews (Dephi II)**
	Number of interviews	Number of interviews
Total	17	17
Residual streams/ valorisation	9	3
Bio-engineering/ Biopolymers	2	4
PHA/PHB	4	4
Extracted/ microbial Protein	2	6
Country		
Germany	3	1
Spain	7	3
Belgium	1	1
France	3	4
Netherlands	1	3
Australia	1	/
Switzerland	1	/
Ireland	/	1
Denmark	/	1
United Kingdom	/	1
Type of company		
suppliers of residual streams	9	2
traders, processors, converters of PHA	3	8
users of the PHA applications	3	1
feed traders and processors of extracted and microbial proteins	2	6
Position of the interviewee		
Management	7	5
CEO	2	3
Coordinator	1	3
Production manager/ director	2	2
R&D manager	4	3
Chief New Business Officer	1	1

3.3.6 Set up of the product brief

As the first and second round of the Delphi method are aimed at identifying the market potential and readiness of agricultural-residue-based products, there is no specific product brief. The product brief will be developed and adapted during the course of the project.

3.3.7 Outlook: Round 3 of expert interviews

The next step after having finished the interviews and analysis of Delphi II is to conduct another round of expert interviews. In this third phase, we will validate the hypotheses derived from Delphi II and supplement the results with further expert assessments. The aim is to confront interviewees in the third round of data collection with pre-formulated hypotheses forged in previous interview rounds or derived from literature to verify these results (Padel & Midmore, 2005; Okoli & Pawlowski, 2004; Frewer, et al., 2011). The questionnaire will, inter alia, also include those topics that did not reach consensus during the second round.

3.3.8 Collaborative approach with INRAE

As indicated in the description of the action, the approach used in AgriLoop is twofold, combining iterative interviews (ECOZEPT/DSS+) with innovative computational methods of justification analysis (INRAE) to explore the reasoning behind preferences, thus opening up to conflict management and consensus building (from the Delphi method).

There is a close collaboration between Ecozept and INRAE to optimise the synergies and interaction of the iterative interviews and the innovative computational methods. The first step was to develop a tool for automating the categorisation of interview responses. In the second step, and within the next Delphi round, the preference justification tool will be improved and implemented.

Automation of interview response categorization

To automate the routine task of text annotation in the MAXQDA software (Fig. 1), the ICO team at INRAE has developed a specialized tool called AgriCode. The tool is designed to predict a category or code from Ecozept's category system, which was defined during Delphi I. AgriCode can be particularly useful for automating analysis and/or verifying annotation errors in Delphi II and III (if implemented).

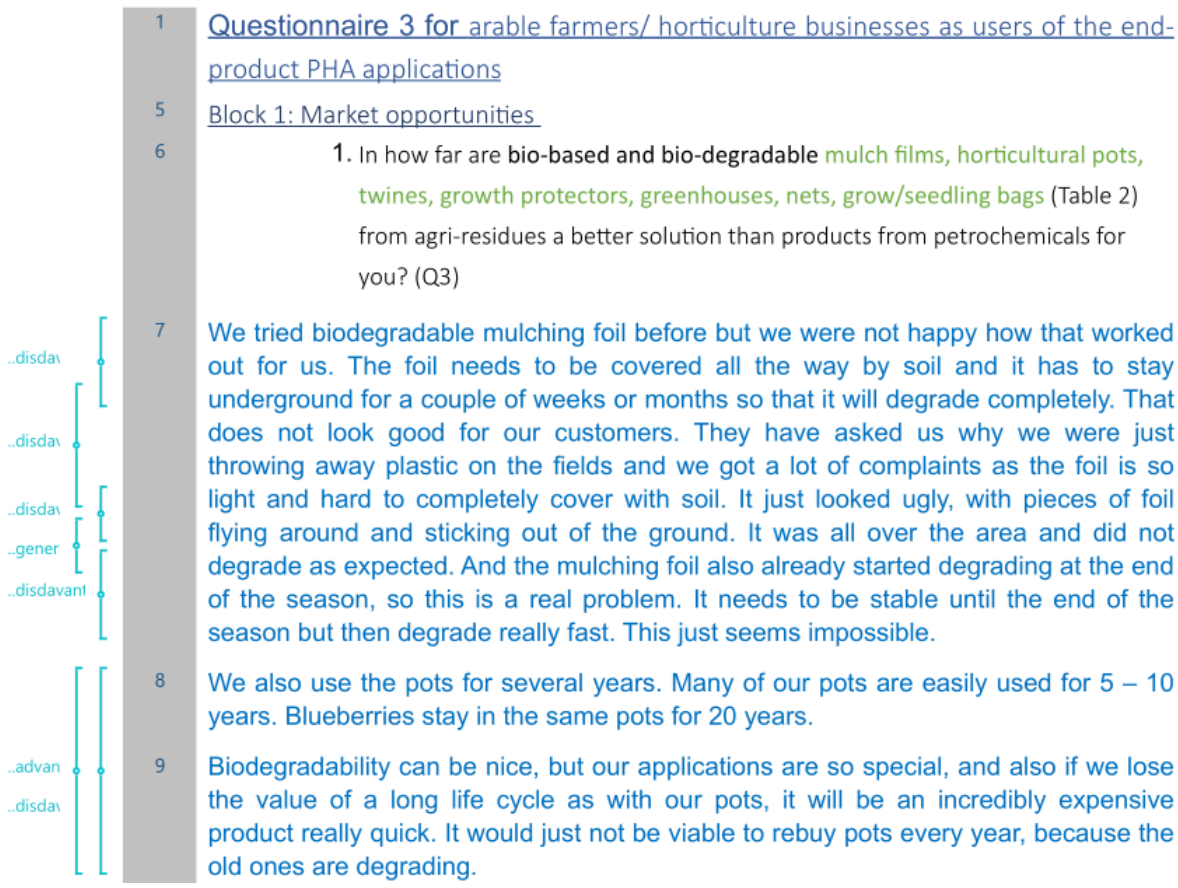

Figure 1: An example of annotation in the MAXQDA software (own compilation of Ecozept).

The AgriCode tool was developed through close collaboration between Ecozept and INRAE. The steps in this process included the following:

(1) Development of a technical assignment for ICO
(2) Analysis by the ICO team of the annotation process performed by Ecozept in MAXQDA
(3) Acquisition by ICO of Ecozept's category system and annotated transcripts from Delphi I
(4) Development of the methodology and the tool's interface by ICO
(5) Evaluation of the tool by Ecozept

The tool is based on machine learning and is trained on the annotated transcripts from Delphi I. To improve prediction quality, the data has been augmented using a state-of-the-art methodology. In this process, data from a relevant project (NoAW – No Agricultural Waste: https://noaw2020.eu) was used as a source for generating new annotated examples. Both the data from Delphi I and NoAW were anonymized beforehand with the permission of the interview participants.

AgriCode can predict both the first level (7 categories) and the combined first and second levels (15 categories) of Ecozept's category system. For each level, predictions can be made at either the paragraph or sentence level (Fig. 2). The 7-category setting offers more robust predictions, achieving up to 88 % accuracy compared to up to 82 % for the 15-category setting. However, the 15-category setting is more useful for manual annotators. Similarly, paragraph-level predictions are more accurate (88 % accuracy for 7 categories and 82 % for 15 categories) than sentence-level predictions (82 % accuracy for 7 categories and 78 % for 15 categories). Nonetheless, sentence-level predictions are more relevant for real-world use cases.

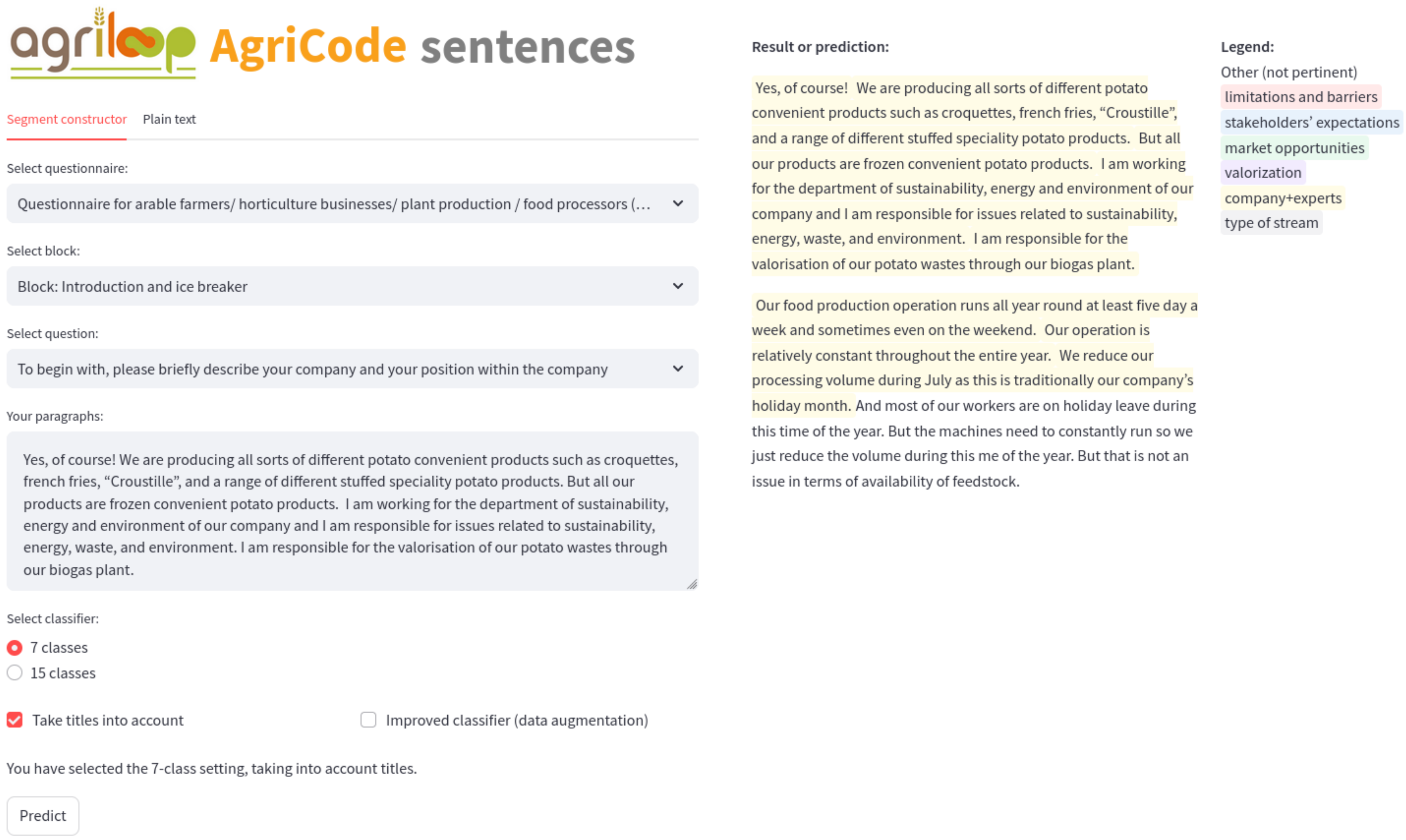

Figure 2 The AgriCode interface in the Sentence classification mode (on the left) and the result of prediction (on the right) (own compilation of INRAE).

In its current state, the tool has some limitations: predictions are limited to a maximum of two levels of the category system, and performance for fine-grained settings could still be improved. The perspectives for AgriCode development are the following: The tool will be evaluated using data from Delphi II. Based on the results, methodological improvements could be made to enhance the tool's performance. Data from Delphi II could be used to improve prediction quality either during the training phase by adding it directly to the main corpus and/or by increasing the number of categories (e.g., predicting for levels 1, 2, and 3 of the category system). Alternatively, data augmentation could be performed using state-of-the-art methods with this new data.

<u>Improving criteria identification and preference ranking</u>

The current methodology has one major limitation: all important criteria are identified manually using a simple frequency method. For example, in order to address the "main issues and challenges in the valorisation of PHA applications", the criteria identified among the respondents' answers were: "price", "legislation", "availability of by-products" and "development". These criteria were then ranked according to their frequency to identify the most, least and intermediate arguments. This methodology could be improved by two steps:

(1) Automating the identification of arguments and frequency calculations by developing a specialised tool.
(2) Using the preference ranking taking into account the justifications previously developed for the NoAW project (Karanikolas et al., 2018; Sohn et al., 2020).

The first task is to develop a text mining tool to semi-automatically find arguments in the interview responses. For example, the user could enter criteria such as 'price', 'legislation', 'availability of by-products' and 'development'. The system would then search for these arguments in the expert responses, highlight them in the text and count the number of experts who mentioned each argument. This could be particularly useful for guiding manual annotation and checking for annotation errors.

The second task aims to achieve a more advanced ranking that takes into account not only the frequency of responses but also the reasons given by respondents. This approach would improve collective decision making in the current project, automate preference aggregation, and increase the transparency and interpretability of the methodology.

A major challenge in applying the NoAW methodology is the lack of a specialised ontology, which is essential for transforming justifications from natural language into a formal language representation. The development of such an ontology requires domain-specific knowledge, including the systematic identification of important concepts and their relationships. As a step towards this goal, a specialised knowledge graph could be constructed to facilitate automatic knowledge extraction in the context of agricultural waste valorisation. This graph would support the development of a specialised ontology and enable the application of preference ranking with justification.

4. Preliminary results of market assessment in Europe

In the following chapters, we present the results of the first and second round of data collection (= round I and II of our Delphi survey). We present the results of the expert interviews conducted with four different expert groups and with a focus on different target products. After each paragraph, the most important findings are summarized in a few sentences. These summaries are highlighted in green.

4.1 Results of the qualitative expert interviews (Delphi I)

Since the interviews were divided into 4 groups and therefore different expert groups, we present the results divided into the 4 paragraphs: agricultural residues, PHA, PHA-applications and MP. Within the paragraphs, we elaborated the stakeholder's expectations, possible limitations or barriers as well as the market opportunities of the different products. All results reflect experts' opinions, and therefore do not claim to be a holistic consideration of the subject matter.

4.1.1 Valorisation of agricultural residues

One of the objectives of WP1 is to look at the current valorisation, to analyse strengths and weaknesses and to capture stakeholders' expectations regarding the valorisation process. Therefore, the current structures, advantages, opportunities and expectations are presented below.

4.1.1.1 Current structure

<u>Current valorisation process</u>

With regard to the current valorisation process, the processes described vary according to the agricultural by-products. For nuts, the shells are combined and sold as biomass or in the form of flour for various applications. The shells are pressed and collected, but there is no use for them yet. The shells are thrown on the field or fed to cattle. One company is taken to an extractor to get the rest of the oil out or thrown on the field.as fertilizer as pomace and lees are compulsory. In the case of fruit, the current process is described as the transformation of the second category of fruit into concentrates for the production of juice. In the case of olives, pomace oil is extracted from the by-products. The common feature of all the processes described is that they add value to the final product. On the other hand, a few operators work with charitable organisations and donate their residues. One expert mentioned that all waste is fed into their own biogas plant.

Payment also varies between by-products. For nut by-products, one expert mentioned that shells are currently paid at 100 €/t and shell flour at 250-300 €/t. With regard to fruit, it was mentioned that the payment varied according to the species. The price range for apples and pears residues is described as 6-18 €/kg, while yellow peach residues are paid around 18 €/kg. In conclusion, the prices paid for olive by-products were given. Pomace oil is paid at 2.10 €/t, pinyol at 160 €/t and dried pomace at 180 €/t. Some experts mentioned that there are by-products for which they are not paid or for which the payment is practically zero.

When considering transport, the experts also mentioned different processes. Several experts described that the transport of by-products from the field to the processing area is paid by the cooperative, as well as the transport from the company to the buyer, which is paid by the buyer. One expert added that there is usually a compensation of the transport costs by the costs paid by the cooperative for the by-product. In contrast, other respondents stated that they pay for the collection, transport or disposal of by-products. However, one company receives subsidies for the collection of by-products.

Intermediate resume

Current valorisation processes vary depending on the agricultural by-products. All processes aim to provide an end-product with a greater value. Transportation is either paid by cooperatives or paid by the company itself.

Main benefits

When considering the main benefits of current valorisation, the experts identified several benefits resulting from the current processes. According to the experts, two of the main benefits were positive environmental and economic effects.

Taking a closer look at the environmental effects, several experts stated that the current valorisation of by-products has a positive impact on the environment and is linked to several Sustainable Development Goals (SDGs). One voice mentioned that there are also benefits in terms of environmental management of by-products by associated companies and cooperatives. In summary, it was stated that a centralised collection of by-products at farm and cooperative level could lead to a reduction in CO_2 emissions. In line with the previous arguments, one expert stated that another additional benefit was the production of renewable energy. It was explained that the by-products are fed directly into the biogas plant. This reduces the dependence on fossil fuels. Finally, the residues from the upgrading process can be used as fertiliser.

Just as often, the experts mentioned economic effects as an advantage of the current valorisation. One of the main benefits mentioned was the elimination of by-product management costs. In this respect, one voice confirmed the ease of outsourcing the management of by-products, which helps to avoid costs and logistics. The experts went on to explain that valorisation has general economic effects. On the one hand, the producers themselves benefit from the process, as it creates new business opportunities, and on the other hand, it can lead to the creation of companies that work with by-products, thus creating new jobs in a region. Finally, one expert mentioned that there is a possibility to get a return on the by-products.

Several experts also mentioned that adding value to by-products is a major advantage. It is in line with a company's ambition to get the best value for its production. In addition, the increase in value was seen as beneficial for the final price paid to farmers. Finally, one voice stated that valorisation makes it possible to build loyalty to the producer, as it allows all of his production to be marketed.

Intermediate resume

Experts highlight key benefits of current valorisation processes, with positive environmental and economic effects at the forefront. The positive environmental impacts linked to SDGs were emphasized, noting that centralised collection of by-products could reduce CO_2 emissions. From an economic perspective, experts point to cost savings associated from reduced by-product management, new business opportunities and added value for both companies and farmers, as well as increased producer loyalty through the ability to market the entire production.

Satisfaction with current valorisation and challenges

Satisfaction with current valorisation is discussed below. As there is a strong correlation between low satisfaction and the main obstacles to valorisation, the challenges are also addressed in this section. The topics are presented in descending order of the frequency with which they were mentioned by the different experts.

As mentioned above, most of the experts described their satisfaction with the current valorisation as low. The most frequently mentioned reason for low satisfaction was profitability. It was stated that the current valorisation does not generate enough profit and that the profitability varies too much depending on the production. It was also said that, at the level of the producer, it does not cover the costs and, at the level of the cooperative, it is done in order not to have to pay the price of destruction. Another voice mentioned that this business model is currently difficult to make profitable, even though a company has diversified enormously in terms of products and markets. It is therefore necessary to constantly improve processes. Finally, two experts highlighted the situation of farmers. Due to the recent increase in costs, some farmers have decided not to pick small fruit, with the consequent loss of labour costs and phytosanitary applications. In summary, the current effort is not being compensated. This is necessary because of the positive social aspect of contributing to social welfare before non-marketable production is damaged.

The second most frequently mentioned issue was legislation. Several experts consider it necessary for legislation to facilitate new ways of working with by-products. The current legislation was described as too restrictive at regional level and still needs to be developed at national level. One voice suggested that it should be harmonised in order to work under the same conditions. On the other hand, one expert pointed out that existing subsidies allow access to the by-products of wine-growing. This shows that favourable legislation could contribute to the valorisation of by-products.

Furthermore, several experts agreed that there are unequal campaigns. It was stated that, depending on the campaign, it is difficult to plan the collection of by-products, as producers do not have a forecast either, and therefore the storage period is extended, which increases the costs for the company. In addition, one expert described the campaigns as uneven in terms of quantity and quality of production.

Contrary to the statements analysed so far, few experts found the current valorisation process satisfactory. One voice described the process as elaborate but well-functioning. Specifically, priority is given to the rapid disposal of residues from food production, which are immediately fed into the company's own biogas plant. The continuous removal of processing waste is successful, as is the disposal of biogas plant residues with the help of a reliable logistics company. Storing the residues would be costly and raise hygiene issues, so smooth cooperation with the logistics company is described as crucial. Another voice stated that there is a high level of satisfaction with the current valorisation because of the convenience of using an external company in the area. In addition, the process addresses environmental issues, thus reducing the carbon footprint. Finally, the solution of legal issues was mentioned, as more and more regulations are needed for the recycling of waste and for the sustainability of the cooperative.

Intermediate resume

Experts express predominantly low satisfaction with current valorisation practices, with profitability being the most frequently cited concern. Profit margins are described as inconsistent and often fail to cover costs, making it difficult to make the business model profitable. Legislation is also identified as a key issue, with experts calling for more supportive and harmonised regional and national regulations to facilitate by-product utilisation. Further, challenges related to unequal campaigns quality are noted. While most experts express low satisfaction, a few find the current valorisation process satisfactory, highlighting effective waste management and environmental benefits, particularly in reducing carbon footprints and meeting regulatory requirements.

4.1.1.2 Stakeholders´ expectations

General expectations and Ideal solution for the valorisation of by-products

When it comes to their expectations, all stakeholders are united in the opinion that the valorisation should generate more profit while adding an increased economic value with new business lines. This will make it possible to obtain a return on the farmers' work and to increase the price of the monetary settlements paid to the farmers by the cooperative. This issue seems to be very important, as one expert described the farmers as poorly paid and the weakest part of the value chain, who are not sufficiently compensated for their work and the products they produce, and for the financial risks they are exposed to in each agricultural campaign. Another voice underlined the importance of a good cost-benefit ratio, as a minimum effort and investment is expected for a maximum benefit. In addition, the expert noted that in the absence of a clear benefit, direct valorisation by the company could not be justified as it would entail logistical and management changes that could not be expected to deliver the desired benefits to the company. However, one expert noted that a financial and human effort will be required as there are many emerging technologies and solutions. In the short term, it is recommended to take advantage of tested options, while in the medium to long term, solutions will be found to adapt to market needs and make the sector more sustainable.

In order to better understand the expectations and wishes of stakeholders, they described their ideal conception of the valorisation process. Several experts agreed that the ideal valorisation process for organic waste should have a high added value. Several voices underlined the importance of added value for producers. From the perspective of farmers and processors, the ideal valorisation process for farmers is to find a profitable way to sell their products while ensuring a stable demand. This can be achieved by extracting high value compounds from by-products that are useful in the agri-food or other sectors. Therefore, the process should take advantage of the properties and compounds of the products for human and animal food. In addition, one expert stated that it should be simple enough to adapt to logistical cycles and use less energy and water. A critical voice, however, doubted that the ideal processes would all require investment, knowledge, time and logistics that are not always properly compensated. Finally, several experts described promising valorisation processes. One said that it would be interesting to be able to use the wastewater together with part of the sorghum as an organic fertiliser. Another company is considering using protein to create new products, but doubts that some by-products may not have enough protein. Other processes described as difficult to obtain included green hydrogen, compounds for the food industry and approved additives in animal feed. On the other hand, a single voice stated that the current solution was the best at the moment and that they were not aware of any other and better valorisation.

Intermediate resume

More profit is expected from the valorisation of by-products. The ideal valorisation process should provide high added value to make the process more profitable. In addition, the process must be simple enough to fit into logistical cycles. Potential valorisation pathways could include organic fertilisers, protein products, green hydrogen and animal feed additives.

Support structure

The factors that can have a supportive impact on valorisation are discussed below. The most frequently mentioned factor by the experts was financial support. One expert stated that financial support is needed to initially carry out small-scale studies which, if positive, can be scaled up to a pilot plant. Another expert considered that support would not be needed if the residues were collected free of charge or if the payment for the residues was fair. The experts also considered legislative support to be important. There was a consensus that a supportive legislative framework was needed to extend authorised additives, e.g. in animal nutrition. In addition, the experts wished for a regulatory framework that did not hinder the commercialisation of the compounds obtained and that was adapted to the reality of the production processes. Finally, several experts mentioned a functioning network and helpful organisational structures as important supporting factors. The networks could create synergies with other companies in the area or possible suppliers/customers of by-products and products. In addition, joint efforts with cooperatives in the sector could make it possible to find the best alternatives and reduce costs such as transport. Several voices mentioned that they were looking for a partner for logistics and residue management. Finally, cooperation between technology centres and applied research at industrial level was identified as supportive. In terms of organisational support, one expert wished for support from the administration and other bodies such as the FCAC and research and technology centres.

Intermediate resume

The main supportive factors with an impact on valorisation identified by the experts were financial support, a favourable legal framework and a functioning network and helpful organisation. Payment should be fair, the legal framework should be adapted to the reality of production and networks should create synergies with other enterprises.

4.1.1.3 Main issues and challenges

In the following, the topics that are seen as the biggest obstacles for the market potential of the current valorisation are discussed. The topics are addressed in decreasing order according to the frequency they were mentioned by the different experts and weight of the argument.

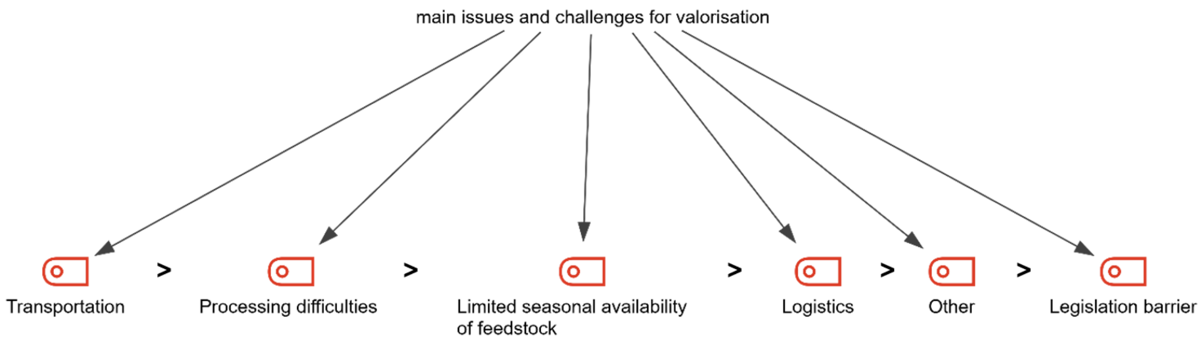

Figure 3: The most frequently cited limitations or challenges to the current valorisation process by experts (own compilation of Ecozept).

Transportation and logistics

Transport and legislation were the most frequently mentioned challenges. Regarding transport, there are certain limitations that make transport costly. In particular, the high water content of digestate makes transport costly. Drying the residues is not feasible due to the high energy and cost requirements. In addition, long transport routes are not feasible with the current water content. Furthermore, one voice expressed the need for sufficient space for collection.

In terms of logistics, all experts agreed that there is currently a problem with the volumes needed to be profitable. One voice stated that large volumes need to be generated in a short time. However, the transformers are sometimes unable to absorb them, resulting in a lower added value to the product. In addition, another expert doubted that the current problems could be caused by environmental conditions (rain and humidity). The second major problem mentioned by several experts is the storage of by-products. One expert pointed out that by-products cannot be stored on central logistics platforms for optimisation purposes, as the raw materials need to be collected and processed quickly. He added that central platforms for concentrating raw materials would require large facilities that meet food standards. Another voice noted the challenge of storing waste during the winter months when farmers cannot fertilise their fields. It was felt that the solution could be to work with an external logistics company. Finally, several experts assessed that hygiene was a major issue in storing the waste, while oxidation and chemical degradation were not a concern.

Intermediate resume

High-water content in fermentation residues makes transport costly. Further, a logistical challenge lies in the volume management as large volumes are needed in order to be profitable. Experts doubted the feasibility of central logistics platforms.

Processing difficulties

The second most frequently mentioned issue was processing difficulties. The experts gave different reasons for the difficulties. Several experts stated that there could be difficulties due to the chemical composition, e.g. high lignin content of grape stalks. In addition, one expert stated that products with a high water content make it difficult to compost the whole fraction. Another voice raised the specific case of almond shells, where the need for prior drying makes the cost of treatment high. Finally, one expert mentioned the changing quality of by-products as a result of climate change. As a result, the compounds extracted from the raw materials can vary.

Intermediate resume

Experts identified processing difficulties due to chemical composition of the co-product as well as changing quality of the by-products as a consequence of climate change.

Limited seasonal availability of feedstock

The limited seasonal availability of raw materials is a major challenge. Due to the seasonality of production, the work is highly seasonal, which is currently exacerbated by the need to work quickly to avoid decomposition in the open air. Depending on the type of raw material, the by-products must be processed within a few months. Another expert identified another challenge in predicting the volume of feedstock. Accurate forecasting of volume is necessary because a constant volume is required to make a very accurate forecast of product availability. Finally, another voice noted that there is a strong correlation between transport and limited seasonal availability.

Intermediate resume

Limited seasonal availability of feedstock is a huge challenge as processing needs to be quick in order to avoid decomposition. Further, precise prediction of the volume is difficult.

Legislation

As mentioned above, the experts considered legislation to be a constraint. It was noted that regional legislation can differ from national legislation. One voice stated that there is a problem to reuse water from olive oil production in agriculture due to the restrictive legislation in Catalonia compared to Spanish legislation. Another expert pointed out that legislation in the field of animal nutrition is highly regulated. Therefore, only one additive is allowed for grapes. Finally, the experts wished for a legal framework that would not hinder the marketing of the compounds obtained and that would be adapted to the reality of the production processes, including the reuse of by-products.

Intermediate resume

Legislation is described as restrictive and diverse. The regulatory framework should not hinder the commercialisation of the compounds obtained and should be adapted to the reality of the production processes.

Solutions

Several experts shared their solutions to the existing challenges. One solution, mentioned by several voices, is the collaboration of technological centres, research and universities with the productive sector in order to deliver and adapt the results to the real needs of the companies. At the same time, it could be useful to pool efforts between companies in the sector in order to reduce costs, for example in transport.

In terms of processes, there is a consensus among the experts that optimising industrial use and transformation would help to reduce the problems of possible odours, seasonality and logistics. One voice further stated that another solution would be to find non-commercial fruit processing products with added value whose transformation could be profitable. Finally, one expert noted the need for new extraction, cleaning, separation, transfer, assembly and concentration processes that consume less water and energy.

Intermediate resume

The collaboration of technological centres, research and universities with the productive sector to deliver, as well as the unification of efforts between companies, is identified as crucial to overcome the challenges. In terms of processes, optimising industrial use and transformation could be a solution to several challenges.

4.1.1.1 Outlook and perspectives

When asked about the outlook for the development of the valorisation process, the experts considered that the economic and market situation of production is not fully taken into account in the scenarios for more profitable valorisation. The experts also identified farmers as key actors in making these scenarios a reality, but a lack of funding and cooperation is hampering progress. However, the valorisation of by-products can add value to the price the farmer receives for his production.

In addition, experts are looking for new solutions to make use of by-products. Possible new applications include food for insects, transformations with microorganisms to obtain compounds of interest such as polymers for the production of bio-plastics, and fermentation to obtain energy and/or green hydrogen. However, when considering biorefineries, the expert noted that trying to exploit everything that can be extracted from a by-product is theoretically simple, but more complicated in practice due to logistical and transport issues, the temporary seasonality of cultivation, and the difficulty of agreeing with cooperatives and companies to resolve the issue of minimum quantities. Finally, one voice stated that they were looking for new solutions for the ornamental plant sector, particularly in terms of reducing peat in substrates and plastic in packaging. They are therefore participating in the SACS project to produce biodegradable bags for horticulture from maize by-products. Development in this sector is focused on research into suitable raw materials and by-products for bioplastics and alternatives to peat.

Intermediate resume

The economic and market situation of production is not fully taken into account in scenarios for more profitable valorisation. Farmers play a crucial role in making these scenarios a reality. The industry is looking for new solutions such as food for insects, transformations with micro-organisms to obtain interesting compounds.

4.1.2 PHA from agricultural residues

In the following, the stakeholders' expectations as well as possible limitations and challenges with regard to PHA´s end-products are illustrated based on the assessments of experts from traders, processors and converters of the end-product PHA. A deliberate distinction was made between experts from traders, processors and converters of the end-product PHA and users of the end-product PHA applications such as arable farming or horticulture businesses, as this allows the different requirements and desires of the groups to be identified.

4.1.2.1 Stakeholders´ expectations

When it comes to stakeholders' expectations, the experts were asked to assess PHA with regard to their expectations and desires in terms of the quality of PHA-products, function of PHA-products and Price development of PHA applications in agriculture.

Quality of PHA-products

Regarding the quality of the PHA product, several experts described that applications for food packaging would require extensive testing for food contact safety, which could be a major challenge. In addition, the experts agreed that GMO-free products are mandatory. In Europe, the cultivation of GMOs is prohibited, so it is necessary to ensure that biodegradable products are GMO-free. Care must therefore be taken to ensure that the bacteria are not genetically modified organisms, as are the raw materials, e.g., transgenic crops. In terms of biodegradability and composability, experts stated that 100 % PHA would be the best choice to create a product that is fully biodegradable and bio-sourced. A blend of PHA and starch was also considered viable. The expert went on to describe that the addition of PLA would change the end-of-life cycle, even if PLA is bio-sourced, due to its difficulty in biodegradation. Finally, the voice mentioned that the composition of PHA material should not be an issue as it is possible to change the basic properties of PHA, in particular its biodegradability. Finally, one expert stated that PHB products need additives to be a plastic. Therefore, they are not compostable as components such as cellulose are not. Finally, one expert stated that the use of lignin in biopolymer films is limited due to its low molecular weight and lack of mechanical properties. In addition, lignin films are not suitable for food contact. Another expert stated that the blending of materials in terms of texture is perfectly feasible, e.g., PHA + cellulose.

Intermediate resume

Experts expect PHA-products to be GMO-free and consider food contact safety to be difficult. 100 % PHA is expected to be the best choice in terms of biodegradability. However, mixtures are practical too. In practice, the addition of PHA helps to achieve the desired functions and properties.

Functionality of PHA-products

With regard to the functionality of PHA products, the experts described their expectations in terms of durability, purity, contamination, compostability, flexibility and in contrast to conventional products. In terms of **service life**, one expert expects clips to be used during the growing season, particularly in the first few months when use is at its peak. The more the plant grows, the less the clip or other production aids will be used. Other experts agreed that the life of a film depends on the type of crop. They added that thin films should be used for crops such as lettuce, while thick films are needed for crops such as peppers. The film should also disintegrate more quickly in crops with less shade.

When it comes to **contamination** and **purity**, there is a strong link between the two. However, expert opinions differ. One expert highlighted the importance of purity in downstream processing, as impurities can lead to brittle and weak material. It was also noted that optical purity also affects material properties, as even tiny bits of cell debris can degrade material quality. In line with this, another expert stated that the raw material must be very pure and uniform in terms of properties, and even more so the raw PHA. If the raw PHA is not pure, it cannot be processed into plastic. Therefore, it cannot be processed with residues from food processing as this could accelerate the degradation rate by a factor of 10 or even 100. On the other hand, one voice argued that there are no additives that would cause a contamination problem. Concerning PHA **composites**, one expert stated that composites with a broad spectrum of nutrients, including nitrogen and phosphate, are described as beneficial for biodegradation as they provide a wider range of nutrients for decomposing organisms. In addition, another expert mentioned that PHA composites lose their flexible properties when straw or lignin is added. Finally, another voice pointed out that there is no use for pure PHA for long term applications (10-15 years life) as there will always be an Esther bond in the mix which can be hydrolysed with water. In conclusion, this voice expects that long term applications with pure PHAs will not work.

Finally, the experts compared PHA products with conventional products. One expert suggested that PHA could be a viable alternative for cheap products such as plastic clips and twine, where it is not feasible to invest time and money in recovery. However, the expert expected that biodegradable mulch film would be the easiest and best application for PHAs at the moment, replacing conventional mulch film, as it could save time and money.

Intermediate resume

Experts expect that the service life should correspond to the type of crop and its growth period. Concerning contamination, purity is very important for material properties as impurities can lead to brittle and weak material. Compostability is expected to be better with composite materials consisting of more than just of PHA. Biodegradable mulch film is expected to be the best application for replacing conventional products.

Price development of PHA applications for agriculture

According to the experts, the cost of PHA has fallen from 5 €/kg to 2.5 €/kg. The experts believe that a number of factors can influence the price development. Copolymers and economies of scale, where larger plant sizes reduce the price, have been identified as influential factors. Research is also being carried out to reduce the cost of working with the bacterial stream and the use of waste streams. Finally, the purification process was identified as a major cost driver in current production and is expected to be reduced.

However, the experts agreed that customers will not accept any price. It is expected that end users and processors will not be willing to pay a significantly higher price compared to conventional products. One voice further estimated that farmers will not pay more than 3-5 % more for PHB-based products. In addition, the expert expects that due to the production process, a price less than 3-5 % higher than for PHB-based products is not feasible, unless there are large scale fermentation plants, e.g. >100,000 tons/year.

Intermediate resume

Experts estimate that the cost of PHA has fallen from 5 €/kg to 2.5 €/kg. However, it is expected that the end consumer will not be willing to pay a price that is significantly higher than the price of conventional products. Farmers will pay no more than 3-5 % more than for PHB-based products. Large scale fermentation plants are needed to achieve lower prices.

4.1.2.2 Main limitations and challenges

In the following, the topics that are seen as the biggest obstacles for the market potential of PHA and PHA-end products are discussed. The topics are addressed in decreasing order according to the frequency they were mentioned by the different experts.

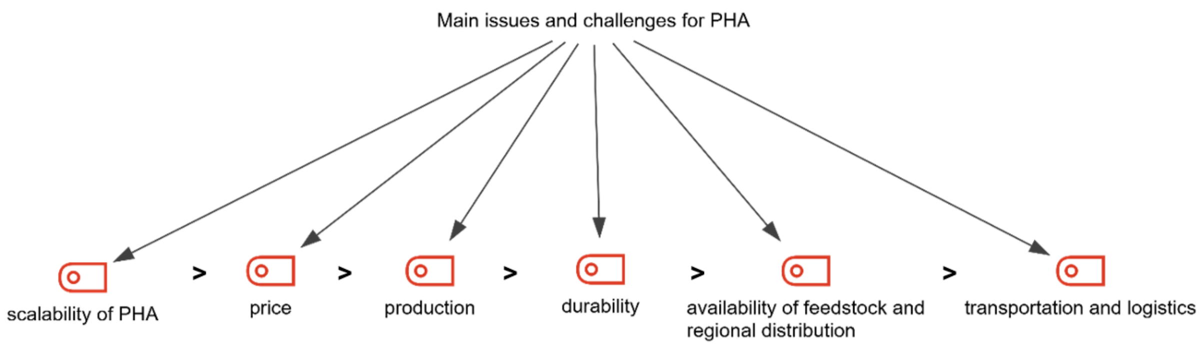

Figure 4: The most frequently cited limitations or challenges for the market potential of PHA by experts (own compilation of Ecozept).

<u>Scalability</u>

Scalability is the most frequently mentioned issue. However, expert opinion is divided. The majority of experts believe that the scalability of PHA production is limited by physics and that it will take at least five to seven years to reach commercial scale production. During the pilot phase, it is expected that companies will have to invest money without seeing revenues in order to achieve economies of scale. In addition, economy of scale is limited by the size of the fermenter. In addition, one voice mentioned that there is only one 50,000 ton production plant, which required a development phase of 40 years. In contrast, another voice believes that the issue of scalability in PHA production can be overcome by increasing the number of bioreactors, as seen in China. The expert further explained that there are technical limitations on the size of bioreactors, but is convinced that these problems can be overcome by increasing the number of bioreactors. Finally, he believes that with sufficient funding, large-scale PHA production could be achieved within 5 to 10 years.

<u>Intermediate resume</u>

Most experts believe that the scalability of PHA production is limited by physics, although one expert estimates that increasing the number of bioreactors could solve the scalability problem within 5 to 10 years.

<u>Price</u>

As described in 3.1.2.1, price could be a major limitation to the market potential of PHA, as end-users and converters are not willing to pay a significantly higher price compared to conventional products. One expert stated that current processes are still too expensive. It was also mentioned that the raw materials only account for about 50 % of the total cost. In addition, PHAs were described as by far the most expensive biopolymer on the market. One voice estimated that they cost €5/kg or more and therefore simply cannot compete with conventional polymers or other biopolymers. Another voice doubted that the cost of PHAs above €5/kg would change in the near future. In addition, it was mentioned that up-scaling requires a significant investment of a few 100 million € as large scale fermentation facilities are needed.

Intermediate resume

Experts have identified price as a key barrier to PHA's market potential. Current prices are too high to compete with conventional polymers or other biopolymers. Upscaling is needed to achieve lower prices, but requires significant investment.

Production

The production of PHAs is also a major challenge. It is described as a difficult and complex process that requires uniform raw materials with predefined properties. Typically, sugar or vegetable oils are used as raw materials, but residues cannot be used without processing. The residue must be concentrated to around 60 % sugar to be suitable for fermentation. However, the fermentation process is not environmentally friendly and requires a lot of energy. The polymer becomes trapped in the bacteria during fermentation and must be extracted by removing the bacteria biomass.

Intermediate resume

The production of PHAs presents significant challenges due to their complex and resource-intensive nature. Raw materials such as sugar or vegetable oils are typically used, but require specific properties, and residues need to be processed to achieve a suitable sugar concentration for fermentation. However, the fermentation process is environmentally unfriendly and energy intensive.

Durability

With regard to durability, experts stated that any outdoor application that needs to be durable is not a viable option for PHAs as they degrade very quickly. In this regard, one voice further explained that PHAs hydrolyse when in contact with soil or water and are easily degraded by bacteria and fungi. In addition, organisms can degrade PHAs within days or weeks because PHAs have been around for billions of years and are known to every organism, making them susceptible to degradation. Finally, the use of PHAs in agricultural or horticultural applications was questioned. Specifically, the use of biopolymers for silage foils is not possible because bacteria would eat the film and the silage film should not be fed to cattle.

Intermediate resume

PHAs degrade really quick They hydrolyse when in contact with soil or water and are easily broken down by bacteria and fungi. Usage of PHAs in agricultural or horticultural applications is assessed to be difficult. E.g., usage of biopolymers for silage as bacteria would munch away on the foil.

Seasonal availability of feedstock and regional distribution

The availability and transportability of raw materials is seen as a limiting factor. However, there are examples of industries that have found a solution, e.g. the sugar industry has solved the storage problem by producing in campaigns. Also in Greece, different varieties of oranges allow continuous harvesting throughout the year, ensuring a steady supply of orange peel.

Intermediate resume

Availability and transportability of feedstock is considered as a limiting factor.

4.1.3 PHA-Applications

In contrast to 3.1.2, the stakeholders' expectations as well as possible limitations and challenges with regard to PHA applications are mapped in the following based on the assessments of experts who are potential users of the end-product PHA applications from the arable farming or horticulture businesses. The expectations of stakeholders with regard to protein function and quality as well as potential challenges are discussed in more detail.

4.1.3.1 Stakeholders´ expectations

<u>Functionality of bio-based and bio-degradable PHA-applications</u>

Regarding the general functionality of bio-based and biodegradable PHA applications, the experts expected them to be resistant to weight and climatic conditions, especially humidity. Two voices also mentioned that applications should be cheaper than products, including recycling costs. In addition, the ideal application should have the same lifetime, meet agronomic needs and save time. Finally, one expert mentioned that applications in bio-packaging need to be transparent as they need to be shown to customers. However, attempts to use "bio" plastics have resulted in higher prices and consumer perception of plastic.

When looking at PHA applications in detail, experts had specific expectations for each application. One expert stated that **greenhouse materials** should be durable in multiple campaigns to save installation time and money. Greenhouse film is expected to last 7-8 years and needs to be transparent and UV resistant. Another expert expected **pots** to degrade quickly and did not consider them suitable for long-term use. In contrast, transport pots or trays are expected to have a life expectancy of 6 months to 5 years. The material should be weatherproof and rigid, with no light penetration. It must also be able to withstand production, logistics and home storage. In terms of appearance, it must not be transparent and must be able to be dyed. In terms of **twine**, it was noted that garden twine would be needed for our tomatoes, cucumbers and beans. It was mentioned that they need to be physically stable for 6 months, UV resistant and degrade within 2 to 4 months when thrown on compost. Reusable twine would save time, but would be more expensive than conventional products. The function of **strapping and oil bottles** must meet certain standards, including correct elasticity, thickness, compatibility with equipment and good resistance to protect the load and prevent oil migration and light damage. Finally, two experts expected the **mulching film** to retain its properties for a certain period of time and have a service life of at least 6 months. After that, the mulch film should degrade sufficiently quickly. It was also stated that it should have the same life expectancy as fossil-based film or be much cheaper, both in terms of purchase price compared to the conventional product, including recycling costs.

<u>Intermediate resume</u>

Experts expect bio-based and biodegradable PHA-applications to be cheaper than conventional products, have the same life span, meet agronomic needs and save time. However, current attempts to use "bio" plastic have resulted in higher prices and consumer perception as plastic.

Quality of PHA-applications

With regard to the quality of PHA applications, the experts were asked specifically about **contamination** and **purity**.

With regard to **contamination**, the experts judged that there should be no dangerous contaminants, either for human health or for the environment. For agri-food applications, materials should not contribute toxic substances to food, water or soil. It was also stated that packaging materials in contact with the product must be absolutely free of any product harmful to food or the environment. A more critical voice stated that contamination should not be a problem during re-use when disinfected, as it is with conventional products. With regard to **purity**, the experts were unanimous in their opinion that purity is not the decisive factor. One voice stated that purity is not important as long as the functionality is there and the price is right. In line with this, another voice mentioned that a specific purity is not necessary as there is a possibility to adapt to any origin as long as it is safe, sustainable, truly renewable, biodegradable and does not involve an excessive increase in production costs. Finally, in the case of fruit, 100 % PHA purity is not necessary, as assessed by an expert. It is possible to combine it with a certain amount of other materials, but especially with cellulose, the issue of moisture has to be taken into account.

Intermediate resume

In terms of the quality of PHA applications, experts expect materials to be free of any contamination that is harmful to food or the environment. In terms of purity, the experts agreed that purity is not the critical factor.

Customers' willingness to pay

According to one expert, there is an awareness that organic plastics can be more expensive. She considered that it is possible to pay a little more for a new product as long as it meets the necessary requirements. In line with this, one expert stated that there would be a willingness to pay 10 % to a maximum of 20 % more than for the conventional product if the biodegradability works as well as advertised and expected. In addition, one expert suggested exploring new materials and scenarios that are cost effective, environmentally sustainable and accepted by consumers. The focus should be on finding formulations that give an "eco" feel and have a positive impact on the environment.

Other experts were more sceptical about the acceptance of higher prices. One expert stated that there is no willingness to pay a higher price for these types of materials as customers do not value them and therefore do not want to increase the price of the product. In addition, he assessed that companies in this sector operate on very tight margins and are therefore unlikely to absorb this increase in costs. However, one voice mentioned that a slight increase in costs for the use of biomaterials could only be considered if the resulting new business plan included the development of new market niches with more guaranteed profits.

Intermediate resume

Experts believe that customers may be willing to pay higher prices for bio-based and biodegradable PHA applications. However, companies in the sector operate on very tight margins and therefore need new business plans that include the development of new market niches where higher profits can be expected.

4.1.3.2 Main limitations and challenges

In the following, the topics that are seen as the biggest obstacles for the market potential of PHA-applications are discussed. The topics are addressed in decreasing order according to the frequency they were mentioned by the different experts.

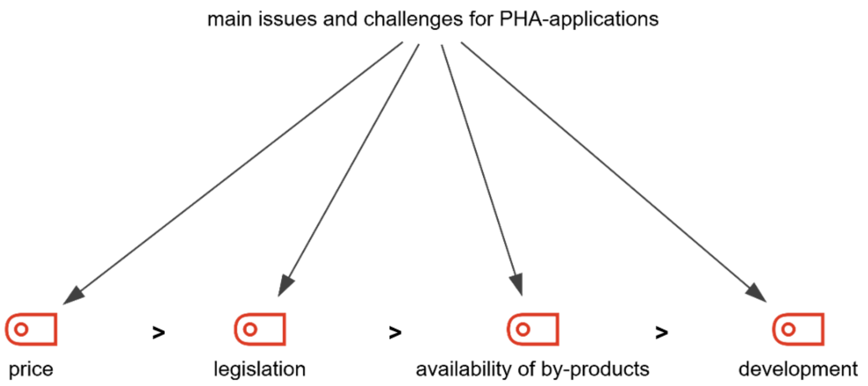

Figure 5: The most frequently cited limitations or challenges for the market potential of PHA-applications by experts (own compilation of Ecozept).

<u>Main challenges</u>

With regard to possible challenges or limitations to the market potential of bio-based and biodegradable PHA applications, experts mentioned several factors. The most frequently mentioned and therefore the most important factor was **price**. It was mentioned that the price of the end product is important, as customers and end users do not want to pay more for certain products. In addition, one voice stated that there will be additional costs as machinery will need to be adapted to new packaging and different crops.

The second most frequently mentioned factor was **legislation**. One expert explained that it is possible to find good solutions because of scientific progress. However, the administration (government) and its legislation change so quickly that the problem encountered is the legislative framework. In line with this, another voice stated that there was a need to facilitate the testing and purchase of new solutions, both for agricultural use and for packaging for final consumption. This would require solid networks of cooperation between companies, technology centers and administrations, as well as the creation of facilities and the removal of barriers.

One expert also identified the pace of **development** as a challenge. He stated that the challenges of generating new solutions from by-products in collaboration with research or technology centers include difficulties in finding funding for trials with new materials and the need for investment to produce or manufacture these materials locally. In addition, the slow pace of technological and knowledge development was mentioned as a practical challenge. Finally, one expert identified the **availability of by-products** as a limiting factor. He further assessed that ensuring a stable supply of by-products without stock-outs and having bioproducts available that meet the specific needs of the industry could be problematic.

Intermediate resume

The main concern was the price of end products, with customers reluctant to pay more and the additional cost of adapting machinery. Legislation was the second most frequently cited factor, with the need for a more favourable regulatory framework to facilitate the testing and adoption of new solutions. The pace of development, including securing funding for trials and local production, and slow technological progress were identified as challenges. In addition, ensuring a stable supply of by-products that meet industry needs was recognised as a potential limiting factor.

Solutions

When asked about possible solutions to the existing problems, all experts stated that **favourable legislation and policies** could help. One expert explained that there is a need for innovation support policies that enable collaboration between companies, manufacturing partners, other material companies and innovation centres such as universities. In line with this, another expert stated that the need for solutions to replace plastics of petrochemical origin requires supportive legislation.

In addition, two experts mentioned that the challenges of finding bio-based alternatives that are price-competitive and meet technical specifications require **further research**. In addition, one voice mentioned that a lot of research is still needed, applied to the working conditions of the industry, to be able to respond to all the challenges of using by-products in the production of new packaging.

Intermediate resume

The experts agree that supportive legislation and policies are essential to address current challenges. They emphasise the need for innovation support policies that encourage collaboration between different stakeholders. They also highlight the importance of additional research to overcome the challenges of finding bio-based alternatives that are cost-competitive and meet specific technical requirements.

Outlook

Regarding the prospects for biodegradable products in agriculture, including mulch films, tree growth protectors and plant pots, all experts expressed a general interest in finding a solution for the use of biodegradable plastics. Two experts emphasised that for new products to be accepted on the market, the barrier for consumers must be low. If the price or the workload associated with the new product is high, it will not be feasible. He also noted that no one will invest time and money for ethical reasons alone. The expert also suggested that the best suppliers of agricultural residues are industries such as apple juice and wine processors. He sees a big opportunity for biodegradable products in crops with a fast turnaround time.

One expert shared his views on specific applications. For plant pots and especially for machine planting, such as automated planting similar to lettuce seed bands (young plants, not seeds), he saw a big opportunity for the automated planting sector in general. He also saw a big opportunity for mulch films for normal growers, e.g. lettuce growers who use a new mulch film every 8 weeks. The expert went on to say that durability and functionality over 3 years would make them perfect for protecting tree growth. But they would have to be able to break down on topsoil without being ploughed or mulched, and they would have to protect against rabbits for 3 years and perform well over those 3 years. Finally, biodegradable products were judged to be perfect for all crops with a quick turnaround time, as there is no controversial need for relatively long performance coupled with the need for a high degradation rate.

Critics argue that the agribusiness industry faces unfair business risks and low returns for farmers. In addition, bureaucracy has increased, further reducing profits. It is hoped that solutions will benefit farmers through consumer demand but burdening them with higher costs or difficult materials would not be viable. The voice added that the industry was already at its economic limit. Another voice said that the problem of homogeneity in their characteristics needed to be solved.

Intermediate resume

Experts are generally interested in the use of biodegradable plastics in agriculture. Specific applications, such as plant pots for automated processes and mulch film for regular growers, are seen as promising. However, concerns are raised about unfair business risks and low profits for farmers, increased bureaucracy and economic constraints on the industry.

4.1.4 Extracted and microbial Proteins

4.1.4.1 Stakeholders´ expectations

Protein quality

According to the experts, the quality of protein is very important and should be ensured through strict hygiene and quality control protocols to minimise microbial risks as well as contamination risks, including those from heavy metals and pesticides. It was also mentioned that proteins should meet specific nutritional requirements, including essential amino acids, vitamins and minerals, for different animals.

Looking more closely at potential factors affecting quality, microbial risks, contamination, toxicity and anti-nutritional factors were mentioned. In terms of factors, the experts distinguished between extracted protein and microbial protein. One expert considered that extracted proteins generally do not pose problems in terms of microbial risks. In contrast, microbial proteins could pose problems in terms of nucleic acid sensitivity, especially in fish feed. Contamination was also considered to be an issue, particularly in food applications, but also in feed. However, all experts stated that the problem of contamination could be overcome with strict control protocols. With regard to anti-nutritional factors, the experts noted that extracted proteins could vary depending on the type of protein extracted, but these should be easier to overcome. On the other hand, microbial protein applications could cause problems in fish, as some species are more sensitive to nucleic acids. However, the industry is aware of this and by adding minimum amounts of certain ingredients to the mix with microbial proteins this challenge could be overcome. Toxicity is not expected to be a problem for either extracted or microbial proteins.

Intermediate resume

Most experts expect protein quality to be unproblematic for extracted protein, but uric acid may be problematic for microbial protein. Microbial risks, contamination, toxicity and antinutritional factors were identified as factors affecting quality.

Comparability with conventional protein

Regarding the nutritional aspects, microbial proteins were assessed to be practically the same as conventional proteins. However, there were also some restrictions on the comparability. Microbial proteins are more difficult to ferment. But as they will never be the sole feed source, the protein can replace part of the feed mix, with the remaining diet balanced around it. In this way, they can replace part of the fish fed. Doubts were expressed by all experts regarding costs and the lack of texture.

In addition, one expert assessed microbial protein as an alternative for conventional fish fed more detailed. He stated that the increase in manure from fish fed with microbial protein can lead to more added costs after the feeding process. Other aspects, such as floating characteristics in fish feed, are also important. In conclusion he pointed out that fish feed is the most sensitive application for protein feed.

Intermediate resume

Experts generally consider microbial proteins to be nutritionally comparable to conventional proteins, but express concerns about their fermentability and texture. They suggest that microbial proteins may not be the sole feed source but could replace part of the feed mix in applications such as fish feed. However, doubts remain about the costs involved and texture issues.

Qualities of agricultural residues as feedstock

According to the experts, the quality of agricultural residues as coproducts is constantly changing, making it difficult to maintain a stable product. Therefore, preparation for processing into microbial proteins is required. While extracted proteins for feedstuff are not affected, food applications require constant quality characteristics. Another expert stated that there has to be a distinction between waste and by-products. This is due to the fact that anything produced from waste cannot be introduced into the human food chain. In summary, the experts assessed the residues/by-products chosen for AgriLoop as generally relevant and suitable.

Intermediate resume

Experts considered the residues/by-products selected for AgriLoop to be generally relevant and suitable. The constantly changing quality of agricultural residues makes it difficult to maintain a stable end product.

4.1.1.1 Main limitations and challenges

In the following, the topics that are seen as the biggest obstacles for the market potential of MP are discussed. The topics are addressed in decreasing order according to the frequency they were mentioned by the different experts.

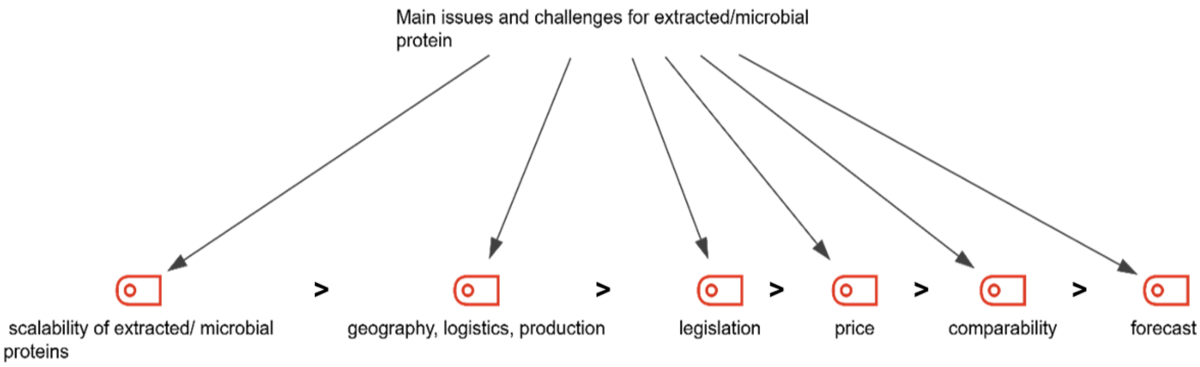

Figure 6: The most frequently cited limitations or challenges to the market potential of extracted / microbial protein by experts (own compilation of Ecozept).

Price and production cost

The price was assessed to be one of the main factors limiting the market potential of MP. Factors that can be considered influencing the price range and the development of new proteins from coproducts are the price of the coproducts, the costs of processing, e.g. purification, the price of microbial broth and the production volume.

With regard to production costs, all experts were united in the opinion that the costs are still too high, therefore more progress in development is needed. Moreover, a large amount of feedstock is needed in order to be profitable. In contrast, one expert assessed the range of costs for conventional plant-based proteins and for extracted protein as roughly the same, as the spread can be huge and can range from 4 € /kg to 30 € /kg. When considering microbial proteins, it needs to compete with the price fish meal is described as the highest priced protein.

Intermediate resume

All experts consider price to be one of the main limiting factors. The price of by-products, the cost of processing, the price of the microbial broth and the volume of production all play a significant role in the price range.

Legislation

Legislation is one of the issues most frequently mentioned. It was stated that legislation plays a crucial role in the development of new food and feed products, especially in terms of safety and compliance with regulations. The process is assessed to be challenging and time-consuming, requiring thorough checks of every aspect of production and original resources in order to ensure that all aspects comply with the requirements of food and feed safety.

In terms of food safety, there is a predefined process according to the EU NovelFood regulation. It is determined that the protein needs approval in order to be used in human food. One expert assessed that the process costs 1-1.4 million € as several laboratory tests and trials are required. The process was described as complicated but necessary process. Also, feed safety was described to have high requirements, e.g., the requirement to have low heavy metal levels. All in all, developing stable, food-secure processes is assessed to be the key challenge, particularly when dealing with coproducts with varying properties and characteristics.

However, it was stated that once a company has established itself and its products on the market, subsequent products could enter more easily. One expert even mentioned that legislation should not be considered as the biggest problem as it could change. Besides one expert named China as rising market, as food legislation is more relaxed.

Intermediate resume

Legislation is often cited as a major challenge in the development of new food and feed products because of its critical role in ensuring safety and compliance. The process is described as complicated and time-consuming, requiring meticulous checks to ensure compliance with food and feed safety requirements. Developing stable and safe processes, especially for by-products with variable properties, is identified as a key challenge. However, experts are optimistic that legislation can be changed.

Geography & Logistics

All the experts are unanimous in their assessment of the logistical problems: There is a consensus that logistics is very important because profitability depends on it. The high moisture content of by-products makes it difficult to transport them over long distances without spoilage or high costs. Therefore, one expert recommended that processing should take place in the area of origin, preferably close to the production site or even directly at the production site. This ensures quality as the final product can potentially be shipped further, but from a sustainability perspective it should be sold as close to the production area as possible.

In terms of potential geographical challenges, one expert noted that the industry is becoming more interested in the use of by-products, such as the conversion of proteins from brewing to feed. It is mentioned that there has been a change in attitude towards by-products, which could increase competition and limit their geographical availability.

Intermediate resume

Most experts identified logistics as a key challenge to profitability. Production should take place in the region of origin. Regional availability may be limited due to increased competition for by-products.

Scalability

Scalability is assessed to be very good with regard to coproducts as there are high amounts of coproducts on the market. In detail it depends on the business case, e.g., on the paybacks of each product, the required energy input, the downstream processes. The expert assed that if the business case is right the product will skyrocket based on market looking for and demanding more sustainable proteins. In contrast, one expert assessed that the scalability needs to be further developed. It was mentioned that AgriLoop trials are still on a very low scale. In order to meet industry demands, 5-10 tons per day of final product or 100 tons per day of raw material would be required. The minimum requirement for scalability would be 1 ton per day of final product.

With regard to limitations several experts named the technology capacity be important for meeting the demand. Another limiting factor mentioned was contamination. The system needs to be clean from contamination from other bacteria or other sources. In this regard there are certain limitations in size to be able to clean the fermented and keep it hygienic. From a practical point of view, the experts have described AgriLoop as helpful in order to overcome the challenges of developing from lab scale to full scale. It is mentioned that trials on a lab-scale are usually financed, whereas developing a product at sufficient scale for the market is a financial challenge. Especially for smaller companies' investment costs a described as a limitational factor.

Intermediate resume

Scalability is considered to be very good, depending on the specific business case and factors such as energy input and downstream processes, with potential for significant growth in response to market demand for sustainable proteins. However, it was suggested that further development of scalability is needed, as AgriLoop trials are currently at a small scale and industry demand requires larger production capacities. Technological capacity and contamination control are identified as key limiting factors. Further, the transition from lab-scale development to full-scale production can be financially challenging, particularly for smaller companies with significant investment costs.

Consumer acceptance and comparability

Customer acceptance is also assessed to be a limitational factor. It was stated that depending on the application and especially if it is intended for food applications, there could be customer disapproval. For example, insects are a perfect alternative protein source, but consumer acceptance is low in European countries. However, the experts do not consider acceptance to be a problem in animal nutrition.

In addition, it described that there could be a comparison between MP and conventional proteins. Here, conventional proteins are very cheap and well known. They are very practical and can be used for everything. They have no limitations like MP, e.g., high uric acid content, which can accumulate in humans and cause gout. Therefore, the advantages of MP should be well communicated.

Intermediate resume

Consumer acceptance is seen as a potential limitation, particularly in food applications where there may be consumer resistance. In animal nutrition, however, acceptance is not seen as a problem. When compared, conventional proteins are favoured because of their low cost, versatility and widespread familiarity, while MP have limitations, such as high uric acid content. Effective communication of the benefits of MP is highlighted as important.

Outlook and perspectives

It was assessed that the price of protein will probably increase 20-25 % over the next 15 years. The price of the production of bacterial protein is predicted to be lowered simultaneously and resulting in the same price level as that of conventional protein.

On the customer side, experts named that there could be a very small group who buy organically grown sustainable foods due to ideological reasons. This group is willing to accept higher prices but is assessed to not to be focused due to their height. In commercial volume one expert estimates that 5 -10 % price increase would be accepted and therefore could be targeted for mass production.

From the production perspective, experts assessed a decrease of the cost-price in the future, even though they depend on a lot of different factors. Further, the admission of GMOs by the European Union could make a huge difference, as more efficient microbes could be produced.

Intermediate resume

Experts predict a 20-25 % increase in protein prices over the next 15 years, but the cost of producing bacterial protein is expected to fall and eventually converge with conventional protein prices. It's recognised that there is a niche group of consumers who are willing to pay higher prices for organically grown, sustainable food, but this is seen as a limited market. Experts estimate that a price increase of 5-10 % could be accepted in commercial quantities.

4.2 Results of the qualitative expert interviews (Delphi II)

This chapter presents the results of the second round of stakeholder interviews using the Delphi method. The results of the first round of stakeholder interviews were analysed and incorporated into the guidelines for the second round of interviews. As the interviews were divided into 4 groups and therefore different expert groups, we present the results divided into 4 sections: agricultural residues, PHA, PHA applications and MP. Within each section, we have identified stakeholder expectations, potential limitations or barriers, and market opportunities for the different products. All findings reflect the opinions of experts.

4.2.1 Valorisation of agricultural residues

4.2.1.1 Current valorisation

In accordance with the preceding round of expert interviews, the experts delineated the present valorisation of agricultural residues. Subsequently, the case of tomatoes is employed to examine a value chain.

With regard to the valorisation of tomatoes, experts described a diverse landscape of tomato waste management practices, as well as differing opinions among industry experts. Tomato waste consists mainly of skins and seeds and represents approximately 3-5 % of the total weight of processed tomatoes.

According to experts, a considerable number of companies utilises a relatively straightforward approach, whereby the waste is stored in large trailers outside their facilities and subsequently sent for use as animal feed, often without significant valorisation. Although this approach is cost-effective, it constrains the potential benefits that could be derived from the waste. Another voice noted that in Spain, the majority of companies simply give their tomato waste to livestock farmers without any monetary exchange. However, this arrangement is inherently unstable. Companies are concerned that farmers may not collect the waste with sufficient regularity, which could result in storage issues, particularly during the peak processing season from June to September when waste volumes are at their highest. Despite the consideration of drying and selling the waste by some companies, this practice has yet to gain traction.

In contrast, a number of companies have devised novel methods for the recycling of tomato waste. In California, for instance, some companies have initiated the fermentation of this waste to produce compost for agricultural fields, while a French company is extracting valuable compounds, such as lycopene and oil, for utilisation in cosmetics. Indeed, the extraction of lycopene for cosmetic applications has been identified as a viable option. However, smaller companies often lack the financial means to invest in such processes. Recently, the use of tomato waste for biogas production has been explored. While companies usually provide this waste to biogas producers free of charge due to the limited availability of processing facilities, they view this option as more reliable than relying on farmers to collect the waste, as it ensures a consistent method of disposal.

In general, despite the recent progress, innovative initiatives remain relatively uncommon, primarily due to the challenges associated with rapid fermentation processes and the high cost of drying the waste for subsequent utilisation.

Intermediate resume

Experts noted that the valorisation of tomato waste, which represents 3-5% of processed tomatoes and consists mainly of skins and seeds, still has a lot of room for improvement. Many companies take a basic approach by storing waste for animal feed, which limits potential benefits and creates instability, especially during peak processing seasons. In contrast, some companies are exploring innovative uses, such as fermentation for compost and extraction of lycopene for cosmetics, although financial constraints hinder smaller companies to invest. In addition, the use of tomato waste for biogas production has emerged as a more reliable disposal method. Overall, while there are promising initiatives, innovative practices remain limited due to processing challenges and high costs.

4.2.1.2 Financial compensation, satisfaction with current valorisation and impact of redirecting the by-products into another value chain

In examining the financial compensation within the extant value chain, the experts confirmed the conclusions reached in the previously conducted round of interviews. Looking at the tomato industry, one expert noted that many companies simply give away their tomato waste, with some receiving minimal compensation - often only a few € per tonne - while others have long-standing arrangements whereby farmers come directly to collect the waste without any financial exchange. This long-standing practice tends not to generate any revenue for the companies, underlining a general reluctance to sell the waste. In accordance with this, experts emphasise that the majority of companies continue to concentrate their efforts on their core products, such as tomato paste and canned tomatoes, while failing to capitalise on the potential for waste valorisation.

The experts were additionally asked to comment on the potential impact of redirecting the tomato by-products into an alternative value chain. One expert observed that, at present, the majority of companies do little to valorise tomato waste, despite the fact that it contains a number of valuable compounds, including antioxidants, lycopene, vitamin E and oils, which present significant potential. However, the voice also indicated that there is an increasing awareness of the potential of recovering tomato waste. Another expert explained in this regard that efforts have been made to identify more innovative applications for tomato waste. One notable example is a large-scale initiative in Northern Italy that aimed to centralise, dry, and process waste from multiple companies. However, this project was ultimately terminated due to an unfavourable cost-benefit analysis.

In conclusion, although some companies are beginning to take steps towards valorising their waste, the industry as a whole is currently underutilising this resource. It is anticipated that **future initiatives** to repurpose tomato waste will be **driven by economic motivations** or the desire to enhance the company's public image. This highlights the necessity for a paradigm shift in order to fully capitalise on the valuable by-products that tomato waste can offer. The experts evaluate that any initiative to repurpose tomato waste into alternative value chains is likely to generate economic benefits that exceed those of the current valorisation process. In the sector of the tomato processing industry that operates on narrow profit margins, even a **modest revenue** from the currently underutilised 5 % of the tomato could have a considerable impact. Monetising this portion could facilitate a transition from unprofitability to the attainment of a modest yet sustainable profit margin. It is essential to achieve higher profitability, as the results of the previous round of stakeholder interviews are confirmed by all the experts consulted during the second round. These experts have identified low profitability as the primary factor contributing to the current low satisfaction with the valorisation process. Overall, the experts agreed that repurposing by-products for secondary applications can become an attractive proposition for companies, particularly when it has the potential to generate additional profits. This perspective encourages further exploration and innovation in the utilization of by-products within the tomato processing industry, signalling a pathway towards more sustainable and economically beneficial practices.

Intermediate resume

Consistent with the previous round, tomato industry experts indicated that financial compensation for tomato waste is minimal, with many companies giving it away or receiving only a few € per tonne, reflecting a reluctance to monetise this resource. Despite the presence of valuable compounds such as antioxidants and lycopene, most companies focus on core products and underutilise the potential of waste. While some initiatives to recycle tomato waste have emerged, they often stall due to unfavourable cost-benefit analyses. Experts advocated a paradigm shift towards monetising this underutilised 5 % of tomatoes, which could significantly improve margins in a low-margin sector. The reuse of tomato by-products for secondary applications could bring economic benefits and encourage further innovation in sustainable practices.

4.2.1.3 Stakeholders' expectations

Essential supporting factors

When looking at the essential supporting factors for advanced valorisation of tomato by-products, experts confirmed the assessment of the experts from the previous round. They further identify a number of essential factors that influence the valorisation of tomato waste. One expert highlighted the necessity for the sharing of information within the industry, particularly with regard to the **financial aspects** of waste valorisation. The importance of such sharing is becoming increasingly apparent as companies contemplate the deployment of new equipment to enhance their waste management capabilities. Nevertheless, another voice emphasised that a considerable number of firms are in need of **financial assistance** in order to make these investments a reality. Finally, another voice stated that the costs associated with valorisation should be refunded, particularly with regard to long-distance transportation.

One expert further proposed that the primary focus should be on tomato **processing factories**, given that farmers typically do not generate significant quantities of waste. While all parts of the tomato plant have the potential for valorisation, they are frequently employed as direct fertilizers for soil. It is therefore imperative that innovative **waste management** methods be explored at the **factory level**.

Furthermore, the experts posited that the strategy for valorisation will determine whether companies will handle waste internally or outsource it to other processors. In conclusion, companies are more likely to invest in valorisation initiatives when they perceive the potential for profitability and financial gain. This perspective highlights the necessity of establishing a conducive environment that encourages collaboration and investment in waste management solutions. Although waste is frequently undervalued, it is typically not considered a significant pollutant unless it contaminates waterways.

Intermediate resume

Experts confirmed the assessment of the previous round. Further, experts stressed that effective valorisation of tomato by-products depends on improved information sharing on financial aspects and that financial support to invest in new residue management technologies is needed. Focusing on tomato processing plants for innovative waste solutions is preferred, as farmers generate minimal waste. Companies are more likely to invest in these initiatives if they are perceived to be profitable, highlighting the need for an environment that encourages collaboration and investment in residue management.

Ideal valorisation

The experts were further asked to describe their ideal valorisation. In the course of this, the experts confirmed the results of the previous round of stakeholder interviews. The experts underscore the critical importance of creating added value through innovative utilization of by-products.

Focusing on the example of the tomato industry, the experts suggest that the approach to valorisation determines whether companies process by-products in-house or outsource them to other processors. Companies are more likely to invest in valorisation initiatives if they see the potential for profitability and financial gain. This perspective highlights the need to **create an enabling environment** that encourages collaboration and investment in by-product management solutions.

In addition, one expert discussed a notable example in detail, namely lycopene. Lycopene is a powerful antioxidant derived from tomato peels. The experts emphasised that the development of an efficient extraction process to reintroduce lycopene into tomato products could significantly improve their nutritional profile and provide additional benefits to the industry. Another voice highlighted the potential of tomato seed oil, which has already been processed and could be reintroduced to the market. One research initiative aimed to replace olive oil in certain tomato sauces with tomato seed oil, but the industry was reluctant to adopt this strategy due to existing cost-benefit challenges, making the transition appear complex.

Valorisation of by-products to PHA

The experts were also asked about their perception and had a good first impression of valorising by-products to PHA. One expert highlighted the potential using PHA in tomato growers, but acknowledged that several steps are needed to reintegrate it into the industry. Another voice stated that the area of PHA is particularly interesting and suggested that further research could greatly benefit the members of their association. There is an idea of collaboration and industry partners are interested in connecting with other members who are already exploring this topic to identify possible development opportunities. In accordance with this, another expert also recognised the potential of valorising by-products to PHAs within the industry. However, another voice emphasised the need for greater clarity on PHAs. Although there has been research into the use of PHAs from tomato by-products, there have been no commercial launches to date. Typically, companies in the sector choose to sell their tomato waste to external processors rather than manage it internally. The expert further explained the tendency within the industry to undervalue waste or by-products.

Again, if companies can find financial incentives to recognise and value the by-products, they will be more likely to engage in recovery efforts.

Intermediate resume

In agreement with the results of the previous round, experts emphasised the importance of innovative by-product utilisation to create added value, particularly in the tomato industry. They suggested that the approach to valorisation influences whether companies handle by-products in-house or outsource processing, with profitability being a key driver for investment in these initiatives. The potential for extracting intesresting compounds such as lycopene and tomato seed oil is noted, although cost-benefit challenges remain. There is also optimism about the valorisation of by-products into PHA, but clarity on this process is needed as current commercial applications are lacking. Overall, the creation of financial incentives to recognise and valorise by-products will encourage recovery efforts in the industry.

Further attractive pathways.

Looking at alternatives within the tomato industry, one expert noted that the industry is exploring various innovative approaches to the use of tomato waste, with some companies successfully recycling tomato skins into film for coating cans, while others are focusing on extracting valuable lycopene for cosmetic applications. Another added that, in particular, one company had succeeded in extracting lycopene for the cosmetics industry through its own extraction plant, but that many smaller companies faced financial constraints that prevented similar endeavours. In addition, one expert noted that one of the strategies being considered is the drying of tomato residues for resale, although this practice is still relatively rare.

Finally, some voices discussed that there has been progress in the use of tomato waste for biogas production, but companies often choose to give the waste away rather than sell it due to a lack of biogas processing facilities in their perimeter. Overall, many companies see biogas recovery as a more reliable option than waste donation to farmers, as it provides a consistent solution to waste collection.

Intermediate resume

Experts in the tomato industry are exploring innovative ways to use tomato waste, such as recycling skins to coat cans and extracting lycopene for cosmetics. While larger companies have successfully implemented these strategies, smaller companies struggle with financial constraints. In addition, drying tomato residues for resale is being considered, although it remains uncommon. Progress has been made in using tomato waste for biogas production, but companies often prefer to give the waste away due to insufficient processing facilities. Overall, biogas production is seen as a more reliable waste management solution than giving waste to farmers.

4.2.1.4 Biggest limitations and challenges

Assessment on biggest challenges:

The experts of the second round of stakeholder interviews agreed with the stakeholders of the previous round. It was agreed that the challenges previously identified, namely transportation and logistics, processing difficulties, limited seasonal availability of feedstock and legislation, represent the most significant obstacles to valorisation.

In addition, some experts described specific challenges in more detail. In the following the challenges within the tomato industry will be explored as a case study of a value chain. As previously stated, all experts concurred that the most significant obstacle to the market potential of valorisation processes of agricultural residues is the **price** and the associated profitability. A higher revenue is essential for the acceptance of the process.

Moreover, the experts verified that the **transportation and logistics** of agricultural residues represent a significant challenge. One expert emphasised that the timely treatment of materials is a critical factor in the success of fermentation processes. Drying is often the preferred method for preparation, but it comes with high energy demands that can escalate production costs. Therefore, a careful balance must be maintained between energy expenditures and the production of high-value products, such as cosmetics, which show significant potential for profitability. In addition to these considerations, another expert addressed the logistical hurdles involved in converting residues into higher value products. Naming the example of biogas the expert further explained that a primary concern is the strategic placement of biogas plants. Companies intend to recover waste only within a 30 km radius. For companies located beyond this distance, the burden of transportation costs complicates the recovery process, potentially diminishing the feasibility of such initiatives. The same can be said of the extraction of ingredients from residual materials. This emphasises the necessity for effective logistics and planning in order to optimise the value derived from residues while maintaining cost-effectiveness. In conclusion, the experts emphasised the complex interrelationship between processing methods, economic viability and logistical considerations in the pursuit of sustainable residue valorisation solutions.

In terms of **seasonal availability**, the experts also confirmed previous assessments. The experts indicated that there are seasonal constraints for most of the potential varieties. Focusing on tomatoes, one expert noted that while there is a steady supply of larger volumes from various sources, tomato processing in Europe is constrained by its limited and highly seasonal nature, typically lasting only two to four months from July to October. In contrast, countries such as Egypt and Peru manage to process tomatoes for up to nine to ten months of the year. This short processing window in Europe presents significant challenges, particularly for investment in drying equipment, which must operate efficiently to make the most of the short season. Another voice added that to mitigate the impact of this limited timeframe, some companies have started processing alternative products, such as carrot puree or peppers, during the winter months using residues. However, the primary focus remains on the limited tomato processing season. This reliance on a narrow processing window highlights the need for innovative strategies to improve operational efficiency and capitalise on available resources during the peak season. Finally, the experts also considered solutions to the existing challenges in tomato processing. One voice suggested that the creation of small processing units within factories could be a viable solution to the challenges posed by the limited volume of tomato processing in Europe.

Intermediate resume

Experts from the second round of stakeholder interviews agreed with previous findings that transport, logistics, processing difficulties, limited seasonal availability of raw materials and legislation are significant barriers to the valorisation of agricultural residues, particularly in the tomato industry. They emphasised that price and profitability are critical to the market potential of valorisation processes. Transport costs make waste recovery difficult, particularly for biogas, which is only viable within a 30 km radius. In addition, the short tomato processing season in Europe (July to October) presents challenges for investment in drying equipment and operational efficiency. To address these issues, some companies are diversifying their winter processing efforts with alternative products, and the creation of small processing units within factories is suggested as a potential solution to improve efficiency and resource utilisation.

4.2.2 PHA from agricultural residues

4.2.2.1 Stakeholders' expectations

In order to gain insight into stakeholders' expectations, the experts of the second round of stakeholder interviews were, as well as the experts of the previous round, invited to assess PHA in relation to their expectations and desires regarding the quality of PHA products, the functionality of PHA products and the price development of PHA applications in agriculture. Furthermore, the experts gave their assessment on the results of the previous round of stakeholder interview.

Functional requirements

Looking at the functional requirements, experts were optimistic that the practical needs of the industry can be fulfilled. One expert stated that the company produced over 300 types of PHA in the previous year, indicating that properties can be easily adjusted. He further explained that for flexible applications, mechanical properties can be effectively controlled.

Looking at specific requirements, experts identified several crucial requirements for PHA, which are presented in figure 7 and explained below.

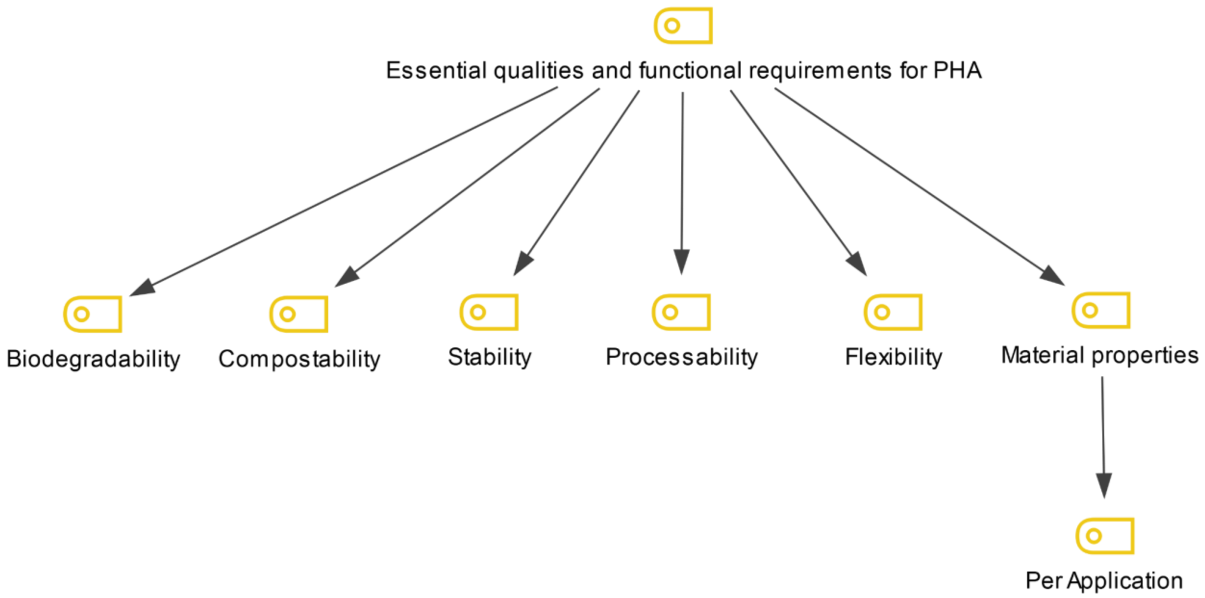

Figure 7: Overview of most frequently cited qualities and functional requirements for PHA assessed by experts (own compilation of Ecozept).

Looking at specific requirements, numerous experts have identified the necessity for **processability** on standard production systems, as this has a significant impact on the overall economic viability. Three experts agreed that the materials need to be processed on existing standard machines (such as glass-based or flat-bottom systems). One expert further underscored that the first functional requirement to focus on when producing a new PHA is processability. A third expert agreed with the previous statement, noting that PHA should have as close as possible to 100 percent of the properties of conventional materials, although exactly the same properties are unlikely with new materials from PHA. Another voice added that processability is particularly relevant to produce mass products such as mulch film, as companies are often reluctant to invest in new production systems due to uncertainties surrounding regulatory decisions, particularly from the EU regarding the packaging and packaging waste regulation (PPWR), which complicates the amortization calculations for new facilities, machines etc. Ultimately, one voice described the requirements for processability in agricultural applications. He highlighted that, particularly in the context of agricultural applications such as mulch films, tear resistance is of critical importance, given that these films are frequently handled by robust agricultural equipment. For applications like films the goal remains to achieve the required mechanical stability while ensuring that the films are as thin as possible to promote degradability. This balance is essential to meet both agricultural needs and environmental standards. A critical voice stated that the processing of alternative materials such as PHA will vary significantly due to differences in melting temperatures and other inherent properties. As a result, the industry will need to adapt to these changes and be prepared to modify existing processes. To facilitate this transition, it is essential that companies receive appropriate guidance and support to ensure that they can effectively manage the complexities associated with integrating new materials into their production systems.

In terms of processability, two experts stated that the **flexibility** of the material was a critical requirement. One expert was positive about flexibility, noting that it can be achieved, to reach flexibility as low-density polyethylene (LDPE) and polypropylene (PP), as these are mechanical properties and measured values. However, another expert used the example of PHBV production to point out that the ratio of monomers used affects the flexibility of the material and needs to be considered.

The experts further identified stability as a crucial requirement. One expert stated that a key requirement is the **long-term stability** of PHA products, as their properties may change significantly over time, potentially becoming brittle due to partial crystallinity. Another voice further described that the short- and medium-term properties must be stable. Here, experts highlighted another key consideration, the lifespan of the product. The aspired lifespan of a product impacts design decisions such as wall thickness and may necessitate compromises in other areas.

On the contrary, several experts stressed the importance of **biodegradability** as one of the most important added values compared to conventional petrochemical solutions. One expert stressed the critical importance of understanding biodegradability in relation to environmental conditions. She points out that the degradation rate of biodegradable films, including fusible films, varies significantly depending on factors such as soil moisture and temperature. For example, these materials degrade at different rates in moist versus dry soils or at different temperatures (30 degrees Celsius versus 10 degrees Celsius). This climate-dependent nature of biodegradability requires a thorough understanding of how environmental factors influence degradation processes. In relation to biodegradability, experts also identified **compostability** as an essential requirement. One expert described that PHA can be composted in both domestic and industrial settings. While PLA degrades more effectively under industrial conditions, PHA is more suitable for home composting. It's important to consider the differences between these environments. In industrial composting, the process typically takes about three months, which requires the management of large volumes and limits the maximum thickness of the materials used.

Finally, the experts highlighted that there is always a need to consider the products **service life** as there is a conflict between stability, functionality and biodegradability. The expert explained that there is a challenge in creating a stable plastic that also promotes biodegradability, as these goals can conflict. This necessitates finding a compromise regarding the application and its duration, as well as the level of biodegradability required. Another expert described it in a more striking way: “PHA should neither degrade too quickly nor too slowly. While thickness can be adjusted to influence lifespan, increasing thickness also raises costs.” It is therefore necessary to adopt a **multi-faceted approach** in order to achieve a balance between stability and biodegradability throughout the service life, in order to meet the demands of the market and the standards set out in the relevant regulations. One expert has proposed that the essential factors for a multi-faceted approach should be processability, functionality/stability, biodegradability and price.

Intermediate resume

Experts were optimistic about the functional requirements for PHA, highlighting its adaptability and potential to meet industry needs. The importance of achieving processability on standard production systems was emphasised as a critical factor for economic viability. Experts noted that while PHAs should strive to replicate the mechanical properties of conventional materials, particularly for applications such as mulch films, ensuring flexibility is also essential. Stability over time emerged as a major concern, as PHAs can become brittle due to partial crystallinity, affecting their long-term usability in various applications.

In addition to mechanical properties, biodegradability and compostability were identified as key advantages of PHA over petrochemical solutions. Experts pointed out that the degradation rates of PHA can vary significantly depending on environmental conditions, which requires a comprehensive understanding of these factors. They also recognised the inherent trade-off between stability, functionality and biodegradability in product design, and advocated a multi-faceted approach that balances these aspects throughout the product life cycle. Finally, the experts suggested that essential factors for successful PHA integration include processability, functionality/stability, biodegradability and price, and emphasised the need for innovative strategies that enable manufacturers to exploit the unique properties of PHA while meeting market demands and regulatory standards.

Key features appreciated by the industry

Within the current round of stakeholder interviews the experts also identified the key features appreciated by the industry.

Looking at the key characteristics valued by industry, one expert emphasised the importance of achieving a balance in the **thermal properties** of new materials, specifically noting that it would be advantageous for these materials to have a lower melting temperature while maintaining the same degradation temperature as conventional PHAs or PHB. This balance would facilitate a usable melt processing window, enhancing the versatility of the materials in various applications.

Another expert also emphasised that **printability** is an important feature for the industry. He mentioned that printability is a key challenge for medium-chain-length PHAs, noting in particular that these PHAs have a natural yellow colour. This colour is a challenge for marketability as products made from yellow polymers tend to have lower sales performance. However, another voice pointed out that when looking at agricultural sectors such as the agricultural film sector, printability is not a significant factor as it operates on a B2B model. The end user does not see the film and there is no need to print information on it, so these criteria are largely irrelevant. Another expert focused further on agricultural films, highlighting that aesthetics are less important than **mechanical properties**. The usual standards for most films do not apply here, which simplifies the process. The main focus is on achieving the necessary mechanical strength while maintaining the thinnest possible thickness to ensure degradability. This balance is crucial in the production of agricultural mulch films.

Another major factor within the industry is the **brittleness** of polymers. Here, brittle polymers are generally viewed unfavourably. This is particularly evident in the case of early PHAs, such as PHP, which gained a negative reputation due to their brittleness. The problem was exacerbated by the fact that their melting temperature was almost identical to their decomposition temperature, resulting in unwanted odours during processing. This experience underscores the need for materials that not only meet functional requirements, but also maintain stability throughout their lifecycle, highlighting the importance of ongoing research and development of polymer formulations to improve performance and reliability.

Overall, most experts agreed that the suitability of a polymer is ultimately determined by its intended application. Some applications demand a very rigid structure for stability, while others require more flexibility to meet specific functional requirements. This nuanced understanding highlights the need for tailored material properties based on the diverse demands of different sectors within the industry.

Intermediate resume

Experts have identified a number of key characteristics that the industry values in new materials, with a particular focus on the balance of thermal properties, which includes achieving lower melting temperatures while maintaining degradation temperatures similar to conventional PHAs or PHB. This balance increases versatility in different applications. Printability was also highlighted, although its importance varies from sector to sector; for example, it is less critical in the agricultural film sector where aesthetics are overshadowed by mechanical properties and functionality. Concerns about polymer brittleness were also raised, particularly in relation to early PHAs such as PHP, which suffered from negative perceptions due to their fragility and processing challenges. Ultimately, the experts agreed that the suitability of a polymer is determined by its intended application, requiring tailored material properties to meet the specific functional requirements of different industries.

Issue of contamination

As there was no consensus within the previous round of stakeholder interviews, experts were asked about the issue of contamination. Within this round, the experts had clear opinions regarding the issue of contamination. The experts were asked to assess the two levels of raw material and end product PHA.

Regarding raw materials, several experts generally agree that although secondary raw materials from food production can be contaminated, they usually meet high safety standards and are rarely exposed to significant toxic substances. Contamination concerns often arise after use, particularly depending on how packaging waste is disposed of. Although some contamination is possible, experts pointed to a dilution or purification effect during processing that mitigates risks, unless there are nearby sources of specific contaminants, such as pesticide storage.

Looking at the end product, there is also a consensus that contamination of PHA products with agricultural residues is unlikely to be a significant challenge. The experts also agreed that the suitability of processes is highly dependent on the processing grade and the specific application. Certain applications are more forgiving than others, underlining the need to ensure that hazardous substances are not present in the final polymer. One expert aptly compared this to the fossil fuel industry, pointing out the absurdity of consuming crude oil while it is acceptable to make drinking cups from it, illustrating the critical importance of processing methods and cleaning protocols for end-use materials.

Some experts also discussed contamination of PHA by agricultural residues. One expert noted that mulch and agricultural films are relatively insensitive applications compared to food packaging. Another voice argues that the requirements for contact films are manageable, allowing effective risk management through careful raw material selection. Notably, one expert expressed confidence in the integrity of PHA during processing and use, claiming that there have been no contamination issues. This positive outlook extends to PHA's barrier properties, which are comparable to those of polyethylene (PE), highlighting its viability as a replacement for conventional plastics in certain applications.

Regarding potential contamination with pesticides, microplastics and mycotoxins, one voice added that the potential for PHA to absorb pesticides is a concern. However, the expert identified biodegradable PHA mulch films as a promising application, particularly in organic farming. Another expert noted that some companies claim that PHA does not generate microplastics. While this may allay consumer concerns about contamination, several experts call for more research to substantiate these claims and question whether the complete degradation of PHA is different from the fragmentation of traditional plastics that leads to the formation of microplastics. In addition, one expert reported minimal consumer concern about mycotoxins, as consumers haven't mentioned any mycotoxin issues.

Finally, some experts also suggested solutions to potential contamination problems. One voice suggested that one solution to mitigate contamination issues associated with mulch films is to introduce anaerobic digestion, which would allow the simultaneous decomposition of both agricultural waste and the mulch film, thereby alleviating contamination concerns. Overall, most experts maintained a positive outlook, emphasising that effective control, risk assessment and quality testing are critical to ensure that materials meet technological and safety standards. This collective understanding reflects the complexity of navigating material safety, regulatory landscapes and the need for innovative approaches in the bioplastics industry.

Intermediate resume

The experts provided clear insights into contamination issues related to both raw materials and end products in the production of PHA. They generally agreed that while secondary raw materials from food production can be contaminated, they typically meet high safety standards, and contamination risks are more pronounced after use, particularly in the disposal of packaging waste. Processing methods often dilute or purify contaminants, and while agricultural residues may pose some risks, the consensus is that contamination in PHA products is manageable, especially for applications such as mulch films. Experts emphasised the importance of processing methods and stringent cleaning protocols to ensure safety, drawing parallels with the fossil fuel industry. Concerns were raised about pesticide absorption and microplastics, but many expressed confidence in the viability of PHA and its barrier properties compared to conventional plastics. The need for further research to address consumer concerns about contamination and to substantiate claims of PHA degradation was highlighted. Overall, the experts maintained a positive outlook and emphasised the importance of effective control, risk assessment and quality testing in navigating the complexities of material safety within the bioplastics industry.

Supplementation of PHA

Experts were also asked for their opinion on the supplementation of PHA. There is a strong consensus among industry experts that the addition of PHA is beneficial for optimal performance. One expert pointed out that the addition is necessary because pure PHA products can degrade too quickly and are often more expensive to produce. When supplementing PHA, one expert advised that the interaction between the two components needs to be tested as it could potentially affect the biodegradability of both. In accordance with this another expert stated that it makes sense to work with materials that do not represent a technological disadvantage, but ensure to ultimately achieve biodegradation and avoid the problem of microplastics.

Three experts went into further detail with the supplement materials. One expert pointed out that the properties of PHAs can be modified with mineral fillers such as chalk or lime. One expert mentioned a project using eggshells as a source of chalk, which is widely available and effective. The compatibility of PHA with the moisture content of fibres derived from green waste is also discussed. A third voice emphasised the need for pre-treatment of these fibres to reduce moisture and improve adhesion, which is critical for successful blending. Other experts stressed that PHA itself has great potential as an ingredient in bio-based compounds because it promotes degradation. The expert emphasised that there are collaborations with the compounding industry to develop blends with PHA that have specific desirable properties. He went on to say that PHA-starch blends are highly compostable and can help reduce costs. In addition, PHA enzyme blends are promising as they facilitate faster degradation of the material. Another voice went on to say that PLA material typically goes to industrial composting, where some customers are looking for faster degradation rates. There is an industrial interest in faster degrading materials.

Finally, when looking at PHA applications, one expert stated that definition of 'pure' is important, as achieving a food-safe product requires several cleaning steps to remove biomass residues. While food packaging requires high purity, it's uncertain whether agricultural PHA needs to be completely clean or whether 99 % sufficiency is acceptable.

Intermediate resume

Industry experts widely agreed that the supplementation of PHAs is critical to improving performance, as pure PHA can degrade too quickly and is often costly to produce. They emphasised the importance of testing the interaction between PHA and additive materials to ensure both biodegradability and avoidance of microplastic issues. Various materials, such as mineral fillers (including eggshells) and pre-treated green waste fibres, can modify the properties of PHA for better adhesion and functionality. Experts also highlighted the potential of PHA in bio-based compounds, noting collaborations to develop blends that improve compostability and promote faster degradation, especially for applications that require faster degradation rates. In addition, the definition of 'pure' PHA is important, particularly for food-safe applications where high purity is essential, while standards for agricultural applications may be less stringent.

Price development

In line with the results of the previous round of stakeholder interviews, the experts also identified production costs and economies of scale as key influencing factors. In addition, one expert added that production costs are significantly influenced by both economies of scale and raw material costs. In line with this, another expert emphasised the need for mass application to drive growth. With only about 40,000 tonnes of global production capacity, the market is still quite small, and while money is flowing into niche sectors, the PHA infrastructure remains centralised in a few locations. Decentralisation is needed to enable PHA production everywhere using simple technology from recyclable or residual materials, which could take 10 to 30 years to achieve.

Looking at current prices, experts believe that the low price of virgin plastics remains a significant barrier to the widespread adoption of bio-based alternatives. Currently, polylactic acid (PLA) is reported to be at least three times more expensive than conventional plastics, and the cost of PHA varies considerably depending on the type. Beyond the results of the previous round, several experts clearly identified legislation as a factor influencing price development. One expert believes that without legislation forcing companies to use bio-based products, price reductions will remain unlikely. Another voice supported this argument by noting that B2B customers are generally reluctant to pay a premium for bioplastics unless forced to do so by strict legislation. While there are customers who are motivated by sustainability, this group is relatively small. Most B2B customers prioritise cost, especially during economic downturns, and prefer cheaper conventional materials. In support of this, another expert stated that petrochemical sources are currently cheap, but the price of mulch films will only increase due to regulations promoting the use of bio-sourced alternatives, which may also lead to taxes on non-bio-sourced materials. However, the expert mentioned that the distinction between B2B and B2C dynamics is important, as end users may be more willing to pay a premium than B2B customers. A more critical expert explained that while there are advantages to using bio-residues as a starting point, the existing legislation poses challenges. For example, the strong incentives for biogas production in Europe lead to competition for the same raw materials used for PHA, as the value of residues is often linked to their potential for biogas production. This dynamic has a significant impact on feedstock costs, making biogas a competitive alternative. One expert also gave an example of agricultural applications.

With respect to price development, several voices stated that prices for bioplastics such as PHA are likely to decrease as production capacity increases and technology advances, including blending techniques. However, another voice added that predicting market development is complex as current PHA production relies primarily on conventional sources such as sugar and vegetable oils, both of which are subject to volatility in their markets and alternative applications. All experts agreed that the price will fall over the next few years. In terms of price ranges, the experts' assessments varied slightly. One expert stated that current prices for PHA are between 5 and 10 € per kilo. He further estimated that prices will decrease depending on variety and volume, but long-term expectations suggest that prices could decrease to around 3 to 4 €, especially for large purchases. Another expert noted that the market price for PHA has fallen from around 8-10 €/kg to around 6 €/kg, with the potential to fall further due to the emergence of large producers in China, which could have a major impact on prices in the long term.

When discussing price developments, most experts identified China as a key player. One expert mentioned that only Chinese players are currently able to produce PHA economically due to low labour costs and cheaper raw material prices, such as prices for agricultural oils, vegetable oils and palm oil. Another expert pointed to important developments in China, where one group is using unsterilised reactors with salt water for bacterial fermentation, resulting in much lower production costs compared to traditional methods for PHA. As these approaches become more widespread, prices are expected to fall further. Finally, another expert highlighted China's willingness to cooperate in the production of PHA in larger quantities.

Intermediate resume

In summary, there is optimism about the price development. However, experts agree that production costs and economies of scale are the key factors influencing the price of PHAs. The consensus is that a lower cost of virgin plastics is a significant barrier to the widespread adoption of bio-based alternatives, with current PHA prices estimated at between €5 and €10 per kilogram. There is optimism that prices will fall as production capacity increases and technological advances, including blending techniques, are implemented. However, experts warn that the low price of conventional materials continues to dominate market dynamics, making legislation essential to drive the transition to bioplastics.

Experts emphasised that without regulatory pressure, many B2B customers will remain reluctant to pay a premium for bioplastics, while end-users may be more willing to do so. Competition for feedstock, particularly from the biogas sector, complicates PHA production as the value of agricultural residues is often tied to biogas production rather than PHA applications. In particular, China is recognised as a key player in the PHA market, benefiting from lower labour and raw material costs that enable economically viable production methods. Innovations such as unsterilised reactors using salt water for bacterial fermentation are noted for significantly reducing production costs. As these methods gain traction, they are expected to contribute to further price reductions and increased market availability of PHA, highlighting the importance of both regulatory

4.2.2.2 Main limitations and challenges

The stakeholders of the second round of interviews were confronted with the results of the previous round. They were first asked to give their assessment of the challenges identified so far. All experts unanimously agreed that the most important challenges were included.

The most important challenges are represented in figure 8 and will be explained below.

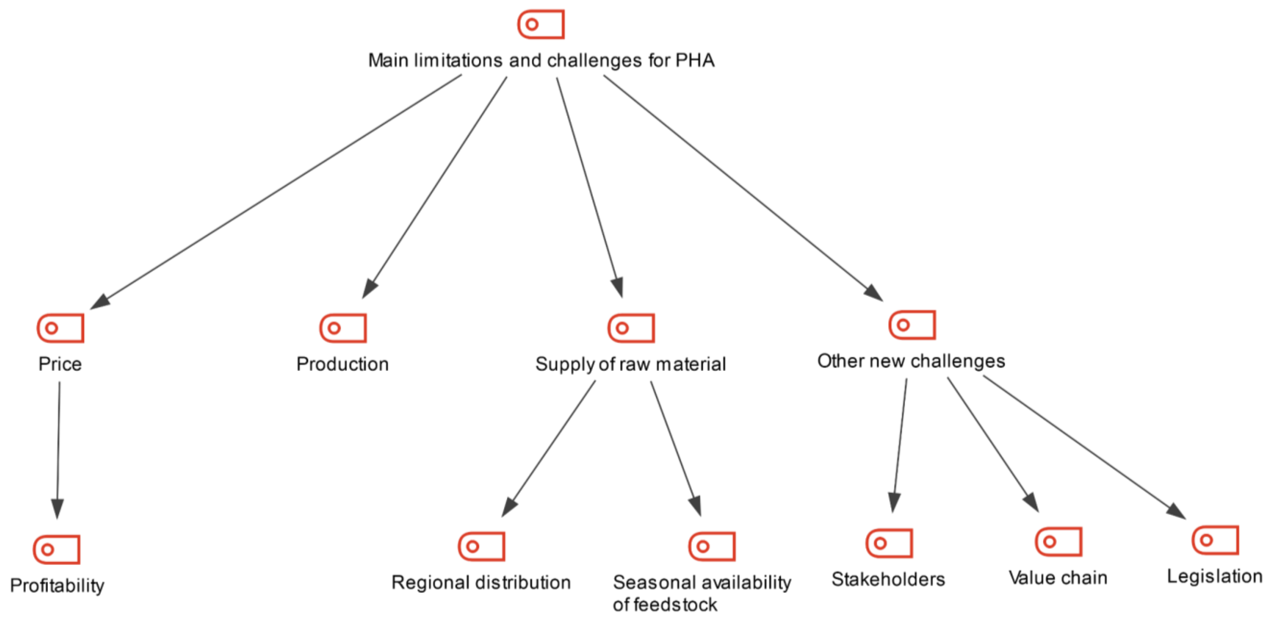

Figure 8: Overview of most frequently cited limitations and challenges for PHA assessed by experts (own compilation of Ecozept).

The experts then described the challenges in more detail and prioritised them. In contrast to the results of the previous round, the experts identified **price** as the most critical challenge to the market potential of PHA. Other experts emphasised that price is the most important consideration for producers and has a significant impact on their willingness to invest in PHA and other bio-based alternatives. There needs to be a clear demand for these materials to justify the investment. Another voice highlighted the critical role of research in demonstrating the added value of bio-based materials and evaluating their performance under real-world conditions, particularly in terms of how plants respond to these bio-based materials. He also identified key institutions such as INRAE, SHBF and CTIFL as key players in this research, underlining the collaborative efforts needed to advance understanding in this area. Finally, two experts stated that profitability remains a pressing issue, noting that more producers are likely to enter the market as demand for bio-based materials grows. This trend mirrors the dynamics of other industries where cost rationalisation, particularly in terms of feedstock, is becoming essential to maintain competitive advantage. Finally, some experts highlighted practical challenges in disposal, particularly when residual agricultural materials like plastic films or twine must be removed. Many disposal companies refuse to accept plastic, including bioplastics, in green waste. For example, in the Netherlands, even certified compostable plastics are not always accepted for composting. Overall, while there is optimism about the potential of bio-based materials such as PHA, addressing cost concerns through focused research and development will be critical to fostering a sustainable market.

Intermediate resume

In contrast to the previous round, experts unanimously identified price as the main challenge affecting the market potential PHAs and other bio-based materials. They emphasised that cost has a significant impact on the willingness of producers to invest and stressed the need for clear demand to justify these investments. Research institutes such as INRAE, SHBF and CTIFL were identified as key players in demonstrating the added value of bio-based materials and assessing their real-world performance, particularly in terms of plant response. Despite the optimism surrounding bio-based materials, experts pointed to ongoing issues related to economics and practical disposal challenges, such as the rejection of bioplastics in green waste disposal. Addressing these cost concerns through targeted research and development is seen as essential to cultivating a sustainable market for PHA and similar materials.

In contrast to the previous round, the experts focused on **legislation** as a key challenge for the potential of PHA. Several experts emphasised that progress depends to a large extent on the regulatory framework. While there's a general reluctance to accept bureaucracy and over-regulation, the lack of appropriate regulation is a significant barrier to progress. In line with this assessment, several voices stressed that legislation plays a crucial role in shaping these dynamics. Several experts noted that legislation is currently counterproductive. Some experts stated that under current regulations, PHA applications for food grade are classified as a plastic and is subject to restrictions, despite its promising potential as a sustainable alternative. This perspective emphasises the need for more supportive policies to encourage the adoption of environmentally friendly materials in different applications. Moreover, two experts gave the same example of a counterproductive legislation independently of each other by mentioning that there is currently a stimulation of biogas production in the European market. The same raw materials used for producing PHAs are also utilized for biogas, creating competition for these resources. Another expert confirmed this and pointed out that organic horticultural pots would be easier to absorb if there were regulations. Another voice further noted that the fossil fuel industry benefits from subsidies, which indirectly lowers the prices of conventional products, while the externalized costs of conventional plastics—such as CO_2 emissions and microplastic pollution—are not reflected in market prices. This absence of accountability complicates discussions around the pricing and adoption of sustainable alternatives like PHAs. Finally, two experts highlighted the significant challenge of an inadequate funding environment to support the circular economy, especially when it comes to venture capital. Scaling up technologies related to circular solutions is challenging due to the capital-intensive nature of these projects and the long timelines involved, which do not match the preferences of typical venture capital firms that favour faster, less capital-intensive investments. Despite significant research support for PHAs in Europe, the expert was irritated and described it as paradoxical that there is insufficient support for market uptake. Another voice also highlights the slow pace of regulatory change in the Single Use Plastics Directive, suggesting that this is hampering progress towards biomaterials. In contrast, he noted that countries such as China are moving faster by recognising the steps needed to support sustainable materials.

Intermediate resume

In contrast to the previous round of stakeholder interviews, the experts highlighted legislation as a significant barrier to the potential of PHAs, noting that the regulatory framework has a major impact on progress in the sector. They expressed concern that current regulations classify food-grade PHA as a plastic, imposing restrictions despite its sustainable benefits. Competition for feedstock, exacerbated by incentives for biogas production, further complicates matters. Experts highlighted subsidies to the fossil fuel industry that distort market prices and undermine the competitiveness of sustainable alternatives such as PHA. They also highlighted challenges related to inadequate funding for circular economy initiatives, with venture capital often favouring faster returns on investment. The slow pace of regulatory change in the EU, particularly in relation to the Single Use Plastics Directive, contrasts with more rapid progress in countries such as China, suggesting the need for more supportive policies to encourage the uptake of environmentally friendly materials.

The experts' statements on **scalability** are in slight contrast to the results of the previous round. The interviewed experts were generally optimistic and pointed out that scalability is progressing well. One more critical voice noted that the current global production capacity for PHA remains limited at around 40,000 tonnes, suggesting that scalability efforts are still at an early stage. They suggested that decentralisation is needed to enable wider PHA production using accessible technologies from recyclable or residual materials, a transition that may take several years.

In contrast, other experts highlighted the scalability of the PHA sector, noting that it can use a wide range of feedstock sources. He also emphasised the importance of being able to process a wide range of feedstock sources, stressing that careful pre-selection and conditioning of these materials is crucial to achieve standardised outputs. A consistent production process is essential to account for variations in raw material quality and seasonal availability, enabling the industry to produce consistent results. In addition, a methodical approach to raw material analysis is advocated, possibly using a database for blending materials to maintain cost efficiency. In line with this, another voice noted that scalability is progressing well, particularly with the ability to use non-sterilised, robust production strains. As production scales up, it is expected that the unit price will automatically decrease.

Regarding the size of plants for the production of PHA from agricultural residues, some experts noted that the reliance on organic waste for production requires adjustments in plant size based on (local) feedstock availability. A typical scale of operation for PHA production is estimated to be between five and 25 kilotons per year, as larger plants are constrained by feedstock availability. It was also noted that a 500 kilotons plant would not be practical as there would not be enough feedstock. In addition, other experts addressed concerns about feedstock consistency, highlighting that there is sufficient waste globally to support the production of significant quantities of PHA. In conclusion several experts mentioned that there are significant efforts to establish and scale up PHA production. Finally, another voice focused on mulch films, stating that the use of PHA in non-food contact products, such as mulch films, is viewed favourably. The possibility of developing multi-layer structures using different types of PHA, where a high-quality variant is used in the outer layer and a less stringent type in the inner layer, could help to meet different application needs.

In terms of **speed of scalability**, experts agreed that there is strong global interest in PHA technology, suggesting that progress could be rapid. One expert highlighted that the scalability of PHA production is progressing well, largely due to the ability to use unsterilised, robust production strains, which helps to achieve larger scales and lower unit prices. She further notes that there's significant potential for different players to enter the market without direct competition, leading to increased scalability and lower costs globally. A key immediate goal is the establishment of the first commercial PHA plant in Europe, with some experts noting that an investment decision is expected by the end of next year or early 2026. Once initiated, construction of this plant is expected to take one to two years, with the aim of being operational by 2027 at the earliest. In line with this, two experts emphasised that the technology required to convert waste materials into PHA, particularly for applications such as mulch films, is already available. However, challenges remain, particularly in increasing productivity and reducing costs. Some speculate that PHA products could become more widely available within the next 5 to 10 years, especially as compostable mulch films gain traction in developed markets.

While there is optimism about the European market, experts noted that the pace of progress will be influenced by external factors, particularly legislation and the availability of funding. In addition, significant licensing opportunities for the technology in Asia offer a route to scalability beyond Europe. Furthermore, one expert pointed out that production capacity in China can be scaled up significantly - from 5,000 to 20,000 tonnes or more - by using readily available resources such as sugar and vegetable oils. She also pointed out that the technology exists and is being used effectively by Chinese players.

Intermediate resume

Consistent with the results of the previous round, experts are generally optimistic about the scalability of polyhydroxyalkanoate (PHA) production, although some experts cautioned that global capacity remains limited at around 40,000 tonnes, indicating that scalability efforts are at an early stage. Decentralisation is recommended to increase PHA production using recyclable materials, which may take several years. Experts emphasised the need for consistency in raw material quality and processing, with a focus on the use of diverse feedstocks. They anticipated that increased production will lead to lower unit prices, and there's significant global interest in PHA technology. The establishment of the first commercial PHA plant in Europe is a key objective, with the expectation that it will be operational by 2027. While challenges remain in terms of productivity and cost, particularly in relation to regulatory and financing factors, the potential for scalability in the Asian market is remarkable, particularly with Chinese companies using readily available resources. Overall, while progress is being made, successful scalability will depend on continued innovation and collaboration within the industry.

The experts also identified new challenges compared to the previous round of interviews. One of these challenges is the impact of **stakeholders**. Other experts highlighted challenges within the value chain, in particular regarding the role of suppliers and waste management. Currently, a circular business model cannot be fully implemented due to inadequate infrastructure and lack of knowledge.

In line with this, another expert noted that stakeholders in the agricultural sector, including both users and producers, typically lack sufficient understanding of bioplastics and their advantages over conventional plastics. This knowledge gap is exacerbated by a prevailing stigma associated with plastics, with products such as mulch film often viewed negatively as mere plastic waste. Many people do not realise that these films can be bioplastics that contribute to a circular economy. Another voice added that there are challenges consumers face in understanding the degradation of biodegradable products, particularly when it comes to expectations around the rate of degradation of items such as flower pots. Many consumers mistakenly believe that these products should decompose within a short period of time, such as ten days, without realising the crucial role that micro-organisms in the soil play in the degradation process. He also stressed the need to educate consumers, who often tend to simplify plastics into categories of hard and soft materials.

However, despite some resistance to acceptance, most experts believe that growing awareness and evolving criteria for understanding these materials will facilitate a more positive perception over time. Furthermore, this increased awareness is influencing both brand owners and consumers to make more environmentally conscious choices, indicating a positive shift towards sustainable practices in the industry.

Intermediate resume

Experts identified several emerging challenges in implementing a circular business model for bioplastics, particularly in relation to the role of suppliers and waste management. A key issue is the lack of understanding among stakeholders in the agricultural sector about bioplastics and their benefits compared to conventional plastics, compounded by the stigma of plastics as waste. In addition, consumers often misunderstand the degradation processes of biodegradable products, mistakenly expecting rapid decomposition. Despite these challenges, experts are optimistic that growing awareness and evolving criteria will foster a more positive perception of bioplastics, encouraging environmentally conscious choices among brand owners and consumers, and facilitating a shift towards sustainable practices in the industry.

Experts also focused on the challenge of addressing brand owners and end consumers. The expert highlights the growing awareness of PHAs as a material that can effectively penetrate specific niche markets. The challenge lies in identifying these niches and facilitate discussions with brand owners to explore potential opportunities for PHA applications.

In this regard, a notable trend is the growing awareness among end consumers, particularly in Western Europe, of the detrimental effects of excessive plastic use and associated waste, including microplastics. Younger generations are becoming more attuned to these issues, prompting brand owners to rethink their strategies, possibly moving to more sustainable alternatives such as bioplastics. In addition, farmers are taking proactive steps to minimise the use of plastic to reduce waste, signalling a wider commitment to sustainability across all sectors. Another expert reinforced this statement by mentioning the emergence of consumers known as LOHAS (Lifestyles of Health and Sustainability), who prioritise healthy and sustainable living while minimising material consumption. This group embodies the philosophy of ensuring a cleaner environment for future generations and is seen as a significant force for change, particularly in influencing government policy. Several experts highlighted the close connection between end consumer behaviour and brand owner strategies. Overall, the experts stressed the importance of brand owners recognising the growing consumer awareness and prioritising bioplastics such as PHA in their strategies. Balancing end consumer expectations with regulatory requirements and brand owner strategies will be essential for the successful integration of PHA into mainstream markets.

Intermediate resume

Experts highlighted the challenge of engaging brand owners and end-users in the adoption of PHAs in niche markets. They point to growing consumer awareness, particularly in Western Europe, of the negative impact of plastic waste and microplastics, which is prompting brand owners to consider more sustainable alternatives such as bioplastics. Younger generations and environmentally conscious groups such as LOHAS (Lifestyles of Health and Sustainability) are driving this change and influencing government policy. The experts stressed the need for brand owners to recognise this shift in consumer expectations and integrate bioplastics into their strategies, while balancing regulatory requirements and market demands for successful mainstream adoption of PHA.

Solutions to current challenges

Experts also focused on possible solutions to current challenges. As described in the previous paragraph, several experts stressed the need for **favourable legislation** that is **harmonised both across Europe and globally**. Some of them are concerned that some discussions among officials appear to be ideologically driven and disconnected from the practical realities faced by industry. New European regulations should not disadvantage manufacturers from Asia or America, potentially creating import barriers that hinder business growth and innovation. In addition, another expert pointed out that as long as bioplastics remain significantly more expensive than their conventional counterparts, customers are unlikely to switch on the basis of goodwill or ideology alone. To encourage growth in the bioplastics sector, clear guidelines and policies are needed, such as **legal restrictions** on conventional plastics in agriculture (taxes, fines) to create a level playing field. In line with this, another voice highlighted that to truly promote bio-based solutions and achieve greater independence from fossil fuels, it is essential to stimulate the use of bio-based alternatives. In addition to restrictions, stimulation could be facilitated by **subsidies** or **legislation requiring** the use of bio-based or biodegradable options in certain applications. Finally, another expert advocated internalising the costs associated with conventional plastics, stressing the importance of a fair price that includes the costs associated with CO2 emissions and microplastic pollution.

On the **production** side, some experts outlined several key considerations for PHA production. They highlighted the importance of addressing water use in raw material processing, noting that washing potatoes generates significant starchy wastewater. The **establishment of PHA production sites in Europe**, ideally **close to raw material suppliers**, would facilitate cooperation with cooperatives and processing plants, thus increasing efficiency. In addition, another expert highlighted the critical need for effective treatment of waste from PHA production, as processing 10 litres of liquid typically produces only 1 usable litre of PHA, resulting in significant waste. The establishment of nearby composting or methanisation facilities could help to manage this waste effectively. In particular, the expert mentioned that PHA can be produced from agricultural waste, reducing dependence on external raw materials.

Intermediate resume

Experts identified several solutions to the challenges facing the bioplastics sector, emphasising the need for harmonised legislation across Europe and globally. They are concerned that ideological discussions among officials may overlook practical industry realities and disadvantage manufacturers from other regions, potentially creating barriers to growth and innovation. The high cost of bioplastics compared to conventional plastics remains a significant barrier to customer adoption, requiring clear guidelines and policies that encourage the use of bio-based alternatives, such as legal restrictions or subsidies. In addition, experts stress the importance of internalising the environmental costs associated with conventional plastics to create a fair market. On the production side, locating PHA production facilities close to raw material sources can improve efficiency, while addressing waste management from PHA production, such as composting or methanisation, is critical for sustainability. The use of agricultural waste as a feedstock can further reduce dependence on external materials and promote a more resilient

4.2.3 PHA-applications

In the context of PHA applications, the previous round of stakeholder interviews provided a comprehensive characterisation of the end users' requirements with respect to agricultural applications.

Given the close interlinking of Work Package 1 and 4, the results were incorporated into the design of a questionnaire in WP4. As outlined in section 3.1.4, the questionnaire was developed in accordance with the Delhi methodology. Based on desk research, research questions were formed, hypotheses were subsequently formulated to answer the research questions and finally questions were developed, the answers to which answered the hypotheses put forward.

The questionnaire was used in a case study in Catalonia in order to further specify the requirements of farmers with respect to PHA products for agricultural applications. The questionnaire specifically inquired about the type of plastic material used, if applicable, along with the crop and annual quantity. Furthermore, the type of material was discussed (conventional, bio-based, biodegradable, other). In the second step, the parameters service life, frequency of usage and disposal were asked. Finally, the farmers provided an assessment of which plastics could be replaced by bioplastics in agriculture. The collected data will be presented within milestone 14 and deliverable report 4.1.

4.2.4 Extracted and microbial Proteins

4.2.4.1 Stakeholders' expectations

Quality and Functional requirements

Looking at the functional requirements for MP, experts highlighted their expectations regarding the requirements for food and feed. These requirements are illustrated in figure 9 and will be explained below.

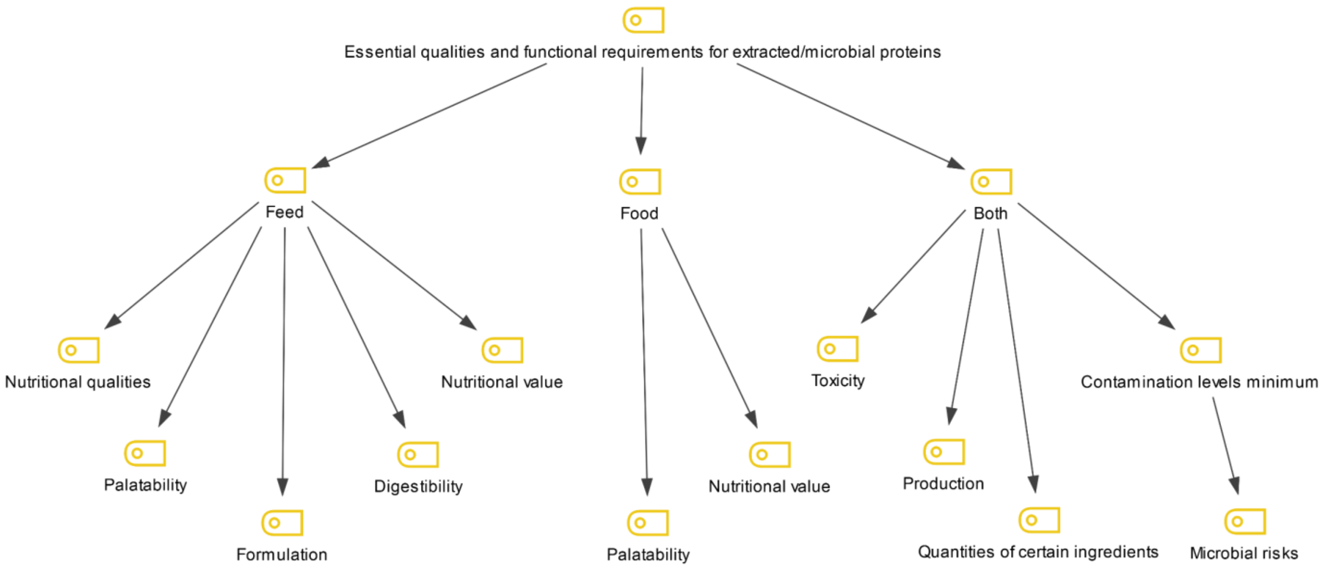

Figure 9: Overview of most frequently cited qualities and functional requirements for MP assessed by experts (own compilation of Ecozept).

Regarding **food** applications, some expert stressed out concerns about current dietary trends, emphasizing that consumers often prioritize taste over nutritional value when selecting foods, with little regulatory support to promote healthier eating habits. While the need for complete proteins is acknowledged, it is expected to grow as lifestyle-related health issues emerge more frequently among younger populations. Organizations like the World Health Organization (WHO) and Nestlé underline the critical importance of the first 1,000 days of life in mitigating future health problems. However, awareness regarding the long-term effects of dietary choices remains notably low. The expert calls for improved utilization of amino acids and fibres in diets as a potential solution to these challenges.

Looking at the crucial characteristics other experts emphasised the critical importance of both palatability and nutritional value. They stated that for any product to be successful, especially in the food industry, it must not only be nutritious but also appealing to consumers. Palatability is a key factor in ensuring that individuals are willing to eat the product. Overall, the consensus is that striking a balance between these factors is essential for the acceptance and effectiveness of food and feed products in the market.

In terms of the most important functional requirements for MP for **feed**, experts were able to precise the results of the first round of stakeholder interviews. The identified several key themes such as nutritional value, palatability, digestibility, and the specific roles of various ingredients. Beginning with **nutritional value** experts unanimously emphasized that nutritional value is paramount, particularly in animal feed. They agreed that while additional functionalities and benefits are important, they must not overshadow the primary focus on delivering high-quality nutrition. One expert highlighted the importance of maintaining a consistent protein level while allowing for variations in peptide profiles. Another voice added that a sufficient protein level is crucial for aquaculture. Speaking of aquaculture, one expert agreed that maintaining a balanced **amino acid profile** is vital for optimal fish health and growth. Two experts further focused on the amino acid profile. Other voices stated that essential amino acids in animal feed are lysine, methionine, threonine, and histidine with histidine limiting the cataract problems in fish. They further emphasised that the balance of amino acids must be respected. Another voice added that the supplementation synthetic amino acids can be beneficial as they enhance the nutritional content of feed. Additionally, he stressed out the importance of fats, particularly omega fatty acids, especially for salmon that require high-fat diets. Plant-based fats, like rapeseed, are preferred to reduce saturated fat content in animal diets. Finally, another voice added that particularly for carnivorous species of fish carbohydrate inclusion can lead to lower digestibility.

Two other experts identified **palatability** as a critical factor, particularly for fish feed. Some experts stated that palatability is essential because the product has to be something the fish want to eat. In line with this, another expert noted that certain peptides can improve palatability for fish as they have attractant molecules. However, the health benefits associated with some peptides are not widely recognised in the industry and more concrete research is needed to support these claims. Overall, the incorporation of attractant molecules is considered essential to improve fish palatability and ensure that the feed is desirable enough for fish to consume.

Speaking of palatability lead the experts to the next requirement. The **formulation** of feed products is seen as a critical aspect of improving overall quality and efficiency. Several experts suggest that developing improved pellets or kibbles that require fewer additives can offer a significant advantage. One voice highlighted ingredients such as wheat gluten for their strong binding properties, which help maintain the structural integrity of the pellets. However, challenges remain, particularly in managing the stickiness that can arise from enzymatic hydrolysis of proteins during processing in industrial machinery. In addition, another expert emphasised that **digestibility** of feed is another significant concern. He further explained that low digestibility can lead to waste, especially in aquatic environments. This underscores the importance of formulating feeds that maximize nutrient absorption to minimize environmental impact.

Overall, while there is a consensus on the importance of nutritional value and palatability, experts recognized the challenges in formulating effective feed products that meet these criteria. There is a call for further research and development to optimize these formulations and ensure they provide the necessary benefits for animal health and sustainability.

<u>Intermediate resume</u>

Experts highlighted the importance of quality and functional requirements for MP in both food and feed applications. For food, they noted that while consumers often prioritise taste, the demand for complete proteins is growing, particularly due to lifestyle-related health issues. Achieving a balance between palatability and nutritional value is essential for market acceptance, as appealing flavours significantly influence consumer choice.

In animal feed, experts emphasised the importance of maintaining high nutritional value and a balanced amino acid profile, particularly for aquaculture. Palatability remains a key factor, with certain peptides increasing attractiveness to fish. Experts also discussed the need for improved feed formulations, with a focus on developing pellets that require fewer additives while managing stickiness from enzymatic hydrolysis. Digestibility is another major concern, as low digestibility can lead to wastage in aquatic environments. Overall, there is a consensus that further research and development is needed to optimise feed formulations to ensure they meet animal health and sustainability requirements while remaining marketable.

Qualities compared to conventional Proteins

The experts were also asked about the qualities compared to conventional proteins. Most of the experts agreed that the proteins have the same qualities as conventional proteins. Two voices stated that these new protein sources can match or even exceed the quality and safety of conventional proteins such as meat-based proteins, highlighting their viability as alternatives in food production. One of the experts added that conventional proteins often do not meet health standards for human consumption. He also pointed out that many widely available options, such as veggie burgers from fast food chains, can be as unhealthy as sugary drinks, a fact that is not widely recognised. Another voice added to the previous statements by noting that MP has the same qualities. He pointed out that MP is a new ingredient that requires minor adjustments to existing recipes. He emphasised that although these ingredients may be different, the basic concepts remain the same for different protein sources. Finally, another expert addressed the issue of shelf-life, stating that when MP is processed into dried powders, it usually has a satisfactory shelf-life.

However, other experts were more critical, pointing out that MPs have a different nutritional profile than traditional proteins. Previous studies have shown that these MP can lead to reduced feed intake, possibly due to an imbalance in amino acids. Finally, another critical voice warned that if MP are introduced without proper consideration, they may end up being just a source of protein with no additional health benefits.

Intermediate resume

Experts generally agreed that new protein sources, including MP, can match or exceed the quality and safety of conventional proteins, such as meat-based options, making them viable alternatives in food production. Some experts highlighted that many conventional proteins do not meet health standards and pointed to the unhealthy nature of certain processed vegetable options. While MP can be easily incorporated into existing recipes and have a satisfactory shelf life when processed into powders, concerns remain about their nutritional profile, particularly the amino acid balance, which may lead to reduced feed intake. Critics emphasised that careful consideration must be given to the introduction of these proteins to ensure that they provide real health benefits, rather than simply serving as an alternative protein source.

Qualities of agricultural residues as feedstock

As there was no consensus reached within the previous round of stakeholder interviews the experts were also asked to share their expectations on the qualities of agricultural residues as feedstock.

As in the previous round of stakeholder interviews, the experts identified **reproducibility and stability** as essential qualities. Several experts highlighted the importance of stable raw materials. Some experts underscored the necessity of reproducibility in quality across the agro-industry by noting that variations in agricultural feedstock necessitate recalibrating machines with each new harvest, which complicates the production process. This principle extends to side streams used in production, where a stable composition is crucial for achieving optimal outcomes. Variability in these side streams can disrupt production efficiency and consistency. One voice proposed that one solution is to gasify all materials into syngas, which would create a consistent starting point with a uniform composition for further processing.

In addition to the results of the first round, the experts formulated other necessary characteristics. In relation to the stability mentioned above, two experts stressed the importance of having stable raw materials to ensure **consistent protein content**. Other experts highlighted that inconsistent amino acid levels in raw materials can hinder the production process and affect the overall quality of the final product.

Finally, some experts emphasised the need for **economic viability** in the development of protein solutions for animal feed. He points out that many suppliers are mistakenly aiming to replace fishmeal, which has seen a significant drop in price in recent years. They highlighted that the focus should shift to alternatives such as corn gluten, which can be more price volatile due to seasonal changes. The expert also suggested the potential for proteins that are more cost effective than corn gluten, while highlighting the need for formulations that are less palatable. While there may be a willingness to pay more for proteins that benefit animal health, such benefits need to be substantiated. In addition, one voice noted the need for caution in the use of agricultural residues, particularly in relation to pigments; while some fish species such as trout and salmon may benefit from certain pigments, they may be undesirable in other applications.

Intermediate resume

Experts emphasised the importance of reproducibility and stability in the quality of agricultural residues as raw materials for animal feed, noting that variations in these materials can complicate production processes. The need for consistent protein content is critical, as inconsistent amino acid levels can negatively affect the quality of the final product. While some experts suggested gasification of residues into syngas to achieve a consistent composition, economic viability remains a concern. They cautioned against focusing solely on fishmeal replacement due to its recent price decline, and suggested focusing on more cost-effective alternatives such as corn gluten. They also highlighted the need to ensure that any animal health benefits of these proteins are well supported, while noting the potential challenges posed by pigments in certain fish species.

4.2.4.2 Main limitations and challenges

Looking at the main limitations and challenges to the market potential of MP, all the experts acknowledged that while there are several important limitations to consider, the ones discussed in the previous round are the most significant barrier. The experts then discussed the main challenges. These challenges are illustrated in figure 10 and will be addressed below.

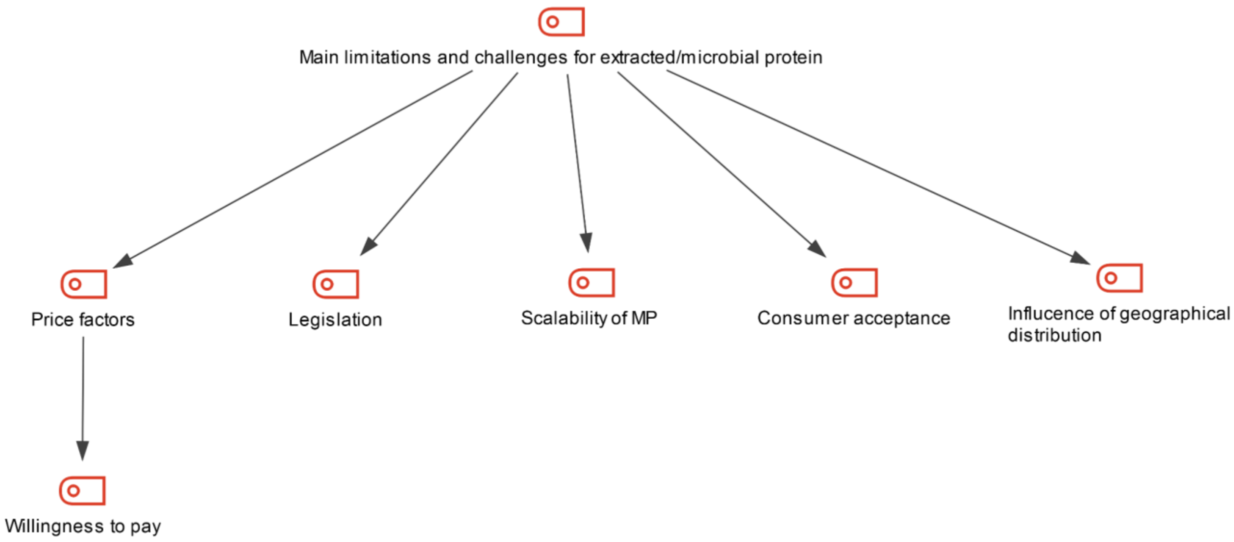

Figure 10: Overview of most frequently cited limitations and challenges for MP assessed by experts (own compilation of Ecozept).

In slight contrast to the previous round, the experts clearly identified **price** as the main challenge to the market potential of MP. Some experts stated that the current pricing structure poses challenges. They went on to explain that competitive pricing is crucial, even with additional benefits. For example, there have been difficulties in selling feed containing insect meal, where despite initial interest from producers, the high price discouraged purchases. In this context, several experts argued that cost reduction is crucial for producers to gain a competitive advantage over traditional protein sources. If MP could be offered at a lower price, this would improve its business case, attract more investors and ultimately stimulate growth in the sector. In addition, another expert noted that an attractive price for MP could potentially facilitate the overcoming of regulatory hurdles. Finally, a third expert stressed the need for competitive pricing, particularly in the feed industry where economics are essential to drive sales. In contrast, other experts believed that market dynamics will eventually lead to effective solutions that reduce costs. Overall, experts considered price as the most significant barrier to entry for MP. Without significant reductions, the likelihood of investment in these proteins is reduced, highlighting the need for continued efforts to develop economically viable production methods.

Experts also described their perceptions of the **price of MP compared to conventional proteins**. One expert described that currently the prices of conventional proteins have decreased, which puts further pressure on alternative proteins such as MP to remain competitive in price. However, MP needs to be priced at the same level as sources such as soya and rapeseed. A more critical expert noted that the recent inflation in raw material prices is likely to continue, which could further affect the pricing of MP and complicate efforts to achieve competitive parity in the market. Another voice highlighted an additional problem. While comprehensive data on conventional proteins is readily available, often from detailed EU reports, small start-ups struggle to effectively evaluate and compare their costs against these established benchmarks. Economies of scale are crucial. Some experts emphasised that small reactors are unlikely to be profitable until they reach pilot scale, typically around 50,000 litres. This is a significant barrier, as convincing stakeholders to invest in pilot plants is a critical step towards achieving larger production capacities. However, there is optimism that if prices can be brought down to levels competitive with conventional proteins, significant market demand could follow. In this context, some experts suggested that incorporating carbon or environmental footprints into the pricing strategy could reshape market dynamics and lead to a reassessment of cost calculations. This approach could attract consumers who are increasingly concerned about sustainability and environmental impact.

Finally, the experts were asked to give their assessment of **willingness to pay**. The experts agreed that the willingness to pay more for alternative solutions is low, especially for feed. In addition, several experts focused on feed. Some experts stated that if a protein does not have a proven health benefit, there is no justification for paying a premium. Another voice mentioned that benefits could be a differentiated amino acid profile or advantages in digestibility and bioavailability. However, another expert noted that the company would consider paying a higher price for MPs if they offered clear animal health benefits. For example, the wall of the yeast Saccharomyces, when processed into flour, has been shown to improve digestive health in certain animals such as ruminants. However, the experts cautioned that the market needs to be chosen wisely. They mentioned that the corn gluten market is already well established, making it a challenging sector to compete in. Finally, another voice added that feed prices are currently around €350 per tonne, with raw materials accounting for 85 % of the cost. On the other hand, one expert suggested that there is potential for a positive impact, especially if it demonstrates a commitment to a circular economy and enhances the company's image. Ultimately, however, customers will make the final decision.

Intermediate resume

Experts identified price as the main barrier to the market potential of MP, noting that competitive pricing is critical to attracting investment and achieving growth in the sector. They emphasised that if MP could be offered at lower prices, it would improve its marketability against traditional protein sources such as soy and rapeseed. Despite some initial interest, high prices have discouraged purchases, particularly in the feed industry where cost is an important consideration. Experts expressed concern that recent commodity price inflation could further complicate the pricing of MP, making it difficult to compete with conventional proteins. They also highlighted the importance of economies of scale, noting that small reactors may struggle to be profitable until they reach pilot scale. In addition, the experts pointed out that without clear health benefits, the willingness to pay a premium for MP is low. They concluded that while there is potential for a positive shift in consumer interest - particularly around sustainability - market acceptance will ultimately depend on the economic viability and perceived benefits of MP.

Price factors:

The experts also focused on the most important factors in the pricing of MP. Most of the experts agreed with the factors mentioned in the previous round of expert interviews. Some of them also prioritised the factors or added other relevant factors.

In line with the previous round of stakeholder interviews, the experts emphasised that a crucial price factor is the **price of by-products**. In this respect, some experts identified the cost of input materials as a primary concern, noting that residues can be a good solution as they are often cheaper. Experts point out that the use of by-products should not compete with other industries, such as animal feed, which have to comply with strict regulations. For example, when feeding insects for protein production, certain materials cannot be fed to these insects, highlighting the influence of the regulatory landscape on the price and availability of inputs.

In addition, the **cost of production** was by far the most frequently cited price factor. The experts agreed that the viability of alternative protein production is strongly influenced by the costs associated with the process. One expert noted that the investment required to set up production facilities was a significant cost. Another expert looked in more detail at the production process and emphasised that if the production costs cannot be justified by the product price, alternative methods need to be considered. Key cost drivers include fermentation and purification, which are considered to be the most energy intensive and expensive steps in the production process. In this context, some experts highlighted **energy consumption** as a key price driver. In line with the other expert, she perceived energy consumption as a major cost factor, especially in fermentation, which requires a significant energy input. The expert also noted that the transition to green energy sources for these processes may further increase costs. In addition, another voice identified drying as a significant cost factor due to the complexity of converting liquids into powders, although the expert believes that this process can be effectively managed.

Furthermore, several experts identified **production volume** as a key price factor. Some experts stated that the current challenge in the sector is the small scale of operations, which makes it difficult to attract investors for larger scale production. Another voice agreed, adding that it is currently difficult to find investors willing to make the investments to produce on a larger scale. Another voice suggested that an initial focus on higher value products could generate revenue to support expansion into additional revenue streams.

Finally, some experts stressed the importance of **collaboration and value-chain creation**, starting from the perspective of the end user. The expert highlighted the importance of changing the perception that agricultural residues are worthless. Instead, the expert suggested building partnerships with suppliers that benefit all parties, including farmers. By focusing on transparent discussions on pricing and logistics, experts believe that viable solutions can be developed to address current challenges in the industry.

Intermediate resume

Experts recognised several key factors influencing the pricing of MP and emphasised that the cost of by-products, particularly residues, plays a crucial role in determining input prices. They noted that while the use of cheaper residues can be advantageous, it is important that these do not compete with other industries, such as animal feed, which are subject to strict regulations. In addition, the cost of production emerged as the most important factor, with high costs associated with fermentation and purification processes, as well as the energy required, particularly in the transition to green energy sources. The small scale of current operations presents a challenge in attracting investors for larger production facilities, but some experts suggested that focusing on high-value products could generate initial revenues for expansion. Finally, collaboration along the value chain and a change in perception of agricultural residues are needed to develop viable solutions that benefit all stakeholders, including farmers.

Legislation

As in the previous round, there was a strong consensus among the experts to highlight legislation as a significant barrier to the introduction of new proteins such as MP, particularly within the European Union. Several experts highlighted the **complexity and stringency of the novel food application process**, which makes it particularly difficult to introduce completely new organisms. One expert went into detail, noting that the novel food process is **costly**, although she agrees with the need for it. The expert highlighted the lack of consensus on testing requirements and emphasised the need for clarity on guidelines, testing methods and key performance indicators (KPIs). In line with this, another voice highlighted the challenges of passing legislation in relation to new food sources, in particular the difficulties in proving the safety of products such as rapeseed due to outdated legislation that hinders innovation. Another expert added that the process is **lengthy**, noting that it often takes five years and significant financial resources to demonstrate the safety of a product, even when comparisons can be made with similar products that are already accepted.

Other voices added the regulatory landscape varies by region and is influenced by how organisms are already utilized. Other voices added. They further remarked that a key aspect of the regulatory challenge is the requirement for new proteins to be **included in the EU regulatory catalogue**, which necessitates demonstrating adequate digestibility through quantitative assessment (for feed). Finally, a third voice highlighted that while the U.S. may offer a slightly more accessible pathway depending on existing literature, significant barriers still persist. However, some voices highlighted that there is potential for extracted proteins, especially with the upcoming deforestation law set to take effect in January 2025, which will prohibit the import of proteins sourced from deforested areas, such as soybeans.

Intermediate resume

Experts agreed that legislation is a significant barrier to the introduction of new proteins, particularly MP, in the European Union. They emphasised the complexity and high cost of the novel food application process, which makes the introduction of new organisms difficult. The lack of consensus on testing requirements and the need for clearer guidance were highlighted as critical issues. In addition, outdated legislation hinders innovation by making it difficult to demonstrate the safety of new food sources such as rapeseed. The lengthy approval process, which can take up to five years, exacerbates these challenges, especially as the regulatory landscape varies from region to region. While the US offers a slightly more accessible pathway, significant barriers remain. Experts identified potential opportunities for extracted proteins, particularly considering the upcoming deforestation bill, which will affect imports of certain protein sources.

Geographical distribution and logistics

As described in the previous round of stakeholder interviews, the experts were unanimous in their view that geographical distribution is an important challenge to overcome. Consistent with the previous round of interviews, one expert emphasised that production in the region of origin is beneficial. However, if a plant is located far from the source, it is essential to have an effective transport and logistics solution to ensure quality. This view was echoed by another voice, which emphasised the local sourcing of its products as part of its commitment to assessing life cycle impacts. This approach is driven by consumer demand for locally sourced products and underlines the wider trend towards sustainability in procurement practices. Finally, and in line with the previous opinions, a third voice noted that proximity to raw material sources is a critical factor, particularly for bioreactors, which require significant amounts of waste. She stated: "An advantage of bioreactors is their flexibility of location; positioning them close to the source of the residue can effectively address logistical challenges". Experts agree that while long-distance transport is manageable, the associated costs and CO_2 emissions can be significant challenges. Fortunately, there is often a sufficient local supply of waste materials, which can alleviate some of the logistical burdens.

In addition, some experts highlighted the specific requirements for transporting proteins, which are generally easier to move than fats, but require stabilisation to maintain quality during transport. Maintaining humidity levels between 5 % and 12 % and keeping water activity (Aw) below 0.7 are critical to protein integrity. In addition, the incorporation of antioxidants such as tocopherols is essential to ensure the nutritional value and shelf life of these products, which must exceed one year.

Finally, experts also addressed the logistical issues, proposing to convert residues into a more chemically stable form that optimises transport and minimises costs. This approach focuses on increasing the caloric content per unit weight, as transporting low-density materials is not economically viable. Another voice added that, for example, agricultural waste such as tomatoes is grown in the South but consumed in the North, highlighting the need for a reliable supply chain.

Intermediate resume

The experts agreed that geographical distribution is a major challenge for the production and transport of proteins derived from agricultural residues. They emphasised the benefits of local sourcing and the need for effective logistics, especially when production facilities are located far from raw material sources. Proximity to waste materials is particularly important for bioreactors, which require significant amounts of input. While proteins are generally easier to transport than e. g fats, maintaining their quality during transport requires careful stabilisation, including humidity control and incorporation of antioxidants. To further improve logistics, experts suggested converting residues into more chemically stable forms to optimise transport efficiency and reduce costs. Overall, a reliable supply chain is essential to overcome these logistical challenges, especially given the disparity between where agricultural products are grown and where they are consumed.

Scalability

Consistent with the results of the previous round of expert interviews, the experts identified scalability as a significant barrier within the bioprocessing industry but were optimistic about finding solutions to the scalability challenges of MP.

Several experts focused on the challenges of scaling up bioprocesses. Some experts highlighted that scaling up production poses significant challenges, in particular when moving from small reactors to pilot-scale facilities of 50,000 litres or more. Another voice added that most bioprocessors typically operate at capacities of no more than 30,000 litres, which makes scaling up a complex task, especially from a commercial perspective. While some facilities exist, such as a maize reactor with a capacity of 230 cubic metres, the majority of operations face challenges in convincing stakeholders of the viability of scaling up due to a lack of understanding of the underlying technology. Another voice emphasised that investment decisions are closely linked to the scalability of fermentation processes. She went on to describe fermentation as highly scalable, as the cost per unit tends to decrease as production increases, making it economically advantageous. However, the high initial investment required, whether for 1,000 litres or 64,000 litres, can deter potential investors.

Looking at the current status within Europe, experts noted that there are no major European companies involved in the sector. To overcome these challenges, he emphasised that it is crucial to generate both sufficient demand and supply. Another voice added that there are established facilities that can carry out small-scale trials, from five to thirty litres, which help to determine the feasibility of scaling up. If these initial tests are successful, they can be scaled up to pilot-scale facilities that handle 1,000 litres. This process leverages existing systems while evaluating new approaches.

Several experts also focused on the **factors influencing scalability**. As mentioned above, many experts emphasised **economies of scale**, noting that costs per unit decrease as production increases. Another added that scalability depends largely on **price**, noting that MP will not charge higher prices than others. Another expert stressed the importance of **convincing investors**, especially venture capitalists. However, investors often perceive the market as saturated. Despite past investments in promising proteins that failed to deliver, the focus remains on maintaining key performance indicators (KPIs) across different reactor sizes. In addition, a fourth voice emphasised that the initial objective is to utilise a consistent production cycle and that the viability of by-products depends on sufficient market demand to justify the establishment of separate production lines. It was also noted that many plants run several products in sequence using shared resources, but this approach can be costly if it requires separate machinery and space. Overall, the expert emphasised that **integration of processes** is essential for efficiency and cost-effectiveness. Finally, and despite the challenges that exist, a fifth expert noted that funding is available if a solid business case can be presented, suggesting that securing investment has never been easier.

Intermediate resume

Experts identified scalability as a significant barrier in the bioprocessing industry, particularly for MP, but were optimistic about potential solutions. They highlighted the complexity of moving from small reactors to larger pilot-scale facilities, noting that most bioprocessors operate below 30,000 litres. While fermentation processes can be highly scalable with decreasing unit costs, the high initial investment may deter potential investors, especially in a market perceived as saturated. Experts emphasised the importance of creating sufficient demand and supply and noted that successful small-scale trials could pave the way for larger-scale operations. They also pointed to economies of scale, price competitiveness and investor confidence as key to overcoming scalability challenges. Despite the barriers, experts believe that funding opportunities exist for well-structured business cases, and that process integration is essential to achieve efficiency and cost-effectiveness in production.

Consumer acceptance

In addition to the previous findings, the experts identified other factors influencing consumer acceptance. In line with the challenges identified by the experts in the previous round, several experts emphasised that consumer perceptions have a significant impact on the uptake of alternative proteins such as MP, especially those derived from waste. Many people are reluctant to consume products derived from waste, which complicates efforts to achieve wider acceptance. Another voice noted that consumer acceptance varies widely from country to country. In France, Norway and Sweden, there is a notable reluctance to accept meat-and-bone meal products due to concerns about zoonotic diseases such as mad cow disease. In contrast, consumers in Italy and Spain show a greater willingness to accept these products, reflecting a regional difference in attitudes. In contrast, one expert argued that consumer acceptance should not be seen as a major barrier, suggesting that with effective communication and education, acceptance can be relatively easy.

Moreover, another expert emphasised that consumers often prioritise taste over nutritional value when choosing foods, which is exacerbated by a lack of regulatory support to encourage healthier eating habits. While the importance of whole proteins is recognised, particularly in light of increasing lifestyle-related health problems in younger populations, there is a notable lack of awareness of the long-term effects of dietary choices. The expert calls for improved use of amino acids and dietary fibre as a potential solution to this challenge. In addition, experts highlighted the importance of the sensory aspects of MP to achieve better consumer acceptance. Some experts highlighted the challenges of replicating the mouthfeel and texture of traditional meat products, particularly when using fibres. While it is possible to achieve a light texture in meat alternatives, the complexity increases when trying to replicate the structures of steak or chicken breast. He also pointed out that most consumers are used to minced meat products, making it easier to recreate the desired sensory experience in these options.

Intermediate resume

Experts highlighted several factors influencing consumer acceptance of alternative proteins, particularly those derived from waste. They noted that consumer perceptions have a significant impact on uptake, with countries such as France, Norway and Sweden particularly reluctant to consume waste-derived products due to health concerns, while countries such as Italy and Spain are more open. Although some experts argued that acceptance can be improved through effective communication and education, taste often takes precedence over nutritional value, exacerbated by inadequate regulatory support for healthier eating. Experts also emphasised the importance of sensory qualities, noting the challenges of replicating the mouthfeel and texture of traditional meat products, which makes acceptance difficult. Overall, there is a consensus on the need to improve awareness of dietary choices and the potential of alternative proteins, particularly through enhanced sensory experiences.

5 Exploration of the market potential

In the following paragraph, we will give an assessment of the market potential for agricultural residue based products on the information from the expert interviews. The market potential will be evaluated and we will give an overview about the general market potential, determining factors for a high market potential and the best fitting applications.

5.1 Estimates of market potential of PHA based on Delphi I

The market potential of PHA or PHA end-products is mapped based on the assessments of experts from the traders, processors, converters of the end-product PHA. Further, the market potential of the end-products, factors influencing the market potential and possible applications are discussed in more detail.

5.1.1 Market potential of PHA-end products (mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags)

Regarding the market potential for PHA end-products, all experts agreed that the potential was very high. One expert described the global starting point for PHA in more detail. It was described that global production of bioplastics will increase from 2.2 million tons in 2022 to 6.3 million tons in 2027, with biodegradable plastics accounting for over 51 % of production capacity. In addition, packaging is expected to remain the largest market segment for bioplastics, but other segments such as automotive and construction are expected to grow. Finally, the potential for PHA production in Europe is described as huge, as there are no major local producers. Several experts identified agriculture as the leading sector for the use of bioplastics. One reason for the high agricultural potential is that there is a real interest in having solutions for agriculture that are ideally biodegradable in the soil, at least compostable at home or industrially. The potential was also underlined by the fact that the number of clips for one hectare of crops is estimated to be between 800,000 and 1 million. Some voices highlighted the importance of PHA as most agricultural materials are made from fossil fuels or contain some PLA. Therefore, these materials will not be certified as biodegradable in soil but may still be compostable at home or in industry. Finally, Asia is described as the current major production centre for bioplastics, with PHA mulch film already being used in China. However, Europe's share is predicted to decline.

The experts also identified several potential markets for PHA end-products. Firstly, bioplastics are used in various markets such as packaging, catering, electronics, automotive, agriculture, toys, textiles and more. Agriculture is expected to be the leading sector for bioplastics. Asia is currently the main production centre for bioplastics, accounting for over 41 % of production, and is expected to increase to almost 63 % by 2027. The agricultural and horticultural markets are considered suitable for the use of biodegradable materials.

<u>Intermediate resume</u>

Experts unanimously assessed that there is significant market potential for PHA end-products, particularly in the global bioplastics industry. Forecasts indicate a significant increase in bioplastics production, with biodegradable plastics taking a dominant share. The agricultural sector will be a primary area for bioplastics, given the desire for biodegradable or compostable solutions. Agricultural and horticultural markets are recognised as promising segments for biodegradable materials.

5.1.2 Determining factors for market potential

In the following, the determining factors for the market potential of PHA and PHA end products are elaborated. The factors biodegradability, logistics, price and legislation are discussed in detail.

Biodegradability

Experts were united in their opinion that the market potential is determined by the biodegradability potential. Ideally, agricultural materials should be non-fossil but soil biodegradable, at least home compostable or industrially compostable. The main advantage over PLA is that even 100 % bio-based PLA is slowly biodegradable. Therefore, PHA-based components must be 100 % biodegradable and free of persistent micro- and macro-plastics to maintain market acceptance. In addition, it was described that large pieces of PLA left in the soil could damage agricultural machinery. Finally, some voices mentioned that PHA and PHB have been observed to degrade faster than expected and therefore the right conditions need to be researched. This voice also mentioned climate change as the main challenge for degradation, as climatic conditions vary greatly across Europe and even more so globally.

Intermediate resume

Ideally, agricultural materials should be soil biodegradable, at least home compostable or industrially compostable. In addition, materials should be 100 % biodegradable and free of persistent micro- and macro-plastics. Finally, climatic conditions should be considered in relation to degradation.

Price

Market opportunities also depend on price. The agricultural industry is price-driven and is only willing to accept a small additional cost for biodegradable PHA-based products. One expert estimated that an increase of 0.1 to 0.2 €/kg would be accepted. However, a significant price difference will not be accepted unless there is a significant time saving, for example by not having to handle the waste material. The current price of PHA is around 2.5 € /kg, which is twice the price of PE, PP and PLA and makes it too expensive for the agricultural industry, despite high consumer interest in environmentally friendly products.

However, several experts considered PHA to have "great" pricing potential. It was stated that there is a great opportunity because the price of fossil-based plastics (PE, PET, PP) is quite volatile due to oil prices. Therefore, the price of recycled plastics and ultimately bioplastics could become more attractive. Furthermore, the potential is even greater if all costs are included in the total price. If the cost of production is added to the cost of collection, disposal, recycling and logistics, the 100 % biodegradable product is more attractive because it costs the same or less overall. Finally, some experts questioned whether the price advantage of converting in China might be negative for converters in other parts of the world.

Intermediate resume

The agricultural industry is only willing to accept a small additional cost for biodegradable PHA-based products. Currently the price of PHA is twice that of PE, PP and PLA. An increase of 0.1 €/kg to 0.2 €/kg could be accepted. However, due to the volatile price of fossil-based plastics and the total cost of conventional products, there are large price opportunities.

Logistics and Legislation

Regarding logistics, some experts noted that transporting highly concentrated waste streams is more efficient and cost-effective than transporting by-products with a high water content. Furthermore, processing by-products at source can also reduce transport problems. The use of by-products from apple processing, tomato pulp, orange peel and BSG is considered common.

Legislation and policy were also identified as key to market potential. One expert estimated that there could be a large market for PHA and PHB if the use of petrochemical products was no longer allowed. Another voice noted the need for subsidies, financial incentives or stricter legislation, e.g. obligation to declare the amount of PP per hectare.

Intermediate resume

In terms of logistics, the transport of highly concentrated by-products streams or the processing of by-products at source were recommended. Favourable legislation with subsidies or financial incentives was also considered important.

5.1.3 Applications

Most promising applications

The experts were divided on the most appropriate applications. In general, all experts agreed that the best applications for PHA are for products that need to be biodegradable in soil. It was also noted that there are three bottlenecks when considering the most suitable applications: material properties, availability and price. It was also judged that in agricultural and horticultural applications, functionality and price are more important than aesthetics.

When looking at specific applications, the experts' opinions differed. The applications mentioned by the experts were agricultural mulching films, vine clips, grow bags, blends and twines. Some experts recommended the production of PHA **clips** that are biodegradable in soil, as they would be superior to those made from PLA due to their biodegradability. It was also mentioned that PHA products are well established in the extrusion industry, but not in the injection industry for products such as clips. It is not currently possible to produce a clip that is strong, flexible and durable enough for cultivation. Another expert suggested that there could be market potential in special applications for **blends**. The expert went on to say that there could be an application in cold regions where biopolymers do not degrade quickly enough. In this case, PHA could be added to a blend to speed up degradation. Several experts identified the use of PHA for **grow bags or seedling bags** as a potential application. However, PHA degrades rapidly in soil. This is not necessarily a limitation, but can add value to the application. Another voice suggested the use of twines that retain their properties for a year. Furthermore, **twines** would be beneficial in greenhouse horticulture, as most of these elements are currently made of polypropylene, which leads to problems with plastic particles in the compost. On the other hand, one critic questioned the suitability of PHA for flexible applications due to its lack of flexibility, high crystallinity and brittleness.

Finally, three experts assessed **mulch film** as a suitable application. One stated that PE mulch film is contaminated by up to 80 % (humus, organic matter, water, sand, etc.) when removed from the field. This means that soil fertility is exported with the film waste. Therefore, biodegradable film solutions are described as very interesting because they leave the organic matter in the soil. One expert considered that biopolymers mulch films would be purchased despite their higher price compared to conventional films if they had advantages such as biodegradability. Another expert suggested that mulch film might be more suitable for large-scale agriculture, where handling large quantities of mulch film becomes a logistical challenge. Here it might be much easier to simply mulch and plough the film into the soil at the end of the season. One critical voice questioned the suitability of PHA mulch film as it may be limited by farmers' cost sensitivity and the fact that it is often reused for several years, making it less suitable for crops such as asparagus, potatoes and strawberries. Another critic went further, stating that PHAs are not suitable for outdoor or agricultural applications because they degrade too quickly.

Other possible target applications mentioned by experts were all kinds of different blends, e.g. coffee capsules, which are a typical application well suited for biopolymers. In addition, one expert identified tree protection products such as tree guards, shelters and tubes as suitable for PHA. Finally, one expert considered that traditional party cups, fishing nets and plastic bags could be replaced by PHA products. Regarding PHB, it could be used to replace plastics on harvesting machines that can break and get lost. PHB would be able to replace these parts and, if broken, would not be harmful.

Intermediate resume

The experts had different views on the most suitable applications for PHA, with the emphasis on the need for soil biodegradability. Agricultural mulch film, clips, grow bags, blends, twine and tree protection products were the most commonly cited applications. The use of PHA in mulch films was considered interesting due to its potential to leave organic matter in the soil and reduce the export of soil fertility. Despite its higher cost, it could be preferred by large-scale agriculture. However, critics were concerned about the rapid degradation of PHA mulch films, particularly for multi-year crops. While one expert recommended PHA clips for their superiority over PLA, others pointed out the limitations in achieving flexibility and durability in products such as clips. Other potential applications included coffee capsules, tree protection products, traditional party cups, fishing nets and plastic bags, with PHB as a replacement for fragile parts in harvesting machinery.

Not suitable applications

The experts also identified several applications that are not suitable for PHA. In contrast to the previous mentioned opinions, one expert stated that PHA material lacks flexibility and is characterised by high crystallinity and brittleness, making it unsuitable for **flexible applications** such as twines. She added that although copolymers can improve flexibility, no products have yet been made with this material property. It was also explained that the **injection** process for PHA is already known, but the injection process has yet to be found. Another voice suggested that PHA is not viable for **plant pots** because the raw material cost is too high and the price is not competitive with fossil-based materials. Therefore, PHA is not recommended for horticultural pots. In addition, one expert mentioned that PHAs have significant disadvantages compared to fossil-based plastics. Processing in conventional extruders is not a problem for biopolymers. However, PHAs degrade at 140°C and degradation accelerates as the temperature rises. In the case of PHB, two experts considered that PHB is not suitable for all applications due to its brittleness. Specifically, mulch films are not possible with PHB.

Intermediate resume

The experts highlighted several applications that were considered unsuitable for PHA. Flexible applications such as twine were seen as problematic, even with the potential improvement of copolymers. PHA was considered unfavourable for plant pots due to high raw material costs and price competitiveness issues. PHB was considered unsuitable for certain applications due to its brittleness, with mulch films mentioned as a non-viable option. In addition, some experts pointed out the disadvantages of processing PHAs at higher temperatures, resulting in degradation.

5.2 Estimates of market potential of PHA based on Delphi II

5.2.1 Market potential of PHA-end products

In the second round of expert interviews, this was compared with the previous experts' assessments of the market potential for PHA.

With one exception, the experts agreed with the assessments of their predecessors and agreed that there is a significant market potential for PHA end-products such as mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags.

The experts explained the background to their positive assessment. some experts noted that despite the involvement of major players, there is a spirit of cooperation between companies, recognising that even with increased production, meeting the high demand remains a challenge. This cooperation reflects optimism about the significant opportunities in the PHA market. Another expert focused on the wisdom of bioplastics. He explained that there are many cases where it makes sense to use bioplastics. For example, applications where the plastic material ends up in the soil and can add value to the soil. The expert argues that bio-based plastics will dominate in the long term, as the aim is to reduce dependence on fossil fuels to produce plastics. Another voice added that the plastics market is large, but the introduction of a new polymer requires careful selection of niche markets due to the high initial costs associated with small-scale production. The focus is on applications where biodegradation is beneficial. She also noted that the Nova Institute has produced a report outlining promising applications for PHA production, particularly in agriculture, horticulture, fisheries and forestry, which are key areas of focus. Overall, while there are a variety of applications being considered, there is a strong focus on agricultural and horticultural uses for PHA. A fourth voice added that while there are some smaller applications, the greatest potential lies in specific high-volume applications that don't fit in with other applications. Finally, one expert added that less than 1 % of the world's land is used for bioplastics. There is enough land in Europe to produce bioplastics, one voice highlighted

Some more critical voices agreed with the concept but pointed out that in practice PHA poses technical challenges in creating a flexible plastic. To achieve flexibility, the processing temperature has to be lowered, but this causes PHA to bleed and become sticky. As a result, he stressed that PHA is better suited to rigid products. Another voice added that agricultural applications were more of a niche market.

<u>Intermediate resume</u>

In the second round of expert interviews on the market potential for PHA, experts generally agreed with previous assessments and identified significant opportunities for PHA end-products such as mulch film. They noted a cooperative spirit among companies despite the challenges of meeting high demand, reflecting optimism about the PHA market. Experts highlighted that bioplastics offer valuable benefits, particularly in applications that improve soil health, and predicted a long-term shift towards bio-based plastics to reduce dependence on fossil fuels. However, they acknowledged that the introduction of new polymers requires careful targeting of niche markets due to high initial production costs and technical challenges, particularly in achieving flexibility for certain applications. While agricultural applications represent a niche, experts emphasised that there is sufficient land in Europe to support bioplastics production.

Overall, the consensus underlines a strong focus on agricultural and horticultural applications, with the potential for high volume applications that stand out from traditional products.

5.2.2 Determining factors

The experts agreed with the determinants of PHA's market potential identified in the previous round of stakeholder interviews. These factors are closely related to the most essential challenges described within chapter 4.2.2.2. The most determining factors are illustrated in figure 11 and will be addressed in the following.

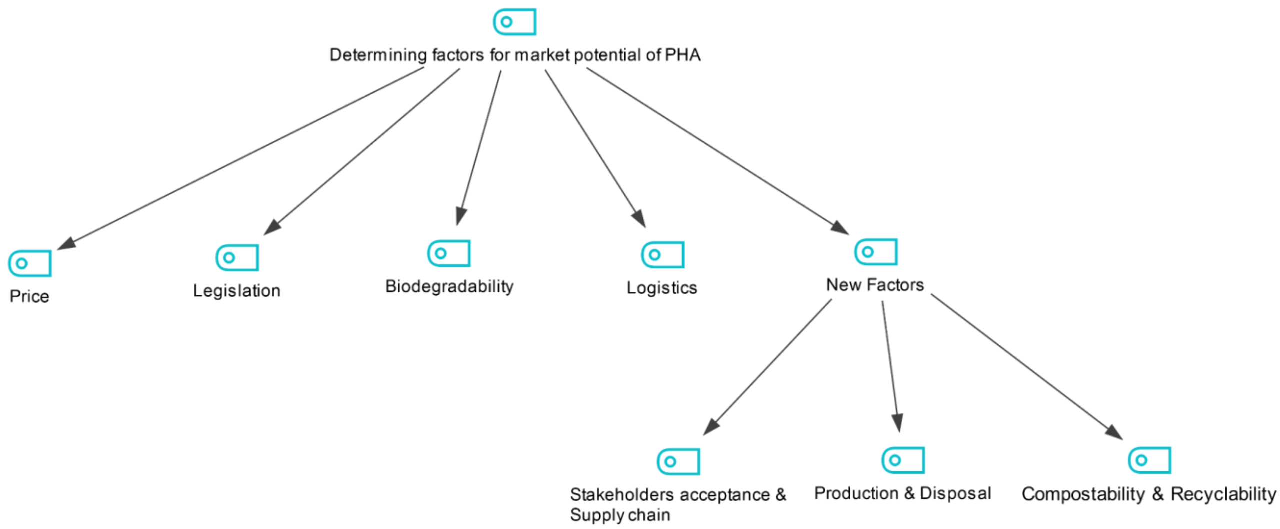

Figure 11: Overview of most frequently cited determining factors for the market potential of PHA assessed by experts (own compilation of Ecozept).

Several experts emphasised that **price** remains one of the most important factors for the widespread adoption of PHA. According to the experts, price is directly related to the scalability of PHA and legislation. Currently, PHA products are significantly more expensive than conventional options such as polyethylene and polypropylene, making them less competitive in the market. In addition, some voices highlighted that price is the most important consideration for manufacturers and significantly influences their willingness to invest in PHA and other bio-based alternatives. However, there needs to be a clear demand to justify the investment. In line with this, another voice noted that price is essentially dependent on economies of scale. He stressed that larger production volumes are needed to achieve lower prices. Another expert emphasised that one factor influencing the price is disposal, in particular the removal of agricultural residues such as plastic film or twine. She went on to explain that clear regulations for disposal are needed, as many waste management companies currently refuse to accept plastics, including bioplastics, in green waste. While TÜV Austria certifies some bioplastics as compostable within six months, most composting facilities only have an operating cycle of 6-8 weeks, making it difficult to integrate these materials into the waste stream.

<u>Intermediate resume</u>

Experts in the second round of stakeholder interviews reiterated the previously identified determinants of PHA's market potential, highlighting price as a critical factor for its uptake. They noted that PHA products are currently significantly more expensive than conventional plastics such as polyethylene and polypropylene, which affects the willingness of manufacturers to invest. The experts emphasised that achieving economies of scale is essential to reduce prices, as larger production volumes can lead to cost savings. They also pointed to the need for clear regulations on the disposal of agricultural residues, as many waste management companies refuse to accept bioplastics in green waste. The certification process for compostability is also a challenge, as most facilities operate on shorter cycles than the composting time required for certain bioplastics.

As mentioned above, price is directly related to **legislation**. One voice highlighted "Price will always be the key factor in decision-making, but it can be heavily influenced by legislation. If regulations mandate the use of biobased products, the sector will grow, and prices will eventually decrease". In accordance with that, another voice stated that PHAs are currently mainly used in cosmetics due to their cost. While price remains the key driver, it can be significantly influenced by legislation, which could drive wider adoption of these materials. In addition, another expert added that in sectors such as agriculture, if legislation mandates a switch to bioplastics, the final product must be able to absorb the increased cost.
Looking at legislation in isolation, several experts identified it as a key driver of market potential for the bioplastics industry. Experts unanimously agree that the development of specific regulatory frameworks for bioplastics is a significant factor influencing the market potential of PHA.

The **absence of a specific regulatory framework** for bioplastics is seen as a significant **hurdle**. Several experts pointed out the negative effects of a framework that is not adapted to practical conditions. Some experts pointed out that legislation tends to be more progressive than the industry's ability to adapt, suggesting that without established legislation, companies are often reluctant to use PHA and PHB products. Looking at current legislation, another voice noted that under current regulation, PHA applications for food grade are considered plastics and are subject to restrictions. With legislation strongly supporting the use of secondary raw materials, the market has become increasingly competitive, with added pressure from the regulatory framework. Whether in the recyclate market or the bioplastics market, it is clear that legislative requirements and pressure from legislators are necessary to encourage customers to use these materials, as they are often more expensive. Secondary raw materials, which are now being promoted by the PPWR and the EU Commission, have significant potential as a result of this legislative push. In addition, another expert highlighted that there is currently a significant gap in legislation regarding PHA and PHB, noting that there are currently no specific laws governing these materials. In line with this, a third voice noted that in the packaging industry, the AGEC law outlines requirements for bio-plastics, but they are not very strict and there are no penalties for non-compliance. Finally, a fourth expert noted that legislation has not supported the development of a large-scale bioplastics sector in Europe, which is why no major companies have emerged.

In contrast, a **well-developed regulatory framework** for bioplastics can be a key opportunity for a **market push**. Several experts mentioned that the proposed European regulation aims at an adapted framework, such as the PPWR (Proposal on Packaging and Packaging Waste), which aims at harmonising packaging management across EU Member States and improving the treatment of packaging waste. A critical voice stated that the PPWR will effectively hinder the introduction of biodegradable plastics. An optimistic expert noted that such a legislative adjustment has already taken place in the construction sector, where thermal regulations require a certain percentage of bio-based materials, leading to their widespread adoption. However, to be effective, such regulations need to be enforced, with penalties for non-compliance. In line with this, another voice stressed that legislation is adaptable and takes into account the practical needs of industry, noting that China is leading the way.

Finally, some experts commented on legislation in agricultural applications. He stressed that legislation plays a crucial role in shaping the market for biodegradable alternatives in agriculture. They further described that only legislation can drive the adoption of biodegradable plastics by imposing requirements that force the agricultural sector to move away from conventional plastics. This regulatory pressure creates unique niches where traditional polymers can no longer compete, allowing biodegradable products to thrive. While biodegradability is essential, it serves as a fundamental aspect of biodegradable polymer development, with legislation acting as a catalyst for market change.

<u>Intermediate resume</u>

Experts agreed that price remains a critical factor in the uptake of PHA and bioplastics, emphasising that this aspect is heavily influenced by legislation. They claim that if legislation mandates the use of biobased products, this could stimulate market growth and eventually lead to lower prices. However, the lack of a specific regulatory framework for bioplastics is seen as a significant barrier, as it discourages companies from using PHA and PHB products. At present, existing legislation often classifies PHA applications as conventional plastics and imposes restrictions that hamper their market potential.

The experts argued that a well-developed regulatory framework could create significant opportunities for market expansion, particularly in the agricultural sector where legislation can drive a shift away from traditional plastics. They note that regulatory pressure has the potential to create unique niches for biodegradable products, allowing them to thrive where conventional materials cannot compete. Finally, experts also emphasised the need for robust enforcement of legislation to ensure compliance and promote the uptake of biodegradable materials. Overall, the experts suggested that while regulatory challenges remain, adaptable and well-enforced regulations could act as a catalyst for significant change in the bioplastics market.

In line with the previous findings, the various experts agreed that the **biodegradability** of PHA and PHB is a key selling point for customers, particularly in sectors where these materials can be effectively utilised for their compostable properties. According to three experts, this characteristic is a key driver of market potential as it significantly influences purchasing decisions as many customers seek environmentally friendly alternatives to conventional plastics.

While biodegradability is recognised as a key factor, two experts noted that its effectiveness can vary significantly depending on climatic conditions. The degradation rates of bioplastics vary depending on environmental factors, highlighting the need for tailored solutions that take into account regional weather patterns. This variability underlines the complexity of implementing bioplastics in agricultural supplies, where environmental conditions play a critical role in determining the performance and sustainability of these materials.

Amid increasing EU regulations aimed at reducing single-use plastics, two experts observed a shift in focus from biodegradability alone to recyclability. While biodegradability remains crucial - as these products ultimately end up in the environment - the new legislative landscape emphasises the importance of developing recyclable products. This shift is in line with broader sustainability goals and the desire to create a circular carbon economy. Thus, while biodegradability is still valued, there is a growing recognition that recycling may be a more effective long-term solution to plastic waste management. In contrast, another expert emphasised that PHA is mainly preferred for compostability rather than recycling. The reason for this preference lies in the inherent challenges of recycling mixed materials. For effective recycling, the materials must be mono-material and free of contamination, making it difficult to achieve high quality recycled products when multiple materials are combined. This limitation positions PHA as a more suitable option for composting, where end-of-life processes can effectively break down organic materials.

Intermediate resume

Experts recognised the biodegradability of PHA and PHB as a key selling point, particularly in markets seeking environmentally friendly alternatives to conventional plastics. This characteristic drives the market potential, although its effectiveness can vary with climatic conditions, highlighting the need for tailored solutions, particularly in the agricultural sector. With increasing EU regulations to reduce single-use plastics, there is a shift towards prioritising recyclability alongside biodegradability, reflecting broader sustainability goals. While biodegradability remains important, the challenges of recycling mixed materials make PHA more suitable for composting, where its organic components can be effectively broken down.

As in the previous round, the experts identified **logistics** and the **value chain** as a key driver of market potential. However, two experts were confident about the logistics involved in the production of new ingredients. Some experts believed that as demand for PHA increases, the whole value chain will adapt accordingly. Another voice added that production levels are currently limited due to the nascent stage of the industry, but strongly believes that as companies mature and expand, logistical operations will evolve to effectively meet market demands. This optimism suggests that the industry is poised for growth, with logistical challenges expected to be addressed as the market develops. Despite this optimism, significant challenges remain within the value chain. Other experts highlighted the complexity of determining supply and disposal logistics, which complicates efforts to establish a circular business model. The lack of necessary infrastructure and expertise exacerbates these challenges, making it difficult for stakeholders to effectively manage the logistics of PHA production and distribution. Another layer of complexity is the acceptance of PHA-based applications within the circular supply chain. Even if pricing issues could be resolved, one expert acknowledged that achieving widespread acceptance remains a challenge. While the benefits of PHAs in applications such as agriculture are clear, the uptake of these materials is still in its early stages. This suggests that, in addition to logistical and infrastructural hurdles, building trust and acceptance among stakeholders and consumers is crucial for the successful integration of PHA into the market.

Intermediate resume

Experts see logistics and the value chain as key drivers of PHA's market potential, and were optimistic about the industry's ability to adapt as demand grows. While current production volumes are limited, there is confidence that logistics operations will evolve to meet market demands as companies mature. However, significant challenges remain, particularly in establishing a circular business model due to complex supply and disposal logistics, lack of infrastructure and the need for expertise. In addition, achieving widespread acceptance of PHA applications, particularly in agriculture, is hampered by current market conditions and the need to build trust among stakeholders and consumers.

In addition to the factors identified in the previous round, the experts highlighted **processability** as a critical factor for market opportunity. Some experts highlighted the complexity of producing PHA compared to other bioplastics such as polylactic acid (PLA) and traditional petrochemical materials. They explained that the industrial processes required to produce PHA are particularly challenging, leading to difficulties in producing 100 % PHA films. The experts went on to explain that it is difficult to produce bioplastics using traditional machinery. According to the expert, traditional plastics processing tools are not suitable for the production of bioplastics. Another voice added that there are currently no large-scale PHA producers in Europe due to the processing challenges, with production mainly taking place in China, Korea and the US. Finally, a third expert added that the fermentation process, together with the extraction and purification of PHA, is the main bottleneck for achieving market competitiveness. Although advances in technology are expected to improve production efficiency over the next decade, the current economic viability of producing PHA from waste materials - such as BSG - remains a challenge.

Moreover, another expert identified the fermentation process as another factor influencing the production of PHA. The expert stated that the current fermentation process is inefficient and both costly and dependent on high quality raw materials such as sugar and vegetable oils. According to the expert, this dependence raises ethical questions about resource allocation, especially as these materials could otherwise be used in the food industry. However, the experts noted that there are solutions to the current challenges. One way would be to use alternative raw materials. Another expert shared an example noting that the production process for PHA can also leverage wastewater, such as that from potato washing, which contains valuable starch. This approach not only adds value to the PHA production process but also aligns with sustainability efforts. In addition, the expert noted that some companies are exploring synthetic methods for PHA production, using waste materials such as fatty acids from the food and agricultural sectors. He mentioned a Dutch company that converts waste into fatty acids that can be used as a feedstock for PHA. However, this approach is still in the pilot phase and not yet cost effective.

<u>Intermediate resume</u>

Processability is a key factor in the market potential of PHA. Experts noted that PHA production is more complex than that of other bioplastics such as PLA or traditional petrochemical materials. The challenges associated with traditional plastics processing machinery and the lack of large-scale PHA producers in Europe, where production is mainly concentrated in China, Korea and the US, hinder scalability. The fermentation, extraction and purification processes are identified as significant bottlenecks, compounded by the high cost and reliance on high-value raw materials, which raises ethical concerns about resource allocation. However, solutions such as the use of alternative raw materials, the use of wastewater for production, and the exploration of synthetic methods using waste materials show promise, although they are still at the pilot stage and not yet cost effective.

Finally, experts identified **stakeholder** acceptance as a crucial factor in the adoption of biodegradable bioplastics, particularly in applications such as mulch films. Some experts noted that, despite the technological advantages these products offer, public scepticism remains significant. Many customers tend to perceive mulch films simply as conventional plastic, failing to recognize that they may be made from bioplastics designed to integrate into a circular economy. This lack of awareness poses a barrier to acceptance, although experts are optimistic that as awareness of bioplastic solutions increases, perceptions will gradually improve.

Furthermore, another voice added that the willingness to adopt compostable materials is currently limited in the agricultural sector. He further noted that this hesitance is largely attributed to the not fully developed supply chain, which complicates the widespread implementation of these materials, despite the technical feasibility and clear added value of products. The expert summarised that even with potentially favourable pricing, the barriers to acceptance within this circular system persist.

Intermediate resume

Experts highlighted user acceptance as a critical factor in the adoption of biodegradable bioplastics, particularly in applications such as mulch films. Despite their technological advantages such as biodegradability, there remains significant public scepticism, with many consumers viewing these products as conventional plastics and lacking awareness of their benefits to a circular economy. This scepticism is a barrier to adoption, although experts are hopeful that increased awareness will improve perceptions over time. In addition, the limited uptake of compostable materials in the agricultural sector is attributed to an underdeveloped supply chain, making widespread adoption difficult despite the technical feasibility and clear benefits of these products. Ultimately, even with potentially favourable pricing, the barriers to adoption within the circular economy remain significant.

5.2.3 Suitable applications

The experts in the second round also gave their assessment of suitable applications for PHA.

The discussion of suitable applications for PHAs reveals a range of perspectives among experts, particularly regarding their use in agricultural contexts. There is a consensus on the potential of PHA in agricultural and horticultural applications, with experts highlighting the suitability of the material for mulch films. Some experts strongly supported this application, highlighting that the current mechanical properties of PHA are well suited to the requirements of **mulch films**. Whilst seeing mulch films as a viable option, one expert was uncertain about the standards they should meet, especially given the differences in soil types and degradation rates in different regions such as Spain, Austria and Poland. He added that the lack of a universal standard could pose challenges in ensuring consistent performance across different agricultural environments. Finally, another expert pointed out that economically successful mulch production depends on either collecting the mulch after use or meeting specific degradation standards in the field. If these conditions are met, production can be increased, potentially improving profitability.

However, there are conflicting views on the effectiveness of PHA in flexible applications. Two experts were sceptical, pointing out that while mulch films are promising, the film blowing process poses significant challenges due to the relatively slow crystallisation rate of PHA. This slow rate makes it difficult to produce flexible films, leading the experts to suggest exploring blends with other materials to improve performance. In line with this, another voice also highlighted the significant technical challenges of producing flexible materials from PHA. He noted that adjusting operating parameters, such as lowering temperatures to match the properties of PHA, can result in reduced flow rates and lower production efficiency. In addition, issues such as bleeding at certain temperatures require adjustments to the mechanical aspects of the production process. Finally, one voice argued that PHA is better suited to rigid products, as the challenges associated with creating flexible materials may hinder its practical application in this area.

Looking at other suitable applications, some experts noted that there is significant potential for **agricultural clips** in both conventional agriculture and viticulture. Another key application highlighted by several experts is **coated fertilisers**, in particular slow-release fertilisers, which traditionally use non-degradable polymers. While these fertilisers provide a gradual release of nutrients, they contribute to microplastic pollution in the environment. Other experts noted that while PHA can also form microplastics, these versions are biocompatible and degrade quickly, alleviating long-term pollution concerns. In line with this, another voice noted that with European regulations set to ban conventional plastic coatings in fertilisers by 2025/26 due to the microplastic issue, there is an emerging market opportunity for PHA-coated fertilisers. The expert emphasised that this shift is being driven by regulation rather than farmer demand, highlighting the potential for developing sustainable alternatives to conventional coatings.

In addition to coated fertilisers, two experts identified several other promising applications for PHA. These include bio-based materials for products such as tea bags, green waste collection bags and fishing nets. One expert was particularly enthusiastic about **biodegradable bags** for organic waste, noting that these bags, if made visibly biodegradable, could increase consumer acceptance and facilitate efficient industrial composting.

Intermediate resume

Experts highlighted the significant potential of PHA, particularly in agricultural and horticultural applications such as mulch films. They highlighted that while the mechanical properties of PHA are suitable for these films, the lack of universal degradation standards for different soil types is a challenge. Scepticism remains about the effectiveness of PHA in flexible applications due to its slow crystallisation rate, which complicates the film blowing process.

In addition, experts highlighted the emerging market opportunity for PHA-coated fertilisers as European regulations prepare to ban conventional plastic coatings due to concerns about microplastic pollution. They also identified other promising applications for PHA, including biodegradable materials for tea bags, green waste collection bags and fishing nets. In particular, biodegradable bags for organic waste were highlighted as having the potential to improve consumer acceptance and facilitate industrial composting. Overall, while there is optimism about PHA applications, experts recognised the need to address technical challenges and regulatory issues to improve its market integration as a sustainable alternative.

5.2.4 Non-suitable applications

Several experts emphasised the versatility of PHAs, noting that they encompass a wide range of materials, with hundreds of variations available. According to some voices, this diversity enables the potential use of specific PHAs in different sectors.

However, despite this adaptability, some experts highlighted significant challenges that limit the practicality of PHAs in certain contexts. Some experts noted that a major concern is the tendency of PHA to crystallise and become more brittle over time as it biodegrades. This characteristic raises doubts about the suitability of the material for permanent structures, as brittleness can undermine the integrity of long-term applications. Another voice added that while the use of additives can improve flexibility, it can also complicate the formulation and reduce the overall attractiveness of PHAs for such applications. In addition, one expert pointed out that PHAs are not particularly resistant to thermal wear and there is a lack of information on their impact resistance when used in agricultural products. This limitation further restricts the range of applications where PHAs can be effectively used, particularly in environments where durability and robustness are required.

Intermediate resume

Experts noted that while PHAs are versatile and can be used in different sectors, there are significant limitations to their effectiveness in certain applications. A key issue is their tendency to crystallise and become brittle over time, undermining their suitability for durable structures. Although additives can improve flexibility, they complicate formulations and can reduce the attractiveness of PHAs. In addition, PHAs lack resistance to thermal wear and there is insufficient data on their impact resistance, particularly in agricultural environments, which limits their practicality in contexts where durability is required.

5.2.5 Competitiveness of PHA from agricultural residues

The Experts of the second round also gave their assessment on the **competitiveness of PHA** from agricultural residues compared to conventional plastics. Several experts agreed that PHAs are particularly valuable in efforts to combat microplastic pollution. They emphasised that although cheaper alternatives such as PBS and PBAT are emerging from countries such as China, PHAs are preferred because of their bio-based and biodegradable properties. The main attraction is their improved end-of-life management, which is seen as a significant advantage over conventional plastics.

Another voice added that with the right incentives and supportive legislation, PHAs could become highly competitive. She further argued that while they may not replicate all the properties of petrochemical materials, the full cost of use - including recycling and disposal - is likely to favour PHAs due to the lower additional costs compared to traditional materials.

Some experts highlighted the range of potential applications for PHAs. They explained that as a polyester, PHA offers the potential to develop a wide range of building blocks, giving it similar properties to conventional plastics. Progress is still at an early stage - there are currently 4 building blocks, but theoretically 1 million are possible. The experts believe that full technical feasibility could be achieved within the next 5 to 10 years. Some experts also gave examples, including coated fertilisers, biodegradable tree protectors and even decorative urns, where PHAs can be highly competitive. Finally, one voice highlighted the possibility of blending PHAs with other materials to achieve desired properties and improve performance, which could increase their market appeal.

In addition, some experts identified applications where **PHA is superior to existing applications**. Here, two experts highlighted the superior biodegradability of PHAs, positioning them as a favourable alternative in applications such as coated fertilisers and tree guards. This biodegradability is becoming increasingly important as regulations evolve to limit the use of conventional plastics. In addition, the expert highlights that products such as mulch films offer significant added value over conventional plastics due to their biodegradability. One voice added that PHAs have the potential to increase biodegradability when blended with other materials, saying that they can be used as biodegradability enhancers. In addition, another expert mentioned that PHA can be superior wherever legislation is in favour of biodegradable plastics. He explained that a forest industry standard in Europe prohibits the use of standard plastics such as PE or PP and requires biodegradable materials instead. Similarly, in Germany there is legislation for forest cemeteries that requires decorative urns to be certified as biodegradable.

Finally, the experts also identified areas where PHA applications **cannot compete with conventional applications**. The consensus of the experts is that PHAs are generally not cost competitive, especially when derived from agricultural by-products. Some voices mentioned that while biodegradable mulch films are functionally effective, they are three times more expensive than conventional plastic alternatives. This high cost limits their market appeal, particularly in price-sensitive sectors such as agriculture. In addition, the expert noted that the presence of cheaper alternatives such as PBS (polybutylene succinate) and PBAT (polybutylene adipate-co-terephthalate) from countries such as China poses a significant challenge to the market for PHAs. As these materials become more accessible and affordable, they threaten to take market share that could otherwise go to PHAs, making competitiveness a key concern for industry stakeholders.

Another voice added that bioplastics are currently not ideal for farmers due to their poor barrier properties and ease of processing. He went on to highlight that these shortcomings are hindering their adoption, particularly by farmers and other end-users who require high performance materials.

Finally, and as mentioned in the previous paragraph, some experts highlighted the complexity and inefficiency of the fermentation process used to produce PHAs. The experts identified the inefficiency of the fermentation process as a major bottleneck for the competitiveness of PHA production.

Intermediate resume

In the second round of interviews, experts assessed the competitiveness of PHAs derived from agricultural residues compared to conventional plastics, highlighting their potential in tackling microplastic pollution. They acknowledged that while cheaper alternatives such as PBS and PBAT are gaining attraction, PHAs are preferred for their bio-based and biodegradable properties, especially as regulations increasingly restrict traditional plastics. Promising applications identified for PHAs include coated fertilisers, biodegradable tree guards and decorative urns, where their superior biodegradability is a key advantage.

However, the high cost of producing PHAs remains a significant barrier, as biodegradable mulch films can be up to three times more expensive than conventional options, limiting their market appeal in price-sensitive sectors such as agriculture. The emergence of cheaper alternatives, particularly from China, and the inadequate performance of bioplastics in terms of barrier properties and ease of processing, further hamper adoption. In addition, experts have highlighted the inefficiency of the fermentation process as a major bottleneck. Despite these challenges, there is optimism that supportive incentives and legislation can improve the competitiveness of PHAs as production scales and innovations in material blending improve performance.

5.3 Estimates of market potential of PHA-applications

In the following, the market potential of PHA applications is mapped on the basis of the assessments of experts who are potential users of the end-product PHA applications from the arable farming or horticulture businesses. Here, the market potential of the end-products, factors influencing the market potential and possible applications are discussed in more detail.

5.3.1 Market potential of bio-based and bio-degradable PHA-applications compared to products from petrochemicals

Comparison

When comparing bio-based and biodegradable PHA applications with petrochemical products, experts mentioned several potential applications. In general, one expert considered that there is currently no alternative to petrochemical products in use. The main reason for not switching to this other type of product is that it is not sufficiently valued in the niche market and neither customers nor consumers want to bear the increased cost of the product. Concerning specific products, one expert stated that in the cultivation of plants for public landscaping, it would be very necessary to find solutions for biodegradable bags and pots that would eliminate the work of managing them after the death or planting of the annual plant. In addition, one expert stated that mulching film and covers for seasonal plants would be a viable option, as they don't need to be removed and put in the bin, thus reducing labour. However, he added that the reality of the current market is that biodegradable products that could be buried are not a good option in terms of price or commercial conditions, e.g. they force you to buy quantities that you may not use and that deteriorate in storage from one year to the next. Finally, one voice considered that bio-based and biodegradable PHA applications may be suitable for materials such as ribbons and staples. However, the expert went on to say that the use of bioplastics in greenhouses could be challenging because of competition from conventional plastics and because it is unclear whether they would work as well.

Intermediate resume

Currently, no alternatives to petrochemicals are widely adopted, mainly due to insufficient appreciation in the niche market. For specific applications like plant cultivation in public landscaping, experts suggested a need for biodegradable bags and pots. Mulching film and coverings for seasonal crops were considered viable, but challenges include market realities like higher prices, forced bulk purchases, and product deterioration.

Advantages

According to the experts, one of the main benefits of bio-based and biodegradable PHA applications replacing currently used plastic materials is the environmental sustainability and carbon footprint impact. One expert considered that this could be a differentiating aspect compared to other competitors in the market. She also mentioned that it would be more sustainable and would allow companies to work together to obtain a value-added product from their by-products, thus closing the loop (circular economy). Finally, three experts stated that another important benefit could be the reduction of waste management and costs related to the management of plastic packaging. In addition, it can reduce the workload with applications as mulching film, tree protection and garden twine, as it can be buried or composted, thus contributing organic matter to the soil.

Intermediate resume

The main benefits of bio-based and biodegradable PHA applications are environmental sustainability, carbon footprint impact, circular economy, waste management reduction, labour reduction and contribution of organic matter to soil.

Possible barriers or disadvantages

The experts also assessed the main barriers to bio-based and biodegradable PHA applications with high market potential. All experts agreed that **higher prices** are the biggest market barrier for bio-based and biodegradable PHA applications. One expert estimated that PHA products will not be profitable if they are more expensive than those of conventional plastics. In addition, another expert commented that the higher costs associated with alternatives cannot be passed on to customers. In terms of cost, one expert considered that machinery would need to be updated, as the same type of **machinery** could not be used for those of petrochemical origin as for those of biodegradable and biological origin. It was also mentioned that **commercial conditions** may require the purchase of large quantities which may deteriorate during storage. It is therefore important to have a stable and sufficient supply to buy only the quantity needed. There is also the question of whether bioplastics can achieve the same **properties and resistance** as conventional plastics. One expert noted that experience with bioplastics to date has been patchy, as they are not sufficiently resistant to moisture and other environmental conditions, which means that their durability is not adequate. Finally, in terms of general limitations, one voice noted that the **recycling process and infrastructure** could be complicated as the composting facility needs to be close by. In addition to the production side, the consumer side was also highlighted by experts. One expert considered that if bioplastics are too similar to conventional plastic, it could have the opposite effect as customers may still consider it as plastic and not buy the product. It was also noted that the vast majority of customers do not value sustainable packaging alternatives and are not willing to pay more for them.

When considering specific applications, one expert specifically mentioned **mulching film**. He discussed that mulching film has been tried but has been found to have several disadvantages. The film has to be completely covered by soil and left in the ground for a few weeks or months for it to decompose completely. He added that it did not look good to customers as it looked like plastic was being thrown on the fields, with pieces of film flying around and sticking out of the ground. There were also a lot of complaints because the film is light and difficult to cover completely with soil. The expert also raised the issue of degradation. He stated that the mulch film started to degrade at the end of the season. This is a real problem because it has to be stable until the end of the season and then it degrades very quickly. In addition, one voice felt that there was also a limitation with the specific use of the **pots**. The pots are used for 5-10 years. Therefore, biodegradability would result in a long life cycle, which would be incredibly expensive. It was explained that it is simply not viable to buy new pots every year as the old ones degrade. Finally, one expert explained that in the case of ribbon, there are not many suppliers and therefore expensive products. In addition, there is a reluctance to ensure that all spools behave in the same way, as the technology is too new for the product supplied to be homogeneous.

Intermediate resume

The main disadvantages of bio-based and biodegradable PHA applications are higher prices, need for updated machinery, need for stable and sufficient supply, lack of properties and resistance, and recycling process and infrastructure. When considering specific applications, mulching film was judged to have problems with appearance, lightness and degradation. Pots used in long life cycles are not viable as a biodegradable application. For ribbon, issues of product homogeneity need to be addressed.

5.3.2 Bio-based and bio-degradable PHA-applications and suitability in agriculture

Assessment on suitability

Regarding the most suitable applications, experts' opinions diverge. Some experts generally stated that bio-based and bio-degradable PHA-applications are very important since there is a huge need to replace plastic that comes from oil and the consumption of plastic will not decrease too much in the coming years. Another expert assessed that bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags are well suited applications from agricultural residues in agriculture. Two experts highlighted mulch foil and assessed that they could be a viable option if they perform well and meet the necessary requirements. Another voice mentioned that it is advantageous to use agricultural waste or agricultural by-products in the agricultural sector. He added that it is important to give priority to being used first in the food chain itself (human and animal food), and after that, think about other valorisations in new materials. Finally, some experts stated that priority should be to work to obtain containers of biodegradable materials that meet the requirements of durability and resistance at prices that can compete in the market.

In contrast, critical voices stated that currently fossil-based materials are preferred due to their low cost and high performance. They further assessed that it is important to not leaving any residues in the field, as customers are sensitive to any visible plastic that could be associated with environmental pollution, even if it's biodegradable plastic. Another critical voice mentioned that, depending on the specific applications and materials, it would still be a long way to go before products of acceptable quality can be used by the industry.

Intermediate resume

Experts considered mulch film, horticultural pots, twine, growth protectors, greenhouses, nets, grow/seed bags as generally suitable applications. Some experts stated that priority should be given to work on biodegradable containers. Critical voices, however, questioned the suitability on cost and performance grounds and noted that there is still a long way to go to achieve high quality products suitable for industrial use.

Other attractive Applications

In terms of other attractive applications, the experts identified several promising alternatives. One expert considered that the use of biodegradable pots for seedlings could save time. However, they may not meet the high demands of certain plants. In addition, the expert explained that biodegradable pots could also work well for courgettes, cucumbers and tomatoes. Other alternatives mentioned were boxes for product transport, agro-films (greenhouses), rigid plastic crates from bulk distribution and bioplastic pallets, as well as mesh bags, rigid bioplastic crates from bulk distribution and bioplastic sticks. Finally, one expert stated that weed cloth could be a promising option. However, the product would have to perform really well and meet our requirements.

Intermediate resume

Other suitable applications identified by the experts included biodegradable pots, weed wrap, transport boxes, agricultural film (greenhouses), large distribution rigid plastic boxes and bioplastic pallets, as well as mesh bags, large distribution rigid bioplastic boxes and bioplastic sticks.

Unattractive applications

Finally, experts assessed which agricultural applications of agricultural residues are not suitable for bio-based and biodegradable PHA. One expert stated that they are not suitable for the production of bio-packaging because the resulting packaging is not sufficiently resistant to moisture and other environmental conditions, which means that its durability is not adequate. Another expert considered that thermoformed containers would not be suitable because multi-layer plastics that protect against light and oxygen barriers would generate large amounts of agricultural by-products. Furthermore, bio-based and biodegradable PHAs are not suitable for use in greenhouses as current applications require the least amount of time and investment to install. Finally, PHA applications were not considered suitable for pots in very intensive production cycles. If the roots are hindered in their development by the biodegradable pot, this will be the case with PHA pots, as the seedlings have to start growing from the moment, they touch the soil.

Intermediate resume

Bio-packaging, thermoformed containers, greenhouse applications and pots in intensive production cycles were considered by the experts to be unsuitable for bio-based and biodegradable PHA.

Table 5: Summary of applications assessment (own compilation of Ecozept).

Application	Advantages	Disadvantages	Requirements	Open questions/
Mulch films	- Degradability delivers a workload reduction - Reduction of logistical costs - Increased soil fertility - Decreased Contamination - Added value - Reduction of carbon footprint	- Difficulties with Degradability: - Unsightly view on field - Impossible with PHB - Price	- Correct biodegradability (Keeping properties long enough then degrading fast enough) - Service life: 6months Competitive price	- Combining Durability with Degradation - Service life - price
Horticultural pots	- Fast degradation - Reduction of carbon footprint	- Not viable for long-term use - Obstruction of develop of rootstock - Price	- Correct biodegradability - Service life: few days Competitive price	- Biodegradable pots with advanced properties for added value in soil
Twines	- Degradability, as it delivers a workload reduction - Reduction of carbon footprint	- Real price would go up - Lacks flexibility - Price	- Physically stability - UV resistance - Service life: 6 months Competitive price	- advanced properties like flexibility - Combining Durability with Degradation
Blends	- Degradability - Cold regions: Accelerate the degradation	- Price	- Competitive price	- /
Agro films/ greenhouse films	- Reduction of carbon footprint - Reduced work and waste management	- Lack of Resistance to atmospheric phenomena - Lack of stability - Price	- Transparent and UV resistant - Same service life expectancy as fossil-based foil - Service life: 5-7 years Competitive price	- Sufficient Resistance and Stability

Growth protectors	- Degradability, as it delivers a workload reduction - Reduction of carbon footprint	- Durability and functionality - Price	- Durability and functionality for 3 years - Competitive price	- Viable durability and functionality
Grow/seedling bags	- Degradability - added value through Dissolution in the soil - Reduction of carbon footprint	- Durability and functionality - Price	- Durability and functionality competitive price	- Viable durability and functionality
Clips	- Cold regions: could be added to a blend to accelerate the degradation - Reduction of carbon footprint	- Yet, impossible to produce strong and flexible clips - macro and micro plastic load in compost	- Strength and flexibility - competitive price	- Viable injection methods
Bio-packaging	- Reduction of carbon footprint - Reduction of managing cost	- Durability - Low resistance to humidity and other environmental conditions - Potential migration	- Avoiding cross-contamination - Durability	- Coss-contamination

5.4 Estimates of market potential of MP based on Delph I

5.4.1 General market potential and markets

The experts rated the market potential of MP in general as very high, especially for animal feed. The main factor influencing the market potential as assessed by the experts was price. It was noted that the main question is whether it is worthwhile, in terms of price, to replace, for example, conventional animal feed with alternative protein sources. The experts also mentioned that the market is not yet developed. The proteins currently used, such as soya, are very cheap and produced in industrial quantities. There are also a few solutions that provide protein, such as sunflower oil residues. When looking at MP, experts have pointed out that they have very high costs combined with a lack of texture to make them acceptable for human consumption. Extra effort is therefore needed to create texture. In terms of potential markets, experts identified animal feed and plant fertiliser as suitable. Some experts even suggested that there is no limit to the applications as there is a demand for all types of protein.

Intermediate resume

The market potential for MP is generally considered to be very high, especially for animal feed. The experts also identified animal feed and plant fertilisers as suitable markets for extracted/microbial protein.

5.4.2 Comparability with conventional protein in terms of functionality

In terms of functionality, the experts judged that MP can generally perform the same functions as conventional proteins. This is due to the almost identical amino acid profile in arthropods and animals. The experts also distinguished between animal and human nutrition.

With regard to animals, some voices emphasised that nutritional value is the main concern and that proteins can easily be replaced by extracted and MP. If the focus is on nutritional value, it is easy to substitute one protein for another and amino acid for amino acid. Furthermore, animal feed is a composition of many different ingredients and protein is only a small part of the animal's diet (between 10 % and 20 %). Therefore, experts have estimated that 100 % of conventional protein in animal feed can be replaced by extracted and microbial protein.

In terms of humane nutrition, food must also have functional properties. Therefore, experts considered that microproteins from fungi have a high potential as they are well suited to produce a structure with bite that can replace meat. Another voice pointed out that arthropods have the same amino acid profile as animals and can be used for human food without causing gout. In contrast, MP have a high uric acid content and cannot be used directly for human food because of the gout problem.

Finally, the experts looked at areas where proteins might be less effective. Here it is difficult to replace eggs with alternative proteins because of their binding and gelling properties. As mentioned above, MP can cause gout due to their high uric acid content.

Intermediate resume

Experts have found that MPs can perform similarly to conventional proteins, especially in animal nutrition, where they can be 100 % replacements. In human nutrition, microproteins from fungi are considered to have high potential. Arthropods are also considered suitable for human nutrition. On the other hand, MP are not perfectly suited for human consumption.

5.4.3 Applications

In terms of the most suitable applications, all experts agreed that animal feed was the most promising use. One expert described feeding fish as a replacement for fishmeal as the holy grail because carnivorous fish species need this type of feed. To feed carnivorous fish, you have to kill other fish first. This is, of course, a very resource-intensive way of feeding. Being able to replace fishmeal would therefore be the best application for alternative protein feed. However, it requires a good amino acid profile, high digestibility and certain unsaturated oils. To this end, MP have been evaluated as having a better chance of replacing fishmeal than extracted proteins. Algae or yeast could also be considered.

As for other attractive applications of MP, many different options were mentioned. One voice mentioned potato protein and extracted protein from brewer's grain as proteins suitable for applications in the food industry. Extracted protein from potato by-products was described as usually highly functional and having very good properties. In addition, extracted protein from brewer's grain is considered to be more of a nutritional protein that could replace soya concentrate, but would not be as functional as potato protein. Finally, MP were judged to be not a good substitute for functional properties in protein production, but valuable for nutritional properties. Other applications worth mentioning are microbial broth derivatives for plant fertilisers, larval fat as animal antibiotics and pet food.

Finally, when it comes to challenging factors for applications of MP, experts identified several challenges. One expert indicated that there is no general limitation in terms of applications. The only challenges he mentioned were functionality and price. In addition, the expert stated that proteins need to be extracted at high concentrations in order to be used in food applications. Use in food applications is recommended because the price paid for food is estimated to be 5 times higher than the price paid for feed. On the other hand, another expert pointed out that the fermentation process requires a lot of energy. Furthermore, there will always be losses during the process as the efficiency is not very high. At the same time, it was mentioned that it could offer the potential to use carbohydrates instead of animal proteins.

<u>Intermediate resume</u>

Experts agreed that the most promising application for MP is in animal feed, particularly for carnivorous fish as a replacement for resource-intensive fishmeal. To fulfil this role effectively, these alternative proteins must have a good amino acid profile, high digestibility and certain unsaturated fatty acids. MP, algae or yeast have been identified as potential sources. In addition, several other applications were considered attractive, such as the use of extracted proteins from potato by-products and BSG in the food industry. Extracted protein from potato by-products is valued for its functionality and properties, while protein from brewer's grain could replace soya concentrate in animal feed. MP were valued for their nutritional properties, but not as functional replacements.

5.5 Estimates of market potential of MP based on Delph II

The results of the first round led to the questions of the second round. Experts validated the results and made additions. Below are the results of Delphi II on the market potential of MP.

5.5.1 General market potential

In line with the previous round of stakeholder interviews, the experts agree on the potential for MP, particularly in the animal feed market. Some experts were optimistic, noting that there is significant potential in both sectors, but acknowledged that access to the human food market is more challenging due to the regulatory requirements involved. Agreeing with this, a sceptical voice questioned the feasibility of incorporating MP into human food in the short term, suggesting that this concept remains more theoretical than practical at present. These cautious perspectives highlight the ongoing debates within the industry about the immediate applicability of MP in human food, as opposed to the more established potential in animal feed applications.

With regard to the feed industry, some experts emphasised that while the specific strain of MP may be less critical than the overall quality of the products, the market remains promising due to the ability to make efficient use of animal feed resources. Many animals can consume residues that are not suitable for human consumption, creating an advantageous situation for incorporating these proteins into animal diets. Pricing is a key factor in the success of MP in feed. Three experts agreed that these proteins need to be sold at competitive prices compared to conventional proteins in order to gain traction in the market. This pricing dynamic is critical to achieving wider consumer and producer acceptance.

The second round of experts also gave their views on the **best practical use of MP** and on inappropriate applications. Regarding the best practical use of MP, several experts agreed that MP has the potential to effectively replace traditional animal-based proteins, such as fishmeal and soya, which are mainly used in animal feed. Other experts noted that this shift to MP could significantly free up land and resources for direct human consumption, with significant environmental benefits. However, another expert noted that it could take another five to ten years to achieve a major change in global meat consumption habits. In addition, another expert discussed potential non-food applications and mentioned that although the functional properties of proteins could theoretically be exploited in the chemical industry - in particular for their nitrogen content as fertiliser - such applications are currently considered to be of low value. Given the high cost of production, they are not a priority. Instead, the experts suggested that these uses might be more appropriate for batches that are not suitable for animal feed or human consumption.

When considering **inappropriate applications**, most experts agreed that there are almost no limitations to MP. Some experts stated that there are no limits to what can be achieved. The only limitations are self-imposed. In line with this, another expert highlighted fermentation as a valuable production method, particularly if a viable business case can be made. However, other experts highlighted the challenges associated with agricultural residues and their characteristics, using rapeseed as an example. The experts pointed out that its unappealing taste and classification as a novel food make it unsuitable for human consumption, as it has not been widely consumed. Although rapeseed can be used in animal feed, its flavour limits its use. However, fermentation of rapeseed can remove unwanted flavours by breaking down anti-nutritional factors (ANFs), making it more palatable. This approach could also be applied to other protein sources, such as fava beans, allowing them to be used in new ways.

<u>Intermediate resume</u>

A strong consensus emerged on the market potential of MP, particularly in the animal feed sector, where they are recognised as viable alternatives to traditional protein sources such as fishmeal and soy. Experts noted the significant benefits of MP in efficiently utilising agricultural residues unfit for human consumption, which could help free up land for direct human food production, in line with environmental sustainability goals. However, it is recognised that the incorporation of MP into human food remains a more theoretical prospect due to stringent regulatory challenges that make this transition unlikely in the short term.

Pricing emerged as a critical factor for the success of MP, with experts emphasising the need for competitive pricing compared to conventional proteins to encourage wider consumer and producer acceptance. While some experts highlighted the wide range of applications for MP, including non-food uses in the chemical industry, they also acknowledged that such applications are currently considered a low priority due to high production costs. Most experts agreed that there are minimal limitations to the potential uses of MP, although challenges remain related to the quality of certain agricultural residues, such as rapeseed. Despite these concerns, innovative techniques such as fermentation may improve the palatability of these residues and open up new applications. Overall, there is optimism about the market potential of MP, particularly in animal feed, although achieving widespread uptake will require concerted efforts to address pricing and regulatory challenges.

5.5.2 Determining factors for market potential

In addition to the results of the previous round of stakeholder interviews, the experts in the current round focused on the determining factors for the market potential of MP. Those results are closely related to the biggest challenges and limitations explored in chapter 4.2.4.2 The experts' differentiated between MP for food and for feed as the factors vary between those fields of applications. The factors are illustrated in figure 12 and will be addressed in the following.

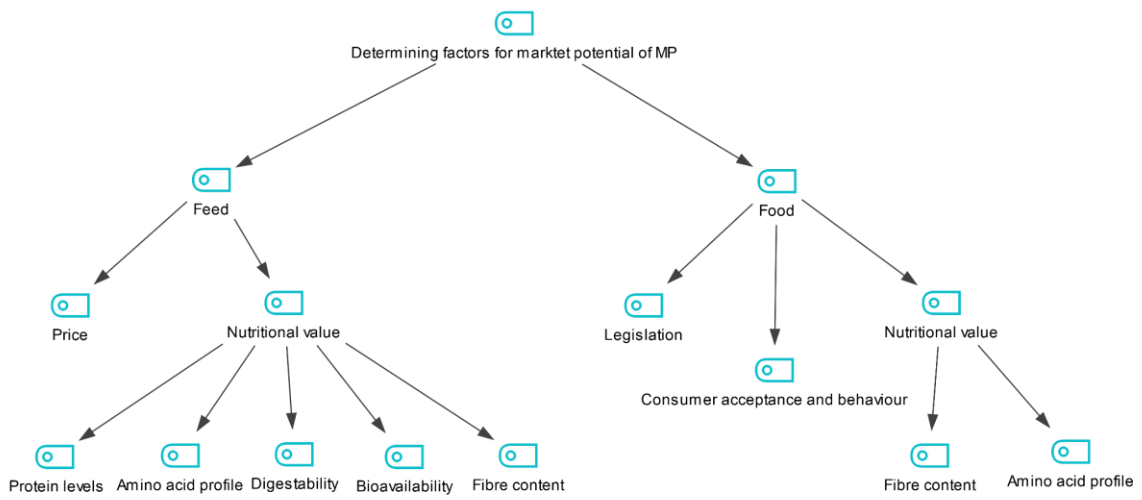

Figure 12: Overview of most frequently cited determining factors for the market potential of MP assessed by experts (own compilation of Ecozept).

In the context of **food applications**, several experts highlighted that although MPs are well suited for use in food, the rigorous **novel food authorisation** process remains an important determinant of market potential. As mentioned in 4.2.4.2, several experts highlighted the complexity and rigour of the novel food application process, which makes it particularly difficult to introduce completely new organisms. Some experts noted that a consensus on testing requirements and clear guidelines, test methods and key performance indicators (KPIs) are needed to optimise the current legislation. In line with this, other voices argued for a review of the legislation on new food sources, in particular to demonstrate the safety of new products such as rapeseed, in order to encourage innovation. Finally, several experts called for a **re-evaluation of these regulations**, advocating a more efficient approval process that could provide feedback within six months, as opposed to the current system in Europe, which they considered slow and costly compared to the more streamlined processes in the US and Asia. Three experts also stressed the need for a **collaborative approach** where stakeholders can work with regulators to address these issues effectively.

Looking at other determinants of market potential, some expert noted that the nutritional value of MP and its amino acid profile is essential. Several experts stated that a comparable nutritional value can be achieved compared to the current alternative. Other experts also noted that different strains of MP have comparable amino acid profiles. In the course of this discussion, two experts mentioned the third key factor determining the market potential of MP, which is price. One voice noted that although the amino acid profile is promising, the cost of MP is a concern. If more affordable sources of nitrogen or protein are available, producers are likely to choose them. Finally, some experts anticipated a gradual shift in **consumer behaviour** over the next five to ten years, with a trend toward reduced meat consumption and a diversification of diets to include alternative protein sources like MP.

<u>Intermediate resume</u>

Experts identified key determinants for the market potential of MP, particularly distinguishing between food and feed applications. For food, the rigorous novel food approval process emerged as a significant barrier, with experts calling for clearer guidelines and a more efficient approval timeline to encourage innovation and streamline the introduction of new products. They emphasised the importance of nutritional value and amino acid profiles, claiming that MP can achieve comparable nutritional benefits to existing alternatives. Experts were optimistic about a gradual shift in consumer behaviour towards reduced meat consumption and greater acceptance of alternative protein sources over the next five to ten years, but stressed the need for collaboration between stakeholders and regulators to improve the viability of MP in the marketplace.

In terms of the drivers for the **feed** sector, the experts agreed that **price** remains a critical factor, with the historically high cost of MP a major concern. According to three experts, farmers tend to choose cheaper sources of nitrogen or protein. However, two stressed that this could create a greater opportunity for MP in the feed market if the price of conventional protein sources increases and MP prices fall due to innovation and economies of scale. Finally, some experts reiterated the importance of competitive feed prices, as farmers are unlikely to adopt MP as long as cheaper alternatives remain available. In this context, one expert presented a programme called Feed Mix, which helps farmers to optimise their feed based on available ingredients and costs to achieve the best nutritional balance. A similar approach could be used to incorporate MP by adjusting parameters to produce a cost-effective feed mix. In addition to the price factor, several experts pointed out that the

composition of the MP is another determining factor. Some experts emphasised the need to optimise the **amino acid profile**, in particular the need for high levels of methionine and glycine. They also noted that **digestibility and bioavailability** should also be optimised. In addition, other experts focused on aquaculture. In line with the previous assessment, the expert emphasised the critical importance of composition, noting that **protein levels, fibre content** and digestibility rates must all be suitable for fish feeding. The expert went on to say that aquaculture feed requires a higher protein content compared to cattle feed. Finally, he stated that it is important to assess the dietary preferences of fish as this can have a significant impact on water quality. In addition, another expert considered that the use of bacterial proteins in animal feed is already more widespread, especially in aquaculture. He further explained that the current objective in this sector is to reduce the reliance on fishmeal, which is inefficient as it takes about 10 kg of sardines to produce 1 kg of sea bass. Instead, the industry is moving towards using fish by-products such as skin and bones to produce fishmeal. Currently, around 6 million tonnes of fishmeal is produced from these by-products, although aquaculture production has increased from 6 to 10 million tonnes per year.

<u>Intermediate resume</u>

Experts agree that price is a critical driver for the feed sector, particularly given the historically high cost of MP. Farmers typically opt for cheaper sources of nitrogen or protein, but there is optimism that MP could become more competitive in the feed market if prices of conventional proteins rise while MP prices fall through innovation and economies of scale. The composition of MP is also critical, with experts emphasising the need for optimised amino acid profiles, particularly high levels of methionine and glycine, as well as improved digestibility and bioavailability. In aquaculture, in particular, the demand for higher protein levels and appropriate digestibility rates is essential, as fish feed requires different nutritional parameters to cattle feed. Experts highlighted the industry's shift away from fishmeal towards the use of fish by-products, reflecting ongoing efforts to improve the sustainability of aquaculture and reduce reliance on inefficient protein sources. Overall, addressing both price and nutritional composition will be key to increasing the uptake of MP in the feed sector.

5.5.3 Potential markets

The experts were also asked to give their views on potential markets for MP. In order to penetrate the market effectively, some experts suggested that it is important to target higher-end markets first. This strategy not only builds trust, but also positions the product as a luxury item, which could eventually facilitate wider acceptance in lower value markets. The concern with entering mass markets too quickly is that consumers may perceive the product as cheap or of low value. In contrast, starting in high value markets can significantly increase the perceived value of the product. In line with this assessment, another voice noted that consumer perception is key, often driven by the story behind the product rather than its price. This approach also applies to pet food, where consumers pay attention to the narrative and are willing to pay a premium for quality products. Another expert agreed with the previous assessments, noting that targeting fish feed and higher value pet products offers the best opportunities, as these markets are typically higher value than standard pet food, but face fewer barriers compared to entering the human food market, which has more stringent regulations. In addition, other experts noted that MP may already be suitable for use in pet food as there is a growing interest in finding more functional proteins. They highlighted that specific molecules have been identified that may have a beneficial effect on conditions such as osteoarthritis in pets. Consistent with the other experts, another voice noted that aquaculture could be the optimal market to start with. He added that MP can also be used in general animal feed. In addition, some experts added that pigments for natural dyes could be an interesting market to explore. Finally, some experts noted that MP can be used in a wide range of applications that go beyond mere nutritional value. MPs have properties such as oil content, oil-holding capacity, water-holding capacity and gelling ability that allow them to replace less natural ingredients in various products, thereby increasing consumer acceptance.

In conclusion, some experts focused on attractive feedstocks for MP highlighting fermented rice seeds and grape seeds. The experts described how fermented rice seeds, considered a by-product after oil extraction, can be versatile and functional. Incorporating just 10 % of these seeds into black bread has been shown to extend shelf life by four weeks. Similarly, grape seeds have demonstrated benefits for gut health, particularly in combating conditions like leaky gut. When fermented with seaweed, they can help reduce inflammation and balance the gut microbiome, promoting beneficial bacteria while decreasing harmful ones. This promising functionality is backed by research and publications, highlighting the diverse applications and benefits of using these feedstocks in conjunction with MP.

Intermediate resume

Experts identified a number of potential markets for MP and emphasised the importance of targeting high-end markets first to build trust and increase the perceived value of the product. This strategy can avoid the negative consumer perception associated with entering mass markets, where products may be perceived as cheap. Consumer narratives and perceptions play a critical role in market acceptance, particularly in sectors such as pet food, where buyers are willing to pay more for quality. The aquaculture sector is highlighted as an optimal entry point due to fewer regulatory barriers, along with opportunities in general feed and functional products. Experts also noted the versatility of MP, citing its beneficial properties such as oil and water retention, which can enhance various applications beyond nutrition. There is also potential to use fermented rice and grape seeds as functional ingredients, offering benefits such as extended shelf life and improved gut health, further demonstrating the diverse applications and benefits of MP in the marketplace.

5.5.4 Determining characteristics of MP

The experts of the second round of interviews also identified determining characteristics for the market potential of MP.

In the analysis of defining characteristics for the market potential of MP, several experts emphasised the need to identify **additional functionalities** that MP can offer. Some experts argued that if a new ingredient can outperform existing options, it has significant potential for success. Other voices added that better functionality can serve as a unique selling proposition (USP) to justify the higher cost. This assessment is influenced by the specific product in question and its processing methods, as these can affect the functional properties of the final product. Finally, another expert emphasised that nutritional value remains a top priority. Although plant proteins are already on the market and perform adequately, they often lack many functional properties. In contrast, MPs tend to have enhanced functional properties, making them easier to integrate and providing added benefits beyond nutritional value.

In addition, some experts emphasised that **proper fermentation techniques** can significantly improve functionality. They advocated solid-state fermentation, which uses less water and slows the process, leading to better results, including higher concentrations of valuable metabolites - up to 1,000 to 1,500. These metabolites can be further transformed using ingredients such as seaweed or rice grains, opening up numerous applications for fermented proteins and by-products from soy and rice. The expert also highlighted the importance of functionality in the food industry, where fermentation can provide natural binders that improve product quality. Done correctly, this process can produce strong, natural binders from whole grains and beans. In addition, the use of by-products in this context can add value without incurring significant costs, which is critical to encouraging farmer adoption.

Finally, some experts stressed that both **bioavailability** and cost are critical factors when considering functional proteins. In line with this, another voice added that new approaches must be economically viable to ensure their uptake. Additionally, other experts noted that the aquaculture sector faces a significant constraint regarding non-GMO practices. The experts underscored the importance of understanding how MP are categorized, noting that the use of GMO fermentation bacteria for amino acids like lysine and glutamine has been halted. Finally, they stressed the necessity of ensuring that dry protein flours are free from toxins, including pesticides and carbonates.

When discussing the essential functions of MP for **food**, several experts emphasised the importance of a balanced dietary protein intake. Some experts highlighted that relying solely on peas and beans can lead to a deficiency of methionine, an essential amino acid that is crucial for healthy hair and nails. To mitigate this, it's important to include additional sources such as rapeseed and sunflower, with rapeseed being particularly suitable for cultivation in Europe. In addition to protein and amino acid profiles, the experts stressed the importance of fibre content. The experts noted that while much attention has been paid to protein intake, fibre sources are often overlooked. Therefore, the expert suggested that fibre-rich by-products should be used in future diets.

With regard to **feed**, experts focused on aquaculture. Some experts noted that the requirements are considerable, with formulations needing protein and fat contents in excess of 35 % to 60 %. The experts also highlighted the importance of analysing protein nitrogen levels in both traditional proteins and MP. They noted that the expert uses an index of 6.25 to differentiate between protein and non-protein nitrogen in products, as high protein content can sometimes correspond to low protein nitrogen levels, leading to challenges in protein assessment. A variety of protein sources are being investigated, including maize gluten (commonly used in Norway), soya concentrate (which contains almost 60 % protein) and fishmeal, which also has a 60 % protein content. When it comes to feeding ruminants at certain stages of growth, the focus shifts to protein concentrates, which provide more nitrogen than actual protein. The experts also mentioned the potential use of liquid protein concentrates in this area. Other voices also pointed out that certain fish species, especially piscivores and carnivores, tend to avoid sugars, which are more commonly found in fibre. Therefore, minimising fibre in protein formulations for fish feed is critical and fermentation processes can help to reduce fibre content.

Intermediate resume

The experts identified several key characteristics that will influence the market potential of MP. They emphasised the importance of identifying additional functionalities that MP can offer, noting that superior performance compared to existing alternatives could serve as a unique selling proposition, justifying higher costs. Appropriate fermentation techniques, particularly solid-state fermentation, were highlighted for their ability to enhance MP functionality by producing valuable metabolites that can be combined with other ingredients such as seaweed or rice.

Nutritional value is paramount, with concerns about achieving a balanced amino acid profile, especially as some plant proteins can lead to deficiencies. Fibre content also needs to be considered, as fibre-rich by-products are often overlooked in current diets. In aquaculture, experts emphasised the need for high protein and high fat formulations and the importance of analysing protein nitrogen levels to meet nutritional requirements.

Experts also pointed out that bioavailability and cost-effectiveness are critical to the successful adoption of MP, along with ensuring compliance with non-GMO practices and the absence of toxins. While the demand for high quality protein sources is growing, the successful integration of MPs depends on optimising their functional properties and overcoming production challenges, which could increase their attractiveness in food and feed applications. Overall, there is optimism about the future of MP, subject to continued research and collaboration within the industry.

5.5.5 Limits of MP

Finally, the experts were asked for their views on the limitations of MP. Two experts were very positive about the functionalities of MP, stating that they didn't think there were any functions that could not be fulfilled with MP. In addition, another voice highlighted that MP proteins derived from agricultural residues are a promising source of protein.

However, other experts identified certain limitations of MP that need to be considered when assessing its market potential. When assessing conventional proteins compared to MP, some experts emphasised the different characteristics of conventional proteins compared to plant-based proteins, highlighting that conventional proteins are simple proteins, whereas plant-based proteins offer additional beneficial compounds that promote gut health. However, the experts stressed that the excessive processing often involved in the extraction of MP can negatively affect gut function, which is a concern in the livestock industry where many diseases could be mitigated by a more natural diet. The experts suggested that the use of fermentation of by-products could be a solution to these problems. In addition, other voices noted that the oil content of different MPs varies. Some lack sufficient oils, whereas algae-based proteins generally contain sufficient amounts. However, the voices stressed that it is possible to achieve a complete replacement of traditional proteins by effectively combining the right strains or products, using a mix of algae, bacteria and yeast. In addition, other experts mentioned that spirulina (algae protein), which contains 60 % alcohol, may have a negative impact on palatability depending on the type of fish. In addition, it is important to consider the inclusion of fats, although it remains uncertain whether it is feasible to extract fats from residues. Finally, one expert acknowledged that cost was a significant barrier and the most difficult aspect to compare.

<u>Intermediate resume</u>

Experts highlighted both the potential and limitations of MP, noting that while MP derived from agricultural residues are promising, significant challenges remain. On the positive side, some experts highlighted that MP can meet different functional needs and its diverse sources, including algae and bacteria, could potentially replace traditional proteins. However, concerns were raised about the over-processing of MP, which could have a negative impact on animal gut health and reduce the beneficial compounds often found in plant proteins. In addition, the variability of oil content between different MP sources was noted, with algae proteins generally providing adequate oils, while others may not. Cost remains a significant barrier to market competitiveness, making comparisons with conventional proteins difficult. Overall, while MP has significant potential, its successful integration into the market will depend on overcoming these limitations and optimising production processes.

6 Preliminary results of market assessment in China

This report on preliminary results of market assessment in China is authored by Gang Li and Xingyang Lai from the Beijing Technology and Business University (BTBU). The report is a draft deliverable that focuses on analysing the current state and challenges of agricultural residue management in China, as well as assessing the market potential for using agricultural by-products. The findings presented here are intended to inform future agricultural sustainability strategies, particularly in the context of recycling and resource utilisation within China's agricultural industry. The findings of this report will continue to be refined as additional data and analysis are incorporated.

6.1 Agriculture development profile

Agriculture is the foundation of the national economy, and it is related to the stability and development of the country. As a big country with a long agricultural history, Chinas development of agriculture has undergone thousands of years of changes. From the traditional agricultural civilization to the modern scientific and technological agriculture, Chinas agriculture has moved forward in the continuous exploration and innovation, and has made great contributions to the country's economic construction, social stability and the improvement of peoples living standards.

At present, Chinas agricultural production structure has been continuously optimized. In terms of planting industry, the proportion of food crops, cash crops and feed crops gradually tends to be reasonable. Grain production remained stable, and the output of major grain crops such as rice, wheat and corn ranked among the highest in the world. The output of cash crops such as cotton, oil, sugar, vegetables and fruits is also increasing, meeting the domestic market demand and export demand.

Animal husbandry and fisheries have also developed rapidly. Animal husbandry has changed from the traditional free-range breeding mode to large-scale and standardized breeding, and the output of meat, eggs, milk and other animal products has been continuously increased. In terms of fishery, the scale of mariculture and freshwater aquaculture has been expanding, and the output of aquatic products ranks first in the world.

People attach great importance to the ecological environment, and Chinas agricultural ecological environment protection has also achieved some results. The state has vigorously promoted sustainable agricultural development models such as ecological agriculture and organic agriculture, reduced the use of chemical fertilizers and pesticides, and protected the agricultural ecological environment。 At the same time, we strengthened the control of agricultural pollution from non-point sources, promoted the improvement of the rural living environment, and improved the rural ecological environment.

However, the agroecological environment still faces some challenges, such as agricultural waste resource utilization. Such problems still need to be further solved.

6.1.1 Food agriculture

Grain agriculture is the foundation of Chinas agriculture, mainly including major grain crops such as rice, wheat and corn. The Chinese government attaches great importance to food security, and promotes the stability of grain production by implementing a series of policies, such as the minimum grain purchase price policy and grain production subsidies. Since the reform and opening up, Chinas grain production has experienced remarkable growth. According to the National Bureau of Statistics, Chinas total grain output increased from about 300 million tons in 1978 to more than 600 million tons in 2022, basically becoming self-sufficient. In addition, the promotion of modern agricultural technology is also improving the efficiency of food production. In recent years, the introduction of precision agriculture and intelligent agriculture has improved the level of tillage management and promoted the improvement of production efficiency.

Although food production continues to grow, the challenges cannot be ignored, including the reduction of arable land resources, soil degradation and water shortages. In addition, the impact of climate change on food security is also gradually emerging, prompting the country to accelerate the adjustment of agricultural structure and scientific and technological innovation, in order to cope with the future of food security problems.

6.1.2 Cash crop agriculture

Cash crop agriculture mainly includes cotton, tobacco, rape, sugar crops, etc. These crops are usually used for industrial processing and export, and contribute significantly to farmers income. China is the world's largest producer and consumer of cotton, and cash crops play an important role in the agricultural economy. After the reform and opening up, Chinas cash crop agriculture developed rapidly, especially in the southern region, where the planting area and yield of cash crops increased rapidly. By introducing advanced agricultural science and technology and management mode, we promote the industrialization and modernization of cash crops. Especially in the context of globalization, Chinas cash crop export has increased year by year, driving the development of rural economy.

At present, cash crop agriculture is developing towards the direction of high added value and brand. The government encourages farmers to participate in cooperatives to enhance the market competitiveness of cash crops. At the same time, as consumers pay attention to health and environmental protection, more and more organic and green cash crops begin to rise to meet the market demand.

6.1.3 Fruit and vegetable agriculture

Fruit and vegetable agriculture covers the cultivation of fruits and vegetables, and is one of the fastest growing areas in Chinese agriculture. With the improvement of people's health awareness, the consumption demand for fruits and vegetables is constantly rising. Chinas fruit and vegetable production is important in the world, especially apples, grapes, oranges and various green leafy vegetables. Since the 1980s, Chinas fruit and vegetable industry has experienced a transformation from traditional small-scale planting to modern large-scale production. Through the introduction of new technologies, high-quality varieties and modern management, the fruit and vegetable industry has gradually formed a relatively complete industrial chain. Local governments have also introduced policies to support the development of the fruit and vegetable industry.

At present, Chinas fruit and vegetable production faces the challenges of product quality and food safety. The state has increased the construction of a standardization and traceability system for fruit and vegetable production. At the same time, the rise of ecological agriculture and organic agriculture has brought new development opportunities for the fruit and vegetable industry. The rapid development of fruit and vegetable e-commerce has also promoted the sale and circulation of agricultural products.

6.1.4 Animal husbandry

Animal husbandry is an important part of the country, including raising cattle, sheep, pigs and poultry. China is the world's largest producer and consumer of pork, consuming more products such as milk and eggs. Livestock husbandry provides an important source of income for the farmers. Since the reform and opening up, Chinas animal husbandry has developed rapidly, the scale of breeding has gradually expanded, and the introduction of modern breeding technology has improved the production efficiency. In particular, the promotion of the "company + farmer" model enables many small farmers to participate in the modern breeding, which increases their income.

At present, the animal husbandry is facing the pressure of environmental protection and animal disease prevention and control. The state has issued a series of policies to promote the green and sustainable development of animal husbandry, and encourage the use of new models such as ecological breeding and circular agriculture. At the same time, consumers increasing demands for meat quality and safety have promoted the market development of high-end and organic livestock products.

6.1.5 Aquaculture

The aquaculture industry includes fishing, fisheries and aquaculture, and the consumption and production of aquatic products in China has continued to grow in recent years. China is the world's largest producer and consumer of aquatic products, and aquaculture has become an important factor driving the growth of the aquaculture industry, especially the cultivation of shrimp, fish and shellfish. The development of Chinas aquaculture can be traced back to ancient times, but the real modernization began in the 1980s.

With the development of rural economy and the introduction of technology, the scale of mariculture and freshwater aquaculture is constantly expanding, and the output of aquatic products ranks first in the world. Breeding technology has been continuously improved, new breeding modes, such as factory breeding and ecological breeding, have been continuously promoted, and the protection and sustainable utilization of fishery resources have been received increasing attention.

At present, Chinas aquaculture industry is facing the problems of excessive exploitation of resources and environmental pollution. Therefore, the state has increased the attention to the sustainable development of aquaculture and promoted the application of ecological aquaculture and circulating aquaculture technology. At the same time, with consumers attention to healthy food, the market demand for high-quality aquatic products is constantly rising, and the aquaculture industry will continue to develop in a green and sustainable direction.

6.2 Overview of agricultural organic by-products

The management and utilization of agricultural organic waste is an important link to realize sustainable development and resource circulation. In Chinas five major agricultural industries — grain agriculture, cash crop agriculture, fruit and vegetable agriculture, animal husbandry and aquaculture, a large amount of organic waste is produced every year, but its utilization efficiency is generally low, resulting in serious waste of resources and environmental problems. The current situation and the reasons behind it will be discussed in detail in combination with the annual waste output of various industries.

1. **Current status of organic waste in food and agriculture**

<u>Production volume and waste conditions</u>

In 2022, Chinas annual grain crop output was about 686 million tons, The output of potatoes was 89 million tons. More than 800 million tons of straw were generated. Although about 240 million tons of straw are considered to be available each year, the actual utilization rate is less than 30%. This means that about 560 million tons of straw are not used effectively every year and are mainly incinerated or idle.

<u>Take advantage of the insufficient reasons</u>

In many rural areas, farmers are still used to burning straw, believing it will quickly clear land and eliminate pests and diseases. However, incineration not only causes the loss of plenty of nutrients, but also causes air pollution.

<u>Lack of technical support</u>

Although there are some straw returning and feed processing technologies, many farmers lack the understanding and practice of these technologies, and it is difficult to effectively transform straw into useful resources.

<u>Insufficient economic incentives</u>

The market value of straw is generally low, the lack of stable recycling channels, making farmers on the use of straw enthusiasm is not high.

2. **Current status of organic waste in cash crop agriculture**

<u>Production volume and waste conditions:</u>

The annual yield of cash crops varies. For example, cotton production annually is about 5 million tons. Peanut production reaches 18.3 million tons per year, while rapeseed yields around 15 million tons. The annual output of related straw and by-products is about 20 million tons, but the utilization rate remains low.

<u>Take advantage of the insufficient reasons</u>

High treatment costs: Waste disposal of cash crops usually requires high costs, especially in dry areas, where transportation and treatment costs increase significantly.

Lack of market demand: Although the waste from cash crops can be used to make organic fertilizer, feed, etc., the market demand is unstable, and many farmers are unwilling to spend the time and energy to dispose of the waste.

Information asymmetry: Many farmers lack an understanding of the potential use value of cash crop waste, leading to a significant waste of resources.

3. Current status of organic waste in fruit and vegetable agriculture

Production volume and waste conditions

The total output of fruits and vegetables is about 700 million tons, while the fruit is about 200 million tons. The production of apples was 47.5718 million tons, About 500 million tons of vegetables. Due to the loss of picking, transportation and storage, around 100 million tons of fruits and vegetables are wasted annually, but the actual utilization rate is less than 30%.

Take advantage of the insufficient reasons

Preservation and transportation problems: Fruits and vegetables are easy to damage in the process of picking and transportation, resulting in a large number of rotten fruits being discarded, resulting in waste.

Consumption habits: Consumers have high requirements for the appearance of fruits and vegetables, and many fruits and vegetables that fail to enter the market due to their poor appearance directly become waste.

Insufficient processing technology: The reprocessing and utilization technology of fruit and vegetable wastes is relatively lacking, and many farmers and processing enterprises lack the ability to transform these wastes into valuable products.

4. Current status of organic waste in animal husbandry

Production volume and waste conditions

In 2022, Chinas total output of livestock and poultry meat is about 70 million tons, and dairy products are about 35 million tons. The annual output of livestock manure is more than 300 million tons, however, less than 20% of the manure is used efficiently.

Take advantage of the insufficient reasons

Environmental pollution problem: Many farms lack scientific manure treatment technology, which directly discharge manure into the natural environment, leading to water and soil pollution.

Lack of technology: Although manure can be converted into organic fertilizer, many farmers lack the relevant technology and equipment to effectively convert them into useful resources.

Low market value: the market demand for organic fertilizer is limited, and the price is generally low, which makes farmers unwilling to invest time and energy to deal with feces.

5. The status quo of organic waste in aquaculture

Production volume and waste conditions:

The annual output of Chinas aquaculture industry is about65 million tons, covering fish, shrimp, crabs and so on. The annual output of organic waste (such as viscera, residues, etc.) produced by aquaculture is roughly more than 10 million tons, but the treatment and utilization rate are relatively low.

Take advantage of the insufficient reasons:

Improper treatment method: many aquaculture farmers have a simple and crude waste treatment method, often directly discarded or discharged, resulting in water pollution.

Lack of recycling channels: Although aquaculture waste can be used for the production of feed or fertilizer, the lack of systematic recycling and treatment channels makes the resources not fully utilized.

Technical obstacles: aquaculture waste treatment technology is relatively underdeveloped, and many farmers do not have the ability to convert waste into useful resources.

6.3 Resource assessment

6.3.1 Organic residue types

In Chinas agricultural production, the amount of organic waste is huge, reasonable management and utilization is particularly important. Several main types of agricultural organic wastes, especially crop straw, livestock manure, and wastes are generated during the processing of agricultural products, including peanut cake meal, potato starch processing skin residue, apple juice processed skin / residue, soybean peel, white wines grains, BSG, citrus residue, corn stalk and corn cob. These wastes are not only huge in quantity, but also contain rich resource value, which is worth in-depth discussion.

1. **Crop straw**

Definition and source

Crop straw refers to the residual stem, leaves, roots and other plant residues after crop harvest and mainly come from wheat, corn, rice, soybean and other crops. According to statistics, the amount of crop straw produced in China is huge, about 800 million tons.

Features

Crop straw is rich in cellulose, lignin and a small amount of protein, which has good biodegradability, and can be converted into organic fertilizer or bioenergy. At the same time, the nutritional composition of straw varies according to the crop type and growth environment, and the application effect of straw of different crops in feed and fertilizer is also different.

Resource utilization

The main utilization methods of straw include:

Feed: straw can be used as feed for cattle, sheep and other herbivores.

Organic fertilizer: straw can be mixed with other organic substances for composting to produce high-quality organic fertilizer.

Biomass energy: it can be converted into biomass fuel through gasification, pyrolysis and other technologies to replace the traditional fossil energy.

Industrial raw materials: used for the production of paper, fiberboard, the development of circular economy.

2. **Livestock and poultry manure**

Definition and source

Livestock and poultry manure refers to the animal excrement produced in the process of breeding, mainly derived from pig, cattle, sheep, chicken and other breeding industry. With the rapid development of the breeding industry, the production volume of livestock and poultry manure has increased year by year, and the annual production volume has exceeded 400 million tons.

Features

The composition of livestock and poultry manure varies with animal species and feeding and management methods, which is usually rich in nitrogen, phosphorus and potassium. At the same time, the organic matter content in livestock manure is high, which has a good soil improvement effect.

Resource utilization

The utilization mode of livestock and poultry manure mainly includes:

Organic fertilizer: through compost, fermentation and other treatment can be made into high-quality organic fertilizer, improve the soil fertility.

Bioenergy: the anaerobic fermentation technology can be converted into biogas, as a renewable energy source.

Feed additive: after safe treatment, some livestock and poultry manure can be used as feed additives.

3. Agricultural products processing waste

There are many kinds of waste produced in the process of agricultural products, including peanut cake meal, potato starch processing waste, skin / slag, soybean peel, white wines grains, BSG, citrus residue, corn stalk and corn cob, etc. Here is introduced one by one.

Peanut cake meal

Definition and source: Peanut cake meal is a byproduct of peanut oil extraction, and it is rich in protein and fatty acids. Peanut cake meal is produced in Chinese peanut oil processing every year4One million tons.

Characteristics: Peanut cake meal is rich in amino acids and is suitable for animal feed, especially for poultry and pigs.

Resource utilization: can be directly used as feed, or through fermentation and other treatment, improve its nutritional value, made into functional feed.

Potato starch processing waste

Definition and source: During the production of potato starch, a large amount of waste residue and wastewater are produced, with an annual output of 1 million tons.

Characteristics: Potato skin residue is rich in cellulose and starch, and has high nutritional value.

Resource utilization: it can be used as feed, composting, or converted into biological gas through fermentation.

Skin / slag processed by apple juice

Definition and source: In the production of apple juice, apple peel and fruit residue are the main waste, with an annual output of about 1 million tons.

Characteristics: Apple fruit residue is rich in vitamins, minerals and organic acids, andnutrients.

Resource utilization: it can be used for feed or deep processing to make jam, dried fruit and other products.

Soybean skin and soybean meal

Definition and source: During soybean processing, soybean peel and soybean meal are the main by-products, with an annual output of about 8 million tons.

Characteristics: Soybean meal is rich in high-quality protein and is widely used in the feed industry.

Resource utilization: Soybean skin can be used as feed, while soybean meal is an important animal feed, and the main protein source, especially in aquaculture.

White wine bad

Definition and source: Liquor production process produces grains of white wine, with an annual output of about 2 million tons.

Characteristics: White distillers grains are rich in protein and a variety of amino acids, suitable for feed.

Resource utilization: it can be used as feed for livestock, or after fermentation treatment, for the production of organic fertilizer.

BSG

Definition and source: Beer production produces BSG, with an annual output of about 1 million tons.

Characteristics: Beer is rich in protein, fiber and B vitamins and suitable for animal feed.

Resource utilization: BSG can be used directly as feed, or mixed with other ingredients to produce functional feed.

Citrus residue

Definition and source: In citrus processing, the production of citrus residue is considerable, with an annual output of about 500,000 tons.

Characteristics: Citrus residue is rich in cellulose and vitamin C, which has high nutritional value.

Resource utilization: it can be used in feed or to make citrus essential oil, dried fruit and other food.

Corn stalk and corn cob

Definition and source: During the planting and processing of corn, straw and corn cob are common waste, with an annual output of about 200 million tons and millions of tons, respectively.

Characteristics: Corn stalk is rich in fiber, suitable for use as an organic fertilizer, while the corn cob has a high calorific value, suitable for use as a fuel.

Resource utilization: Corn stalks can be used for the production of composting, feed or biomass energy, and corn cobs can be used for fuel and industrial raw materials.

6.3.2 Geographic distribution

China is a country with a vast territory and diverse terrain, with different agricultural production conditions, crop types and breeding methods, leading to significant differences in the types and quantities of agricultural organic waste in different regions. 一、Geographical distribution of crop straw

According to the collected database, we calculated the annual yield distribution of crop straw in the five major regions in the past five years (2018-2022). The calculation formula is as follows:

= 1 × 1.01 + 2 × 1.37 + 3 × 1.10 + 4 × 1.44 + 5

× 0.77 + 6 × 3.10 + 7 × 1.26 + 8 × 2.71 + 9

× 0.10 among, Y represents the annual output of crop straw in the province, x1、x2、x3、x4、x5、x6、x7、x8、x9.

It represents the annual output of rice, wheat, corn, beans, potato, cotton, peanut, rape and sugarcane, respectively. The average annual output of straw in the representative province of each region is obtained:

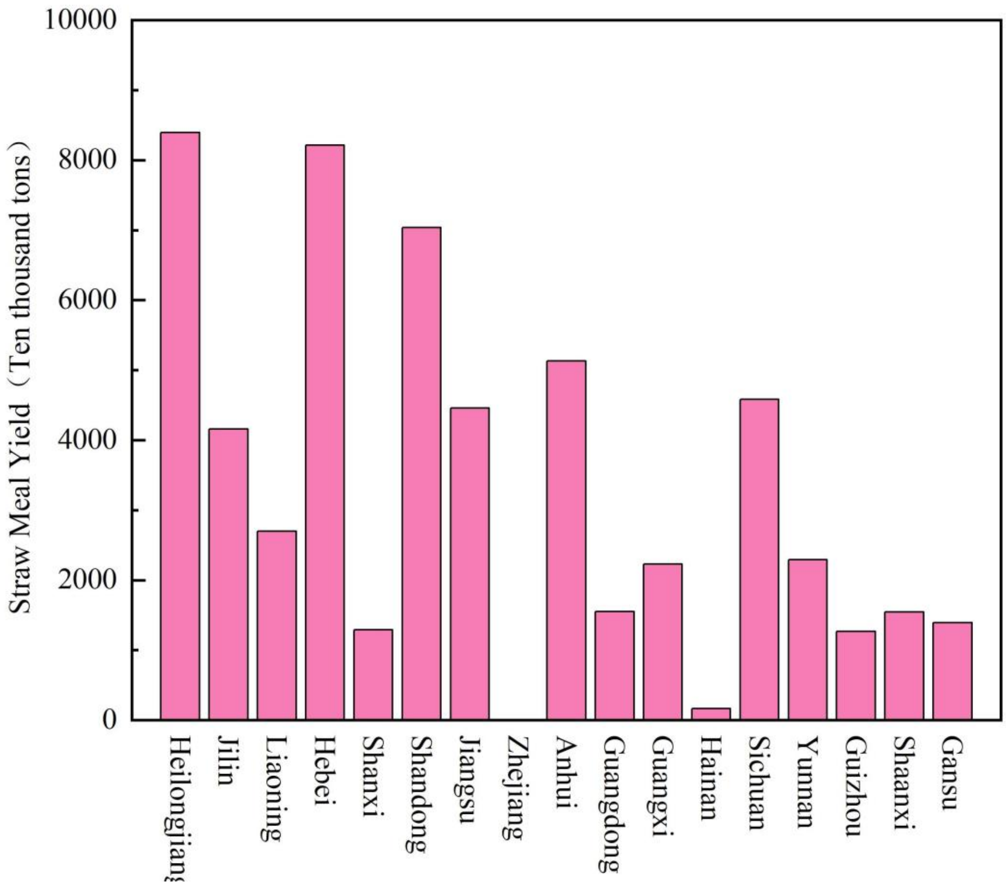

Figure 13: Average annual output of straw in all provinces in the recent five years (2018-2022) (own compilation of BTBU).

Northeast China

Heilongjiang, as the granary of China, mainly grows corn and soybeans, producing an annual straw yield of about 83.96 million tons, mainly concentrated in the autumn harvest season. In Jilin province, corn and rice are also widely grown, with nearly 41.6 million tons of straw produced every year.

Liaoning, similar to other northeastern provinces, has grown corn and soybeans in the plant to produce about 26.98 million tons of straw per year.

North China

In Hebei, where wheat and corn are mainly planted, with an annual straw production of about 82.12 million tons. However, incineration phenomenon remains a common practice, highlighting the need to strengthen the utilization of resources. In Shanxi Province, the cultivation of wheat and corn makes the annual straw yield of about 266.87 million tons, but most of them are not effectively used. Shandong: The province has a wide area of corn cultivation, producing nearly 70.38 million tons of straw every year.

The East China region

Jiangsu: Rice planting is widely, the annual production of rice stalks is about 44.58 million tons, the problem of straw utilization is more prominent.

Zhejiang: mainly planting rice and tea, producing about 20,000 tons of straw every year, the utilization rate is relatively low.

Anhui: The cultivation of rice and wheat produces about 51.32 million tons of straw annually, and the problem of straw burning and random stacking is serious.

The South China region

Guangdong: planting sugarcane, rice and fruit, the annual straw production is about 15.5 million tons, mainly incineration, and the resource utilization is low.

Guangxi: Sugarcane is the main crop, straw utilization is less, the annual production of about 22.33 million tons.

Hainan: Tropical crops are planted, with an annual straw production of about 1.63 million tons, mainly used for fertilizer.

The Southwest Region

Sichuan: The cultivation of rice and corn leads to the annual straw production of about 45.82 million tons, and the resource utilization of straw has gradually been paid attention to.

Yunnan: Mainly vegetables and fruits, the straw production is about 22.93 million tons, but the utilization rate of resources is low.

Guizhou: Various crops are planted, with about 12.69 million tons of straw produced every year, which is mainly used for fertilizer and feed.

Northwest China

Shaanxi: Crop straw output is about 15.46 million tons.

Wheat, maize, and other cereals are the main sources of crop straw. In all kinds of grain crops straw quantity in Shaanxi Province, corn accounts for the highest proportion, followed by wheat.

Gansu: According to the data, the total amount of straw production is about 13.93 million tons.. The average annual output of straw in large areas is shown in the figure below:

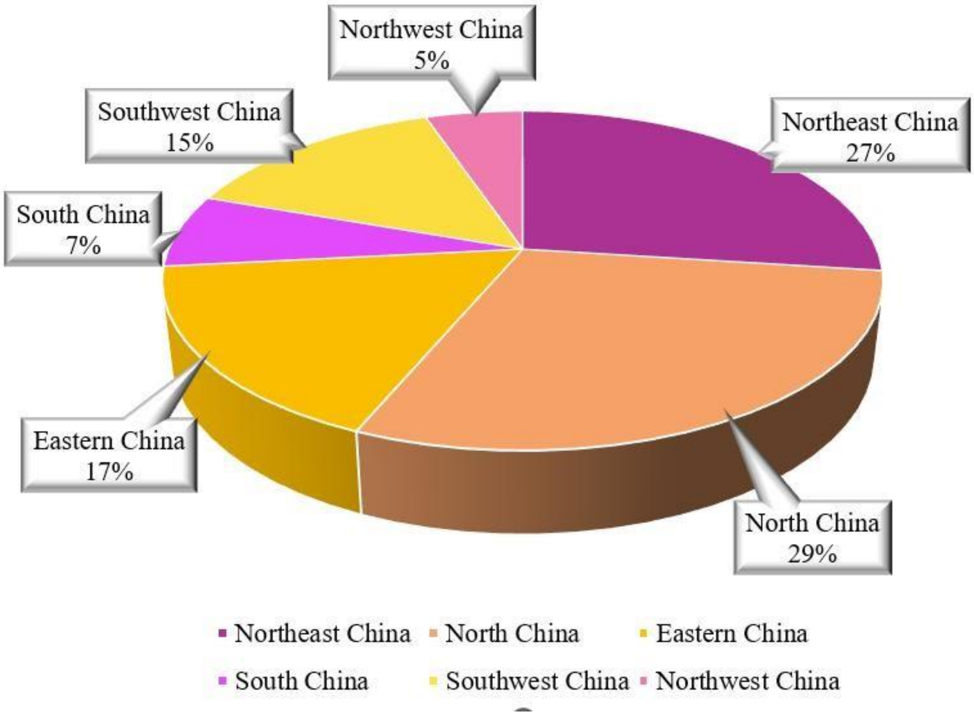

Figure 14:Average annual yield of straw, six Large proportion of regions (own compilation of BTBU).

It can be known that north China is the main area to produce straw waste, and northeast China also accounts for a large proportion because of the large number of corn planting.

Geographic distribution of livestock manure

<u>Northeast China</u>

Heilongjiang: the breeding industry is developed, the annual production of livestock and poultry manure is about 40 million tons, mainly concentrated in raising pigs and cattle.

Jilin: The production capacity of livestock and poultry manure is about 15 million tons, mainly for pigs and cattle, and the resource utilization is gradually improved.

Liaoning: The aquaculture industry is developing rapidly, producing about 20 million tons of feces annually.

<u>North China</u>

Shandong: It is a big breeding province in China, with a large number of pigs, cattle and sheep, with an annual output of 60 million tons.

Hebei: the production capacity of livestock and poultry manure is about 30 million tons, mainly for pigs and chickens, some of which are used for organic fertilizer production.

Shanxi: The breeding industry is mainly sheep and cattle, and the annual production capacity of feces is about 10 million tons.

The East China region

Jiangsu: The breeding industry is diverse, the annual production of livestock manure is about 25 million tons, the utilization rate is gradually increasing.

Anhui: Mainly pigs and chickens, the annual production of feces is about 20 million tons, the resource utilization is low.

Shanghai: The aquaculture industry scale is small, the annual amount of feces is about 2 million tons, but gradually explore the use of organic fertilizer.

The South China region

Guangdong: As a major breeding province, the annual production capacity of livestock and poultry manure is about 40 million tons, mainly used for biological gasification and organic fertilizer.

Guangxi: Mainly raising pigs, producing about 15 million tons of feces annually, and the utilization of resources needs to be strengthened urgently.

Hainan: The breeding industry is dominated by chickens and ducks, producing about 3 million tons of feces annually.

The Southwest Region

Sichuan: The aquaculture industry is developed, the annual amount of feces is about 40 million tons, the use of biogas technology is gradually promoted.

Yunnan: Mainly cattle and sheep, the annual amount of feces is about 10 million tons, and the utilization level is low.

Guizhou: Mainly pigs and chickens, with an annual output of about 8 million tons, and is gradually carrying out the use of organic fertilizer.

Northwest Terr

Shaanxi: The breeding industry is relatively developed, mainly with pigs and sheep. The annual production of livestock and poultry manure is about 20 million tons, and the level of resource utilization is constantly improving.

Gansu: The scale of cattle and sheep breeding is large, and the annual production capacity of feces is about 15 million tons, part of which is used for organic fertilizer production.

Xinjiang: It is an important animal husbandry region, mainly sheep, cattle, and horses. The annual output of feces is about 30 million tons, which is gradually promoted in biological gasification and the utilization of organic fertilizer.

Geographic distribution of agricultural products processing waste

Peanut cake meal

The average annual output of peanut cake over the past five years (2018-2022) is shown in the figure, and peanut cake is mainly concentrated in North and South China. The peanut planting area in Shandong is large, and the annual production of peanut cake is about 715,000 tons; The peanut planting in Liaoning and Guangdong is also high, so the resource utilization is gradually valued.

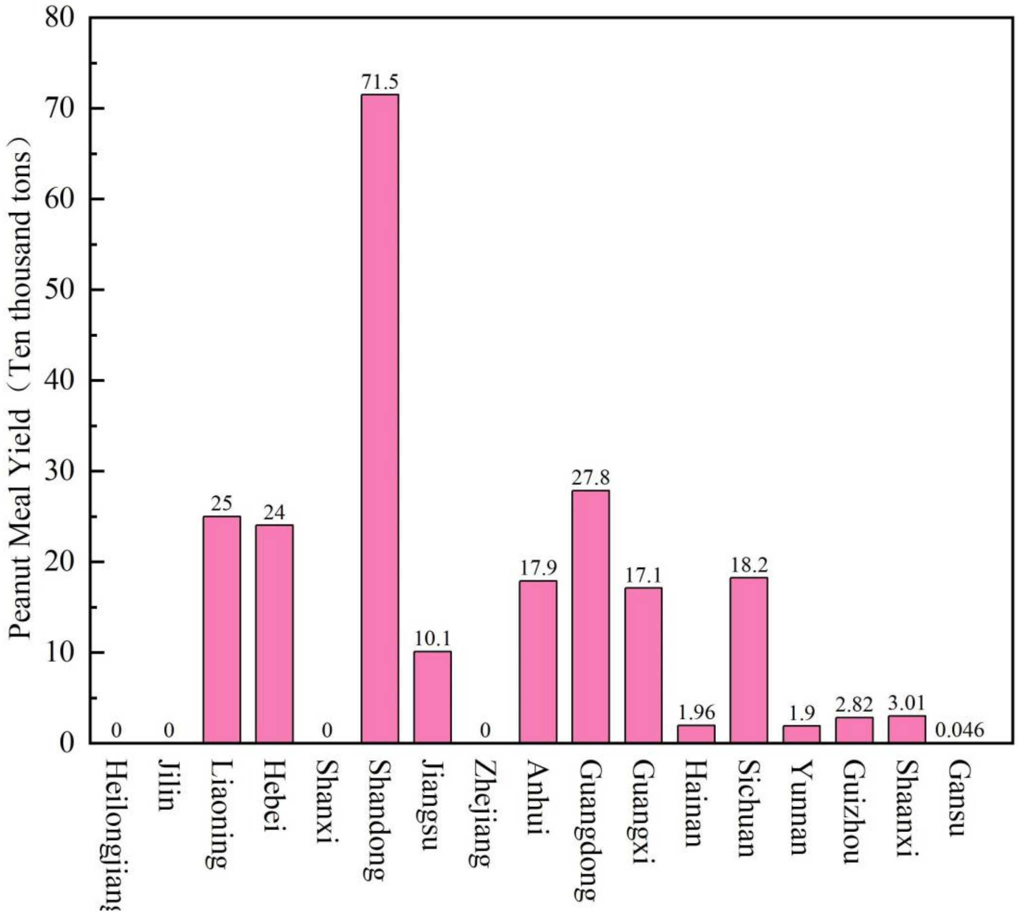

Figure 15: Annual output of peanut cake meal in recent five years (2018-2022) (own compilation of BTBU).

Potato starch processing waste

Distribution area: Gansu, Qinghai, Shaanxi, Sichuan and other places.

Features: Gansu and Shaanxi are the main producing areas of potato, the annual production of potato skin residue and waste water is about 800,000 tons, and the level of resource utilization needs to be improved urgently.

Skin / slag processed by apple juice

Distribution area: mainly concentrated in Shanxi, Shaanxi, Shandong and Liaoning and other places.

Features: The apple planting area in Shanxi and Shaanxi is large, and the annual peel and fruit residue can reach 500,000 tons, and the utilization of resources needs to be strengthened.

Soybean skin and soybean meal

Distribution area: mainly concentrated in Heilongjiang, Jilin, Liaoning, Henan and other places.

Features: The soybean planting volume of Heilongjiang is huge, the annual output of soybean meal is about 8 million tons, and the utilization of soybean skin is also gradually increasing.

White wine bad

Distribution area: mainly concentrated in Jiangsu, Sichuan, Anhui and other places.

Features: Liquor production in Jiangsu and Sichuan is developed, and the production of white wine grains can reach 3 million tons every year, with great potential for utilization.

Beer bad

Distribution area: mainly concentrated in Beijing, Shanghai, Tianjin, Guangdong and other places.

Features: These areas produce a large amount of beer, with an annual production of 2 million tons, mainly used for feed or fertilizer.

Citrus residue

Distribution area: mainly concentrated in Guangdong, Fujian, Guangxi, Sichuan and other places.

Features: Citrus planting in Guangdong and Fujian is large, and the annual citrus residue can reach 300,000 tons, and the utilization rate still needs to be improved.

Corn stalk and corn cob

Distribution area: mainly distributed in the Huang-Huai-Hai region, such as Henan, Shandong, Hebei, Jilin and other places.

Features: Henan and Shandong have a wide corn planting area, and the amount of corn straw produced every year can reach 53.26 million tons. The resource utilization of corn cob has gradually received attention.

Chinas agricultural organic waste presents diversified characteristics due to regional differences. The development degree of crops and aquaculture in different areas affects the production and utilization of organic waste. In the northern region, the production of straw is large, but due to the limitation of the technical level, the resource utilization still faces challenges.

6.3.3 Yield trend

In the past decade, Chinas crop straw output is stable at about 600 million tons per year. However, it will fluctuate in different years and regions, but the overall production remains at a high level. For example, in 2016, the theoretical production of crop straw in China was about 580 million tons, and about 600 million tons in 2020, and remained at the level of about 620 million tons in 2022.

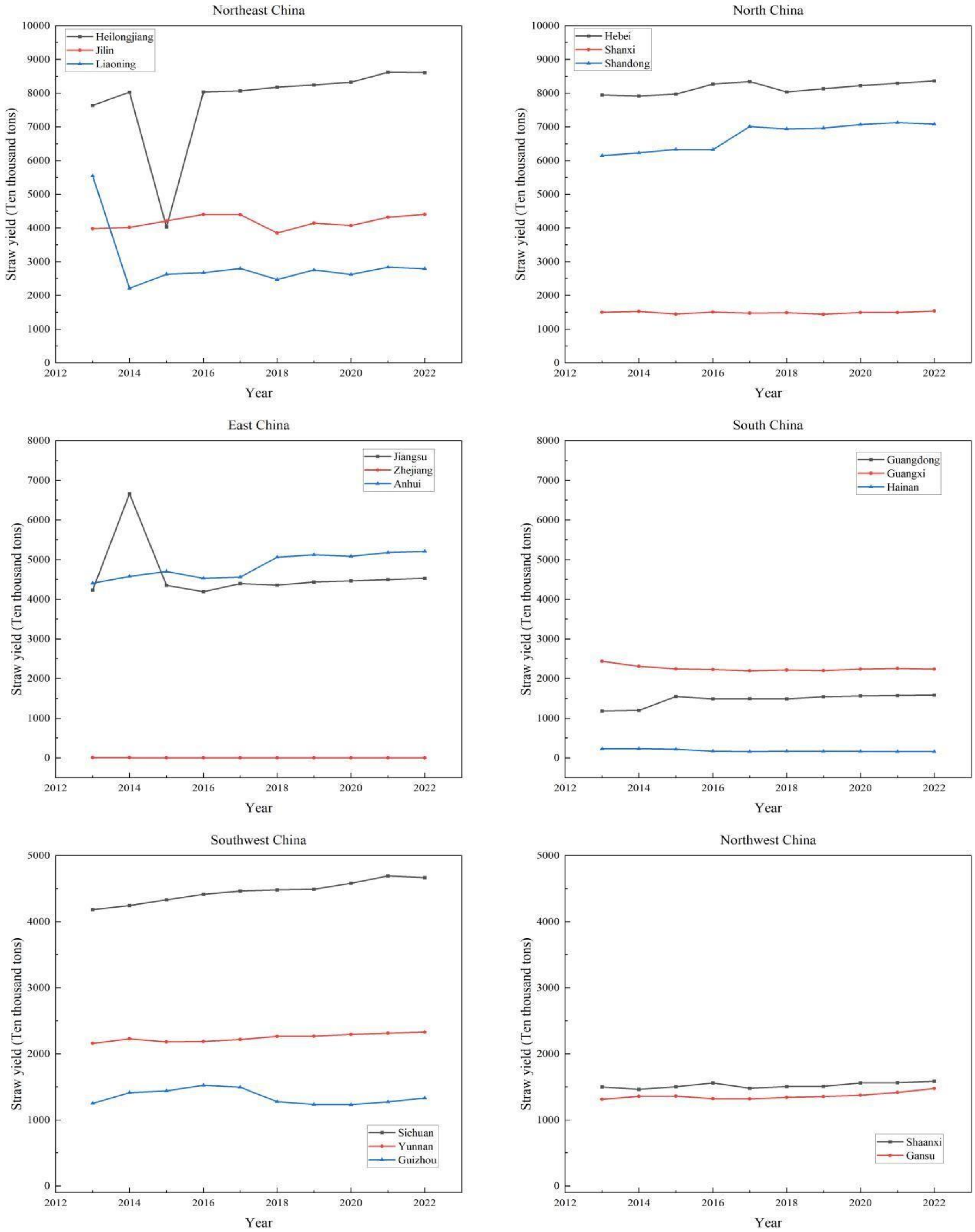

Figure 16: Annual change of straw yield in different regions (own compilation of BTBU).

In terms of distribution areas, the straw output in the middle and lower reaches of the Yangtze River and the Huang-Huai-Hai Plain is relatively high, accounting for about a quarter of the national output. The straw yield in northeast and southwest regions, northwest arid areas and Qinghai-Tibet Plateau areas is relatively small.

At the beginning of the 13th Five-Year Plan, China produced about 3.8 billion tons of livestock and poultry manure every year. In 2021, Chinas annual output of livestock and poultry manure dropped to 3.05 billion tons, down by 19.7 percent compared with 2015. Among them, from the perspective of livestock, the output of pig manure is the largest, and the annual output is about 1.8 billion tons, accounting for 47% of the total; the annual output of cattle manure is about 1.4 billion tons, accounting for 37% of the total, including 400 million tons and beef cattle 1 billion tons; the annual output of poultry manure is about 600 million tons, accounting for 16% of the total.

As an important oil crop in China, the annual output of peanut and peanut cake is relatively stable. Generally speaking, every ton of peanut oil produced produces about 0.5 tons of peanut cake meal.

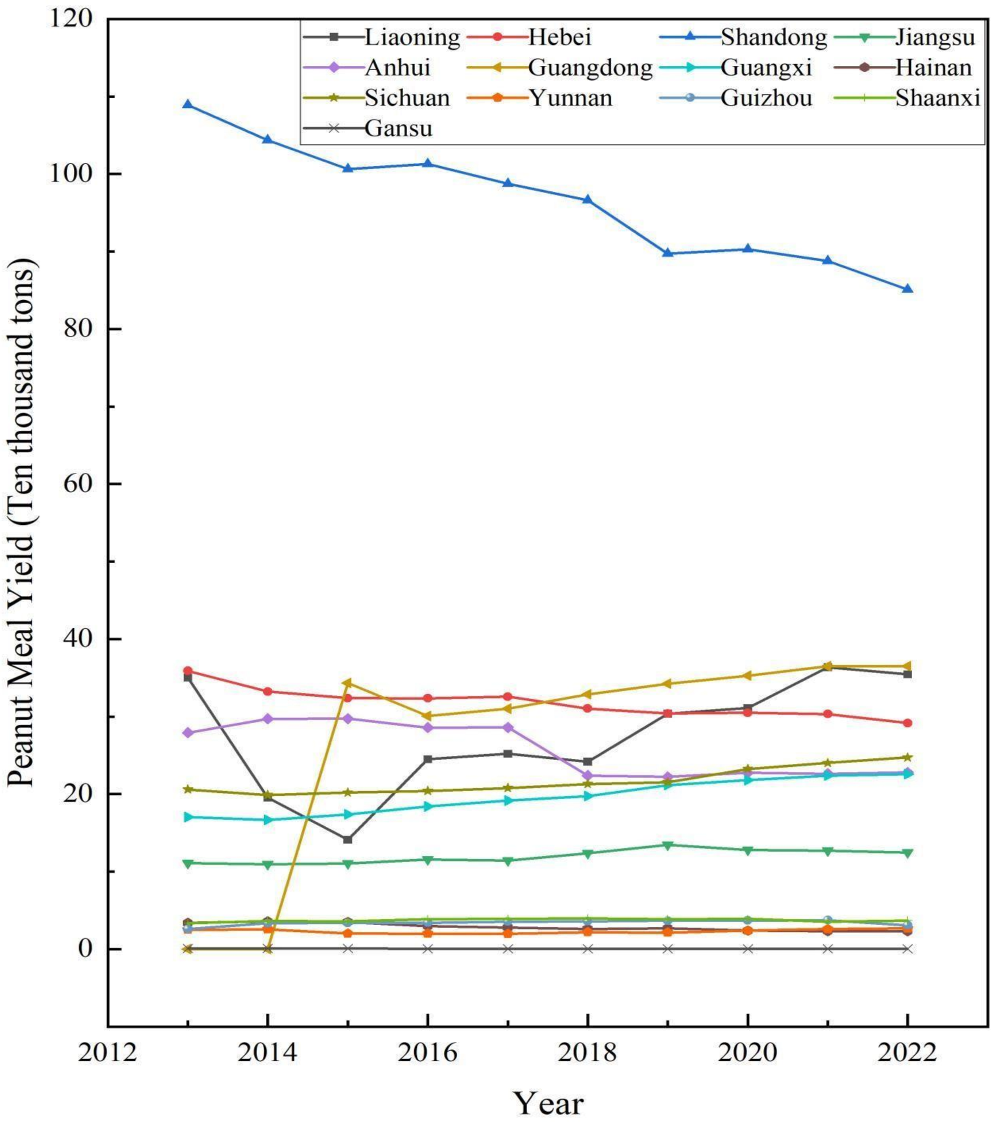

Figure 17: Annual change of peanut cake meal yield (own compilation of BTBU).

With the development of the potato starch processing industry, the skin residue and wastewater are also increasing. Potato starch processing enterprises are numerous, and the production process will produce a large number of waste water and skin slag, the amount of this part of the waste cannot be underestimated.

Of China's apple planting area ceaselessly with the development of apple juice industry, the amount of skin / slag in apple juice processing is also gradually increasing. In some major apple producing areas, apple juice processing plants can produce tens of thousands of tons of skin residue every year. China is the main consumer and importer of soybeans, and the soybean processing volume is huge, so the yield of soybean skin and soybean meal is also very high. In the past decade, with the increasing amount of soybean imports, the production of soybean skin and soybean meal also showed an upward trend. White wine grains, BSG, citrus residue: liquor and beer, as important alcoholic drinks in China, will produce a large number of wine grains in the production process. The increase of citrus planting area and the development of citrus processing industry also increase the amount of citrus residue.

Future prediction

High-value utilization

The high-value utilization of agricultural waste is one of the main trends of the future development. For example, corn cobs and straw are widely used in the production of bioenergy, biofertilizers, and biopackaging materials. In addition, the comprehensive utilization level of corn cob is constantly improved, and the utilization level of industrial raw materials can be effectively improved through the way of multi-product joint production.

Circular economy model

The recycling of agricultural waste is an effective way to achieve green, low-carbon and sustainable development. For example, apple residue can be converted into organic fertilizer and microbial fertilizer, while corn straw can be used for the base material of edible fungi and new energy utilization. This circular economy model not only reduces environmental pollution, but also improves the efficiency of resource utilization.

Policy support and technological innovation

The support of government policy and technological progress are the important factors to promote the utilization of agricultural waste resources. For example, the Ministry of Agriculture and Rural Affairs and the National Rural Revitalization Bureau issued the Typical Technical modes and Cases of Rural Organic Waste Resource Utilization to provide guidance for the harmless treatment and resource utilization of organic waste. In addition, the application of new technologies such as biological fermentation technology and microwave drying pretreatment technology also improves the efficiency of waste treatment.

Market demand is driven

With the enhancement of environmental awareness and the rise of green consumption, the market demand for agricultural waste is also increasing. For example, biofertilizers and bioenergy products are favoured by the market for their environmental characteristics. Soybean skin as a by-product, its market scale is expanding.

6.3.4 Current situation of waste utilization

1. The utilization status of crop straw

Straw returning to the field

Straw returning to the field is one of the main ways to use crop straw. By returning the straw to the field directly or after composting, the soil fertility can be increased, the soil structure can be improved, and the soil water and the soil fertilizer retention capacity can be improved. Returning straw to the field can also reduce the use of chemical fertilizer and reduce the cost of agricultural production. According to statistics, the annual straw return volume in China accounts for about 50% of the total straw production.

In the process of straw returning to the field, we should pay attention to the crushing degree, time and amount of straw returning. If the straw is not thoroughly crushed, it is easy to lead to poor soil permeability and affect the growth of crops; if the return time is improper, such as the return before sowing, it may affect the germination and emergence; if the return amount is too large, it may cause the imbalance of carbon and nitrogen ratio in the soil and affect the growth of crops.

Straw and feed

Crop straw can be used as livestock and poultry feed after proper treatment. Common straw feed treatment methods include silage, ammonification, microstorage and so on. Silage is the fresh straw chopped, put into the silo, compacted and sealed, after a period of fermentation, to make silage. Ammonization in the straw and ammonia or urea and other nitrogen substances mixed, in a certain temperature and humidity conditions, after a period of time reaction, made into ammonia feed. Microstorage is to mix straw with microbial starter, under a certain temperature and humidity conditions, after a period of fermentation, made into microstorage feed.

The utilization of straw feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of straw feed can also reduce the burning and waste of straw, to protect the environment. However, the nutritional value of straw feed is relatively low, and it needs to be used in combination with other feeds to meet the nutritional needs of livestock and poultry.

Straw energy source

Straw biogas:

Straw can be used as the raw material for biogas fermentation to produce biogas through the fermentation effect of biogas digester. Biogas is a clean energy source that can be used for cooking, lighting, heating, etc. The utilization of straw biogas can solve the problem of energy shortage in rural areas, and can also reduce the burning and waste of straw, and protect the environment.

In the process of straw biogas, attention should be paid to the construction and management of biogas digester. The construction of the biogas digester should conform to the specifications to ensure the sealing and safety of the biogas digester. At the same time, the biogas digester should be cleaned and maintained regularly to ensure the normal operation of the biogas digester.

Straw curing and molding fuel:

Straw curing molding fuel is a kind of solid fuel made of straw after crushing, compression and other processes. Straw curing molding fuel has the advantages of large density, small volume, easy storage and transportation, and can replace coal and other traditional energy sources, which can be used in rural home heating, industrial boilers and other fields.

The use of straw curing and molding fuel can reduce the dependence on traditional energy and reduce the energy cost. At the same time, the process of the combustion of straw curing molding fuel produces less pollutants and less pollution to the environment. However, the production process of straw curing and molding fuel needs to consume a certain amount of energy and cost, and also needs to solve the collection and transportation of straw problems.

Straw industrial raw materials

Straw paper:

Straw can be used as a raw material for paper making, through chemical or mechanical methods, the fiber in the straw is separated, made into paper. The utilization of straw paper making can reduce the dependence on traditional paper making materials such as wood and reduce the cost of paper making. At the same time, the process of straw papermaking produced less pollutants and less pollution to the environment.

However, the technical requirements of straw paper-making are relatively high, so it is necessary to solve the problems of straw collection, transportation, storage and so on. At the same time, the quality of straw papermaking products is relatively low and needs to be further improved.

Straw building materials

Straw can be used as raw materials for building materials, by mixing with other materials, made into straw boards, straw bricks and other building materials. Straw building materials have the advantages of heat insulation, heat insulation, sound insulation and other advantages, which can replace the traditional building materials, used in rural housing construction, urban construction and other fields.

The use of straw building materials can reduce the dependence on the traditional building materials and reduce the construction costs. At the same time, the production process of straw building materials produces less pollutants and less pollution to the environment. However, the technical requirements of straw building materials are high, which need to solve the collection, transportation, storage and other problems. At the same time, the product quality and performance of straw building materials also need to be further improved.

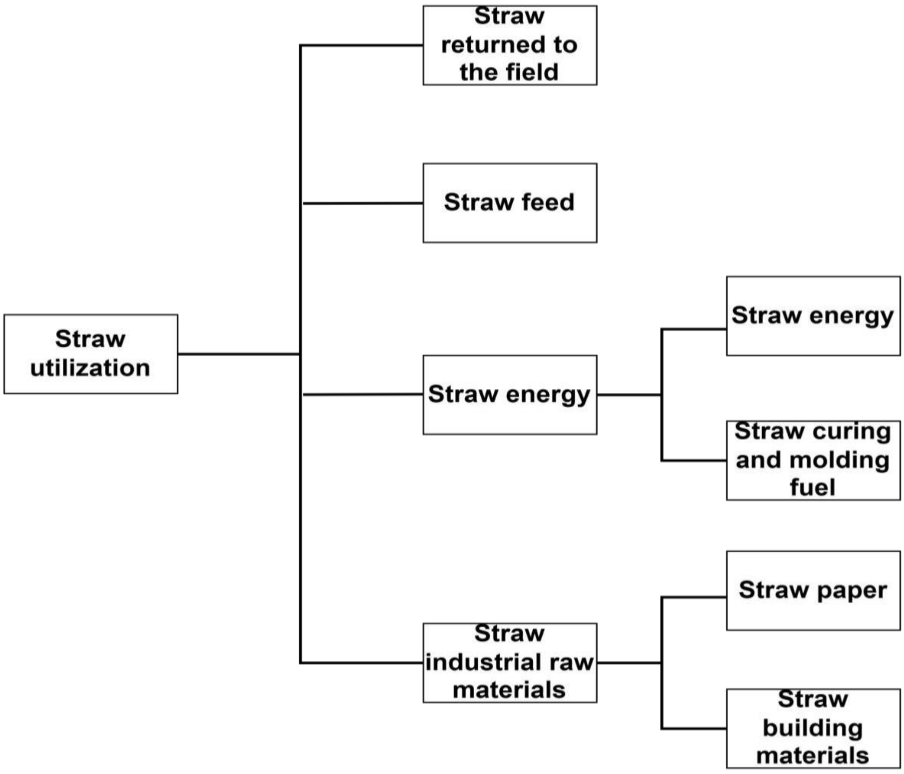

Figure 18: Stover utilization status (own compilation of BTBU).

2. The utilization status of livestock and poultry manure

Fertilizer utilization

Livestock and poultry manure can be used as organic fertilizer after fermentation and decay treatment. Organic fertilizer has the advantages of improving soil structure, improving soil fertility and promoting crop growth. It can replace traditional fertilizers such as chemical fertilizer and other fertilizers to reduce agricultural production costs. According to statistics, Chinas annual livestock and poultry manure fertilizer utilization accounts for about 60% of the total production of livestock and poultry manure.

In the process of fertilizer utilization of livestock and poultry manure, it is necessary to pay attention to the collection, treatment and storage of manure. The collection of feces should be timely and thorough, to avoid the loss and pollution of feces. The treatment of feces should adopt scientific methods, such as composting, fermentation, etc., to ensure the decay and safety of feces. The storage of feces should choose the appropriate location and way to avoid the secondary pollution of feces.

Energy source utilization

Biogas engineering:

Livestock and poultry manure can be used as the raw material for biogas fermentation, and biogas is produced through the fermentation effect of biogas digester. Biogas is a clean energy source that can be used for cooking, lighting, heating, etc. The utilization of biogas project can solve the problem of rural energy shortage, but also can reduce the pollution of livestock and poultry manure, and protect the environment.

In the construction and operation process of biogas project, it is necessary to pay attention to the construction and management of biogas digester, the collection and utilization of biogas. The construction of the biogas digester should conform to the specifications to ensure the sealing and safety of the biogas digester. At the same time, the biogas digester should be cleaned and maintained regularly to ensure the normal operation of the biogas digester. The collection and utilization of biogas should adopt scientific methods to ensure the purity and safety of biogas.

Biomass energy:

After drying and compression, livestock manure can be made into biomass pellet fuel or biomass pressure block fuel. Biomass energy has the advantages of being clean and renewable, which can replace coal and other traditional energy sources, used in rural home heating, industrial boilers and other fields.

The utilization of biomass energy can reduce the dependence on traditional energy sources and reduce energy costs. At the same time, the combustion process of biomass energy produces less pollutants and less pollution to the environment. However, the production process of biomass energy needs to consume a certain amount of energy and cost, but also need to solve the collection and transportation of livestock and poultry manure problems.

Feed utilization

Livestock and poultry manure can be used as feed after treatment. Common fecal feed treatment methods are drying, fermentation, etc. Dry is to remove the water from the feces and make a dry manure feed. Fermentation is the mixture of feces and other feed raw materials, after fermentation, made into fermented feed.

The utilization of fecal feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of fecal feed can also reduce the pollution of feces and protect the environment. However, the nutritional value of fecal feed is relatively low, and it needs to be used in combination with other feed to meet the nutritional needs of livestock and poultry. At the same time, the safety of fecal feed also needs to be further improved to avoid the impact of harmful substances in feces on the health of livestock and poultry.

3. Utilization status of agricultural products processing waste

The utilization status of peanut cake meal and red clothes

Feed utilization:

Peanut cake meal is rich in protein, fat and other nutrients, which can be used as raw materials for livestock and poultry feed. Peanut cake meal and red meal after crushing, fermentation and other treatment, can be made into peanut cake meal feed or red meal feed.

The utilization of peanut cake meal feed and red coat feed

The utilization of peanut cake meal feed and red coat feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of peanut cake meal feed and red feed can also reduce the pollution of peanut processing waste and protect the environment.

Fertilizer utilization:

Peanut cake meal and red coat can be used as organic fertilizer after fermentation and ripening. Peanut cake meal and red-coat organic fertilizer have the advantages of improving soil structure, improving soil fertility and promoting crop growth. They can replace traditional fertilizers such as chemical fertilizers and reduce agricultural production costs.

<u>The utilization status of potato starch processing skin residue / wastewater</u>

Feed utilization:

Potato starch processing skin residue is rich in starch, protein and other nutrients, which can be used as raw materials for livestock and poultry feed. Potato starch processing skin residue after drying, crushing and other treatment, can be made into potato starch processing skin slag feed.

The utilization of potato starch processing slag feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of potato starch processing slag feed can also reduce the pollution of potato processing waste and protect the environment.

Fertilizer utilization:

Potato starch processing wastewater can be used as an organic fertilizer after treatment. The wastewater of potato starch processing and organic fertilizer has the advantages of improving soil structure, improving soil fertility and promoting crop growth. It can replace traditional fertilizers such as chemical fertilizers and reduce agricultural production costs.

<u>The utilization status of the skin / slag for apple juice processing</u>

Feed utilization:

The skin and residue processed by apple juice are rich in dietary fibre, vitamins and other nutrients, which can be used as raw materials for livestock and poultry feed. Apple can be made into apple juice after drying and crushing the skin and slag.

The utilization of apple juice processing slag feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of apple juice processing slag feed can also reduce the pollution of apple processing waste and protect the environment.

Fertilizer utilization:

The skin and residue processed by apple juice can be used as organic fertilizer after fermentation and decay treatment. Organic fertilizer for apple juice processing has the advantages of improving soil structure, improving soil fertility and promoting the growth of crops. It can replace traditional fertilizers such as chemical fertilizers and reduce the cost of agricultural production.

<u>The utilization status of soybean skin and soybean meal</u>

Feed utilization:

Soybean skin and soybean meal are rich in protein, fat and other nutrients, which can be used as raw materials for livestock and poultry feed. Soybean skin and soybean meal after crushing, fermentation and other treatment, can be made into soybean skin feed or soybean meal feed.

The utilization of soybean skin feed and soybean meal feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of soybean skin feed and soybean meal feed can also reduce the pollution of soybean processing waste and protect the environment.

Fertilizer utilization:

Soybean skin and soybean meal can be used as organic fertilizer after fermentation and decay treatment. Soybean skin and soybean meal organic fertilizers have the advantages of improving soil structure, improving soil fertility and promoting crop growth. They can replace traditional fertilizers such as chemical fertilizers and reduce agricultural production costs.

<u>The utilization status of white wine grains and beer</u>

Feed utilization:

White wines grains and beer grains are rich in protein, fat and other nutrients, which can be used as raw materials for livestock and poultry feed. White grains and beer grains after drying, crushing and other processing, can be made into white grains feed or beer grains feed.

The utilization of white liquor feed and beer feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of white wine feed and beer wine feed can also reduce the pollution of brewing waste and protect the environment.

Fertilizer utilization:

White distillers grains and beer grains can be used as organic fertilizer after fermentation and decay. Organic fertilizer of white wines grains and beer grains has the advantages of improving soil structure, improving soil fertility and promoting crop growth. It can replace traditional fertilizers such as chemical fertilizers and reduce agricultural production costs.

<u>The utilization status of citrus residue</u>

Feed utilization:

Citrus residue is rich in dietary fibre, vitamins and other nutrients, which can be used as raw materials for livestock and poultry feed. Citrus residue after drying, crushing and other treatment, can be made into citrus residue feed.

The utilization of citrus residue feed can alleviate the shortage of feed resources in China and reduce the cost of livestock and poultry breeding. At the same time, the use of citrus residue feed can also reduce the pollution of citrus processing waste and protect the environment.

Fertilizer utilization:

Citrus residue can be used as organic fertilizer after fermentation and decay treatment. Organic fertilizer of citrus residue has the advantages of improving soil structure, improving soil fertility and promoting the growth of crops. It can replace traditional fertilizers such as chemical fertilizers and reduce agricultural production costs.

Energy utilization:

Citrus residue can be used as a raw material for biomass energy sources. Citrus residue can be processed into biomass pellet fuel after being dried, compressed or biomass pressing fuel.

The utilization of biomass energy can reduce the dependence on traditional energy sources and reduce energy costs. At the same time, the combustion process of biomass energy produces less pollutants and less pollution to the environment. However, the production process of biomass energy needs to consume a certain amount of energy and cost, but also needs to solve the problems of the collection and transportation of citrus residue.

The utilization status of agricultural organic waste in China is diversified. Crop straw is mainly used by returning, feed, energy and industrial raw materials; Livestock and poultry manure is mainly used by fertilizer, energy and feed, and according to different types. To a certain extent, these utilization methods reduce the pollution of agricultural organic waste to the environment, realize the recycling of resources, and also provide a new way for agricultural production and rural economic development.

However, there are still some problems in the utilization of agricultural organic waste in China, such as low technical level, insufficient policy support and imperfect market mechanism. In order to further improve the utilization level of agricultural organic waste, it is necessary to strengthen technology research and development and promotion, increase policy support, improve the market mechanism, and improve farmers awareness of environmental protection and resource recycling. Only in this way, can we realize the efficient utilization of agricultural organic waste and promote the sustainable development of agriculture.

6.4 Treatment cost analysis

6.4.1 Cost analysis of crop straw treatment

1. Cost of collection

Cost of manual collection

The labour collection cost of crop straw mainly includes the labour cost and the tool cost. Generally speaking, the labour cost of manual straw collection is about 100-150 yuan per person per day, and the cost of tools such as sickle and rake is about 50-100 yuan per set. If the amount of straw collected per person per day, the labour collection cost is about 150-250 yuan per mu.

Mechanical collection cost

The cost of mechanical straw collection mainly includes equipment purchase cost, fuel oil cost, maintenance cost and labour cost. Take the straw baler as an example, the price of a medium-sized straw baler is about 100,000-200,000 yuan, and its service life is about 5-8 years. If 1,000 mu of straw is collected every year, the equipment purchase cost is apportioned to about 20-40 yuan per mu of land. The fuel cost is about 20-30 yuan per mu, the maintenance cost is about 10-20 yuan per mu, and the labour cost is about 30-50 yuan per mu. Therefore, the cost of mechanical straw collection is about 80-140 yuan / mu.

2. Transportation cost

Short distance transportation cost

If straw is collected and transported to nearby processing plants or breeding farms, short-distance transportation costs mainly include vehicle purchase costs, fuel costs, maintenance costs and labour costs. Take a minivan as an example, the purchase cost of the vehicle is about 50,000-100,000 yuan, and the service life is about 5-8 years. If the straw of 1,000 mu of land is transported every year, the vehicle purchase cost is apportioned to about 10-20 yuan per mu of land. The fuel cost is about 10-20 yuan per mu, the maintenance cost is about 5-10 yuan per mu, and the labour cost is about 10-20 yuan per mu.

Therefore, the cost of short-distance straw transportation is about 35-70 yuan / mu.

Cost of long-distance transportation

If the straw needs to be transported to distant areas for processing or utilization, the long-distance transportation cost will be even higher. Long-distance transportation costs mainly include vehicle purchase cost, fuel cost, tolls, maintenance cost and labour cost. Take a medium truck as an example, the purchase cost of the vehicle is about 200,000-300,000 yuan, and the service life is about 5-8 years. If the transportation of 1000 mu of straw every year, the vehicle purchase cost is apportioned to about 40-60 yuan per mu of land. The fuel cost is about 30-50 yuan per mu of land, the toll is about 20-30 yuan per mu, the maintenance cost is about 15-25 yuan per mu, and the labour cost is about 30-50 yuan per mu. Therefore, the cost of long-distance transportation of straw is about 135-215 yuan / mu.

3. Treatment cost

The cost of returning straw to the field

The cost of straw returning mainly includes the cost of mechanical operation and fertilizer cost. The mechanical operation cost is about 30-50 yuan per mu, and the fertilizer cost is about 20-30 yuan per mu. Therefore, the cost of returning to the field of straw is about 50-80 yuan / mu.

Straw feed change cost

The cost of straw feed mainly includes mechanical processing cost, additive cost and storage cost. The machining cost is about 50-80 per yuan / mu, the additive cost is about 20-30 yuan per mu, and the storage cost is about 10-20 yuan / mu.

Therefore, the cost of straw feed is about 80-130 yuan / mu.

Straw energy conversion cost

The cost of straw energy conversion mainly includes mechanical processing cost, equipment purchase cost and operation cost. Take straw curing and forming fuel as an example, the mechanical processing cost is about 80-120 yuan per mu of land, the equipment purchase cost is about 500-800 yuan per ton of fuel, and the operation cost is about 200-300 yuan per ton of fuel. If the straw yield per mu of land is 0.5 tons, the equipment purchase cost and operation cost will be allocated to about 350-650 yuan per mu. Therefore, the cost of straw energy is about 430-770 yuan / mu.

Straw industrial raw material cost

The cost of straw industrial raw material mainly includes mechanical processing cost, transportation cost and production cost. Take straw paper as an example, the mechanical processing cost is about 100-150 yuan per mu of land, the transportation cost is about 50-100 yuan per mu, and the production cost is about 1000-1500 yuan per ton of paper. If the straw yield per mu of land is 0.5 tons, the production cost is allocated to about 500-750 yuan per mu. Therefore, the cost of straw industrial raw materials is about 650-1000 yuan / mu.

TABLE 6: Summary table of crop straw treatment cost (own compilation of BTBU).

Process mode	Collection cost (Yuan / mu)	Transportation cost (Yuan / mu)	Treatment cost (Yuan / mu)	Total cost (Yuan / mu)
Manual collection + short-distance transportation + straw returning to the field	150-250	35-70	50-80	235-400
Mechanical collection + short-distance transportation + straw returning to the field	80-140	35-70	50-80	165-290
Manual collection + long-distance transportation + straw returning to the field	150-250	135-215	50-80	335-545
Mechanical collection + long-distance transportation + straw returning to the field	80-140	135-215	50-80	265-435
Manual collection + short-distance transportation + straw feed conversion	150-250	35-70	80-130	265-450
Mechanical collection + short-distance transportation + straw feed conversion	80-140	35-70	80-130	195-340
Manual collection + long-distance transportation + straw feed change	150-250	135-215	80-130	365-695
Mechanical collection + long-distance transportation + straw feed change	80-140	135-215	80-130	345-485
Manual collection + short-distance transportation + straw energy conversion	150-250	35-70	430-770	615-1090

Mechanical collection + short-distance transportation + straw energy conversion	80-140	35-70	430-770	545-980
Manual collection + long-distance transportation + straw energy conversion	150-250	135-215	430-770	715-1235
Mechanical collection + long-distance transportation + straw energy conversion	80-140	135-215	430-770	645-1125
Manual collection + short-distance transportation + straw industrial raw materials	150-250	35-70	650-1000	835-1320
Mechanical collection + short-distance transportation + straw industrial raw materials	80-140	35-70	650-1000	765-1210
Manual collection + long-distance transportation + straw industrial raw materials	150-250	135-215	650-1000	935-1515
Mechanical collection + long-distance transportation + straw industrial raw materials	80-140	135-215	650-1000	865-1355

6.4.2 Analysis of livestock and poultry manure treatment cost

1. **Cost of collection**

Cost of manual collection

The cost of labour collection mainly includes labour cost and tool cost. Generally speaking, the labour cost of manual collection of livestock manure is about 100-150 yuan per person per day, and the cost of tools such as shovels and carts is about 50-100 yuan per set. If 10 cubic meters of livestock manure are collected per person per day, the manual collection cost is about 10-15 yuan / cubic meter.

Mechanical collection cost

The cost of mechanical collection of livestock manure mainly includes equipment purchase cost, fuel cost, maintenance cost and labour cost. Take a dung suction truck as an example, the price of a medium-sized dung suction truck is about 150,000-250,000 yuan, and the service life is about 5-8 years. If 10,000 cubic meters of livestock and poultry manure are collected every year, the cost of equipment purchase is allocated to about 2-4 yuan per cubic meter. Fuel cost is about 2-3 yuan per cubic meter, maintenance cost is about 1-2 yuan per cubic meter, and labour cost is about 2-3 yuan per cubic meter. Therefore, the cost of mechanical collection of livestock manure is about 7-12 yuan / cubic meter. two 、transportation cost

2. **Transportation cost**

Short distance transportation cost

If livestock and poultry manure is collected and transported to nearby processing plants or farmland, short-distance transportation costs mainly include vehicle purchase costs, fuel costs, maintenance costs and labour costs. Take a minivan as an example, the purchase cost of the vehicle is about 50,000-100,000 yuan, and the service life is about 5-8 years. If 10,000 cubic meters of livestock manure is transported every year, the vehicle purchase cost is allocated to about 1-2 yuan per cubic meter. The fuel cost is about 1-2 yuan per cubic meter, the maintenance cost is about 0.5-1 yuan per cubic meter, and the labour cost is about 1-2 yuan per cubic meter. Therefore, the cost of short-distance transportation of livestock manure is about 3.5 – 7 yuan / cubic meter.

Cost of long distance transportation

If livestock manure needs to be transported to distant areas for treatment or utilization, long-distance transportation costs will be higher. Long-distance transportation costs mainly include vehicle purchase cost, fuel cost, tolls, maintenance cost and labour cost. Take a medium truck as an example, the purchase cost of the vehicle is about 200,000-300,000 yuan, and the service life is about 5-8 years. If 10,000 cubic meters of livestock manure is transported every year, the vehicle purchase cost is shared to about 4-6 yuan per cubic meter. The fuel cost is about 3-5 yuan per cubic meter, the toll is about 2-3 yuan per cubic meter, the maintenance cost is about 1.5-2.5 yuan per cubic meter, and the labour cost is about 3-5 yuan per cubic meter. Therefore, the cost of long-distance transportation of livestock manure is about 14-21 yuan / cubic meter.

3. Treatment cost

Treatment cost Fertilizer treatment cost

The cost of fertilizer treatment of livestock manure mainly includes fermentation cost, packaging cost and storage cost. The fermentation cost is about 20-30 yuan per cubic meter, the packaging cost is about 10-20 yuan per cubic meter, and the storage cost is about 5-10 yuan per cubic meter. Therefore, the cost of livestock manure fertilizer treatment is about 35-60 yuan / cubic meter.

Energy-processing costs

The cost of energy treatment of livestock and poultry manure mainly includes fermentation cost, equipment purchase cost and operation cost. Take the biogas project as an example, the fermentation cost is about 30-50 yuan per cubic meter, the equipment purchase cost is about 100-150 yuan per cubic meter, and the operation cost is about 20-30 yuan per cubic meter. Therefore, the cost of energy treatment of livestock and poultry manure is about 150-230 yuan / cubic meter.

Feed-based treatment cost

The cost of feed treatment of livestock manure mainly includes drying cost, disinfection cost and packaging cost. The drying cost is about 50-80 yuan per cubic meter, the disinfection cost is about 10-20 yuan per cubic meter, and the packaging cost is about 10-20 yuan per cubic meter. Therefore, the cost of livestock and poultry manure feed treatment is about 70-120 yuan / cubic meter.

Table 7: Summary table of livestock and poultry manure treatment costs (own compilation of BTBU).

Process mode	Collection cost (Yuan / mu)	Transportation cost (Yuan / mu)	Treatment cost (Yuan / mu)	Total cost (Yuan / mu)
Manual collection + short-distance transportation + fertilizer treatment	10-15	3.5-7	35-60	48.5-82
Mechanical collection + short-distance transportation + fertilizer treatment	7-12	3.5-7	35-60	45.5-79
Manual collection + long-distance transportation + fertilizer treatment	10-15	14-21	35-60	59-96
Mechanical collection + long-distance transportation + fertilizer treatment	7-12	14-21	35-60	56-93
Manual collection + short-distance transportation + energy-based treatment	10-15	3.5-7	150-230	163.5-252

Mechanical collection + short-distance transportation + energy-based treatment	7-12	3.5-7	150-230	160.5-249
Manual collection + long-distance transportation + energy-based treatment	10-15	14-21	150-230	174-266
Mechanical collection + long-distance transportation + energy-based treatment	7-12	14-21	150-230	171-263
Manual collection + short-distance transport + feed chemical treatment	10-15	3.5-7	70-120	83.5-142
Mechanical collection + short-distance transport + feed chemical treatment	7-12	3.5-7	70-120	80.5-139
Manual collection + long-distance transportation + feed treatment	10-15	14-21	70-120	94-156
Mechanical collection + long-distance transportation + feed treatment	7-12	14-21	70-120	91-153

6.4.3 Cost analysis of agricultural products processing waste treatment

1. Cost analysis of peanut cake meal and red coat treatment

Collect the cost

The collection cost of peanut cake meal and red coat mainly includes labour costs and transportation costs. Generally speaking, the labour cost of collecting peanut cake meal and red clothes is about 100-150 yuan per person per day, and the transportation cost is about 50-100 yuan per ton. If 1 ton of peanut cake meal and red coat is collected per person per day, the collection cost is about 150-250 yuan per ton.

Transportation cost

If peanut cake meal and red clothes need to be shipped to processing plants or farms, transportation costs mainly include vehicle purchase costs, fuel costs, maintenance costs and labour costs. Take a minivan as an example, the purchase cost of the vehicle is about 50,000-100,000 yuan, and the service life is about 5-8 years. If 1,000 tons of peanut cake meal and red clothes are transported every year, the vehicle purchase cost is apportioned to about 10-20 yuan per ton. The fuel cost is about 20-30 yuan per ton, the maintenance cost is about 10-20 yuan per ton, and the labour cost is about 10-20 yuan per ton. Therefore, the cost of transporting peanut cake meal and red coat is about 50-90 yuan / ton.

Treatment cost

Cost of electrochemical feed treatment

The cost of peanut cake meal and red feed treatment mainly includes mechanical processing cost, additive cost and storage cost. The machining cost is about 50-80 yuan per ton, the additive cost is about 20-30 yuan per ton, and the storage cost is about 10-20 yuan per ton. Therefore, the cost of peanut cake meal and red feed treatment is about 80-130 yuan / ton.

Cost of fertilizer treatment

The cost of peanut cake meal and red coat fertilizer treatment mainly includes fermentation cost, packaging cost and storage cost. The fermentation cost is about 30-50 yuan per ton, the packaging cost is about 10-20 yuan per ton, and the storage cost is about 10-20 yuan per ton. Therefore, the cost of peanut cake meal and red coat fertilizer treatment is about 50-90 yuan / ton.

Table 8: Summary table of the cost of peanut cake meal and red coat treatment (own compilation of BTBU).

Process mode	Collection cost (Yuan / mu)	Transportation cost (Yuan / mu)	Treatment cost (Yuan / mu)	Total cost (Yuan / mu)
Feed treatment	150-250	50-90	80-130	280-470
Fertilizer treatment	150-250	50-90	50-90	250-430

2. Analysis of treatment cost of potato starch processing skin slag / wastewater

<u>Collection cost:</u>

Labor cost: In the starch processing plant, workers need to collect the skin residue from the production line and place it to the designated place for subsequent transportation. If the factory is small and the amount of skin slag produced is relatively small per day, only 1-2 workers may be required to collect it.

According to the 8 hours per day and the salary of 20-30 yuan per hour, the daily labour collection cost is about 40-240 yuan. For large starch processing plants, due to the large amount of skin slag production, it may need 5-10 workers or even more, and the daily labour collection cost will increase significantly, which may reach thousands of yuan.

Container and tool cost: Skin residue collection requires the use of suitable containers, such as plastic buckets, carts, etc. The price of ordinary plastic buckets ranges from 50-200 yuan, and the price of carts is about 300-1000 yuan. According to the production scale and collection demand of the factory, it needs to be equipped with a certain number of containers and carts, and the one-time investment cost is about between thousands of yuan and tens of thousands of yuan. In addition, some shovels, brooms and other tools are needed to clean up the skin slag. The costs of these tools are relatively low, but they also need to be replaced regularly, and the annual cost is about hundreds of yuan to thousands of yuan.

Cost of lease or purchase of the transport equipment (if collected): if the factory chooses to transport the slag itself, it needs to purchase or lease the transport vehicle. The rental cost of a small pickup truck is about 200-500 yuan per day, and a purchase costs tens of thousands to a hundred thousand yuan; the rental cost of a medium pickup truck is about 500-1000 yuan per day, and a purchase may need hundreds of thousands of yuan. For large starch processing plants, multiple transport vehicles may be needed, which will cost more. transportation cost:

Fuel cost: The vehicle that carries the waste consumes fuel, and the amount of fuel cost depends on the transportation distance, vehicle fuel consumption, and fuel price. Take a medium-sized truck as an example, the fuel consumption per 100 kilometres is about 20-30 litres. According to the diesel price of 7-8 yuan per litre, the fuel cost per 100 kilometres is 140-240 yuan. If the transportation distance is 100 kilometres, the round-trip fuel cost is

280-480 yuan. If the transportation frequency is high, the monthly fuel cost may be between thousands and tens of thousands of yuan.

Vehicle maintenance costs: transport vehicles need regular maintenance, including oil replacement, tires, brake pads, etc. The annual maintenance cost of a medium-sized truck is about 10,000-20,000 yuan, and the annual maintenance cost of a small pickup truck is about 5,000-10,000 yuan. If the vehicle is used more frequently, the maintenance cost will increase accordingly.

Road toll: If the transport route involves expressway, bridge and other toll sections, also need to pay the road toll. Depending on different regions and toll standards, the cost of each passage may vary from tens of yuan to hundreds of yuan. If the transport frequency is high, the monthly road toll is also not a small expense.

<u>Treatment cost: Slag treatment cost:</u>

Compost treatment: compost treatment is a common treatment method, which can be converted into organic fertilizer. The composting process needs to occupy a certain amount of space, and the rental cost of the site is about 1000-3000 yuan per mu per year. Compost also needs to add some accessories, such as straw, rice husk, etc., to adjust the carbon and nitrogen ratio, the cost of these accessories is about 200-500 yuan per ton. In the process of composting, ventilation and ventilation operations, which requires a certain amount of labour and equipment costs. The labour cost is about 200-500 yuan per day, and the equipment rental cost is about 300-800 yuan per day. The total cost of compost treatment is about 500-1,000 yuan per ton.

Feed processing: processing the skin slag into feed is also a feasible way of treatment. Feed processing needs special equipment, such as grinder, mixer, dryer, etc. The price of these equipment is about 100,000-500,000 yuan. In addition, it is still necessary to add some nutritional additives, such as protein, vitamin, this part cost is about 300-500 yuan per ton. The total cost of feed processing is about 800-1,500 yuan per ton.

<u>Wastewater treatment cost:</u>

Physical treatment: physical treatment methods mainly include precipitation, filtration, etc. The precipitation process requires the construction of the sedimentation tank, and the construction cost is determined according to the scale and material of the sedimentation tank. Generally, the construction cost per cubic meter is 1000-3000 yuan. The price of filtration equipment is determined according to the filtration accuracy and processing capacity, generally ranging from 50,000 to 200,000 yuan. In the process of physical treatment, a certain amount of electricity and water resources are consumed, and the treatment cost of each ton of wastewater is about 2-5 yuan.

Chemical treatment: chemical treatment methods mainly include adding agents for flocculation, precipitation, etc. The cost of the agent is about 10-30 yuan per ton. The specific cost depends on the type and dosage of the agent. The chemical treatment process also needs to consume a certain amount of electricity and water resources, and the treatment cost of each ton of wastewater is about 3-8 yuan.

Biological treatment: The biological treatment method is to use microorganisms to degrade the organic matter in the wastewater. Biological treatment requires the construction of biological reaction pool, and the construction cost is 2000-5000 yuan per cubic meter. In addition, it also needs to cultivate and maintain microorganisms, which requires certain technical and human costs, and is about 5-10 yuan per ton of wastewater treatment cost.

Table 9: Cost table of medium-sized potato starch processing plant (own compilation of BTBU).

Processing link	Cost project	Cost range (Yuan / month)
collect	labour cost	5000-10000
	Container and tool costs	500-2000
	Transportation equipment (if collected and transported independently) Depreciation or lease expense	5000-15000
transport	Fuel costs	8000-20000
	Vehicle maintenance costs	3000-5000
	Road tolls	1000-3000
Skin lag treatment (compost)	Site lease fee	3000-5000
	Costs of accessories	5000-10000
	Labor and equipment costs	10000-20000
Skin residue treatment (feed processing)	Equipment depreciation or leasing expense	8000-15000
	Nutritional additive cost	3000-5000
Wastewater treatment (Physical treatment)	Precipitation tank construction and equipment depreciation costs	10000-20000
	Electricity and water resource costs	3000-5000
Wastewater treatment	The cost of pharmacy	5000-10000

(chemical treatment)	Electricity and water resource costs	5000-8000
Wastewater treatment **(biological treatment)**	Biological reaction tank construction and equipment depreciation costs	15000-30000
	Microbiological culture and maintenance costs	8000-15000

3. Analysis of skin / slag treatment cost for apple juice processing

Collection costs

Labor costs: Apple juice mills usually need to arrange workers to collect the skin / slag. Considering the amount of skin / slag production and the difficulty of collection, 2-3 workers are generally required. Assuming that each person is paid 150 yuan per day, the daily labour cost is 300-450 yuan. If calculated by the processing of 10 tons of apple juice per day, the labour collection cost per ton of skin / slag is about 30-45 yuan.

Cost of tools and containers: collecting skins / slag requires tools such as shovels, brooms, etc. and containers such as plastic buckets and carts. The cost of a set of tools is about 100 yuan, which can be used for a long time, and the cost of each ton of skin / slag is about 10 yuan. The price of each plastic bucket is between 30-50 yuan, assuming that each barrel can hold 50 kg leather / slag, then each ton of leather per slag needs 20 barrels, the cost is about 600-1000 yuan, that is, the container cost per ton of leather / slag is about 60-100 yuan.

Transportation costs

Vehicle rental or purchase cost: If you choose the rental vehicle for transportation, the rental cost of a minivan is about 300-500 yuan per day. Assuming that 10 tons of leather / slag are transported per day, the vehicle rental cost of each ton is about 30-50 yuan. If you buy a minivan, the price is about 50,000-800,000 yuan, the service life is 5 years, and the annual transportation is 300 days, then the annual depreciation cost of the vehicle is about 3333-5333 yuan, the daily cost is about 11-18 yuan, and the depreciation cost of each ton of leather / slag is about 1.1-1.8 yuan.

Fuel cost: The fuel consumption of a minivan is about 10-15 liters per 100 kilometers. Assuming that the price of diesel is 7 yuan / liter and the transportation distance is 50 kilometers, the fuel cost for each trip is about 35-52.5 yuan. For two trips a day, the fuel cost per ton of skin / slag is about 3.5-5.25 yuan.

Road toll: If the transport route involves the expressway or toll section, each toll fee may be between 20-50 yuan. Assuming two trips a day, the road cost per ton of skin / slag is about 2-5 yuan.

Treatment costs

Compost treatment: the lease of the composting site is about 1500-2500 yuan per mu per year. Assuming that the composting site area is 1 mu and can handle 100 tons of leather / slag, then the site rental cost per ton of leather / slag is about 15-25 yuan. In the process of composting, it needs to be added some accessories, such as straw, rice husk, etc. The cost of accessories per ton of skin / slag is about 50-80 yuan. Compost also needs to dump, ventilation and other operations, labour costs and equipment costs are about 80-120 yuan per ton. Therefore, the cost of composting per ton of skin / slag is about 145-225 yuan.

Extract pectin and other ingredients: extract pectin and other ingredients need to buy special equipment. The equipment price is about 50 0,000-1 million yuan. Assuming that the service life of the equipment is 10 years and 1000 tons of leather / slag are treated per year, the annual depreciation cost of equipment is about 5000-10000 yuan, and the depreciation cost of equipment per ton of leather / slag is about 5-10 yuan. The extraction process also needs to consume chemical reagents, energy, etc., the cost per ton of skin / slag is about 100-150 yuan. Therefore, the processing cost of extracting pectin and other components per ton of skin / slag is about 105-160 yuan.

Table 10: Summary of skin / slag treatment costs for apple juice processing (own compilation of BTBU).

Cost project	**Cost range (RMB / ton)**
Collection cost (labour + tool container)	90-155
Transportation costs (vehicle + fuel +tolls)	36.6-56.85
Compost treatment cost	145-225
Treatment cost of components such as pectin extraction	105-160

4. Analysis of soybean peel and soybean meal treatment costs

Collection costs

Labor cost: The labour cost of collecting soybean skin and meal from soybean in the soybean processing plant is relatively low, assuming that the labour cost of 10-20 yuan per ton is required.

Packaging cost: use woven bags for packaging, the price of each woven bag is 2-3 yuan, assuming that 10 woven bags per ton, then the packaging cost per ton is about 20-30 yuan.

Transportation costs

Vehicle rental or purchase cost: minivan rental is about 200-300 yuan per day, assuming that 10 tons of soybean skin and soybean meal are transported per day, the vehicle rental cost is about 20-30 yuan per ton. If you buy a minivan, the price is about 50,000-80,000 yuan, the service life is 5 years, and the annual transportation is 300 days, then the annual depreciation cost of vehicles is about 3333-5333 yuan, the daily cost is about 11-18 yuan, and the depreciation cost of vehicles per ton of soybean skin and soybean meal is about 1.1-1.8 yuan.

Fuel cost: The fuel consumption of a minivan is about 10-15 litres per 100 kilometres. Assuming that the price of diesel is 7 yuan / litre and the transportation distance is 50 kilometres, the fuel cost for each trip is about 35-52.5 yuan. Two trips a day, the fuel cost of each ton of soybean skin and soybean meal is about 3.5-5.25 yuan.

Road toll: Suppose the road toll per ton of soybean skin and soybean meal is about 2-3 yuan.

Treatment costs

Feed processing: buy feed processing equipment, the price is about 100-200,000 yuan. Assuming that the service life of equipment is 10 years and 1000 tons of soybean skin and soybean meal are processed annually, the annual depreciation cost of equipment is about 1000-2000 yuan, and the depreciation cost of equipment per ton is about 1-2 yuan. Some nutritional additives also need to be added in the processing process, and the cost per ton is about 50-80 yuan. Labor costs and energy consumption are about 50-80 yuan per ton. Therefore, the feed processing cost per ton of soybean skin and soybean meal is about 101-162 yuan.

Fertilizer processing: fertilizer processing needs fermentation and other treatment, and the equipment input is relatively low, assuming that the depreciation cost per ton of equipment is about 5-10 yuan. Some accessories need to be added in the fermentation process, and the cost is about 30-5 yuan per ton. Labor costs and energy consumption are about 40-60 yuan per ton. Therefore, the fertilizer processing cost per ton of soybean skin and soybean meal is about 75-120 yuan.

Table 11: Summary table of the cost of soybean peel and soybean meal treatment (own compilation of BTBU).

Cost project	Cost range (RMB / ton)
Collection cost (labour + packaging)	30-50
Transportation costs (vehicle + fuel + tolls)	26.6-35.05
Feed processing cost	101-162
Fertilizer processing cost	75-120

5. Cost analysis of white wine grains processing

Collection costs

Labor cost: the labour cost of collecting white wine grains in the liquor factory is relatively high, assuming that the labour cost is 50-80 yuan per ton.

Cost of transportation container: the purchase price of sealed tank truck is relatively high, assuming that the cost of transportation container per ton of white wine grains is about 100-150 yuan.

Transportation costs

Vehicle transportation cost: due to the particularity of white wines, professional transportation vehicles are needed, and the transportation cost is high. Suppose that the transportation cost of each ton of white wine grains is about 150-200 yuan.

Special road permit fee: Suppose the special road permit fee per ton of white wine grains is about 20-30 yuan.

Treatment costs

Feed processing: the price of drying equipment ranges from hundreds of thousands of yuan to millions of yuan, assuming that the depreciation cost per ton of equipment is about 100-150 yuan. Some nutritional additives also need to be added in the processing process, and the cost is about 80-120 yuan per ton. The labour cost and energy consumption are about 100-150 yuan per ton. Therefore, the feed processing cost per ton of white wine grains is about 280-420 yuan.

Biogas production: the cost of building biogas digester and other facilities is high, assuming that the processing cost of each ton of white distillers grains is about 200-300 yuan.

Table 12: Summary of processing cost of white grains (own compilation of BTBU).

Cost project	Cost range (RMB / ton)
Collection cost (labour + transport container)	150-230
Transportation cost (vehicle + special permit)	170-230
Feed processing cost	280-420
Biogas production cost	200-300

6. Cost analysis of beer grains processing

Collection costs

Labor cost: The labour cost of collecting beer grains in the brewery is relatively low. Assuming that the labour cost is 20-30 yuan per ton.

Storage container cost: Suppose the storage container cost per ton of beer is about 20-30 yuan.

Transportation costs

Vehicle transportation cost: ordinary truck transport beer bad grains, assuming that the transportation cost per ton is about 100-150 yuan.

Fresh cost: In order to maintain the freshness of beer, assume that the cost of preservation per ton is about 20-30 yuan.

Treatment costs

Feed processing: the energy consumption of drying equipment is large, assuming that the drying cost per ton is about 150-250 yuan, plus other processing costs, the processing cost of feed per ton is about 300-450 yuan.

Compost treatment: compost treatment as an organic fertilizer, assuming that the treatment cost per ton is about 150-250 yuan.

Table 13: Summary table of brewer's spent grains processing costs (own compilation of BTBU).

Cost project	Cost range (RMB / ton)
Collection cost (labour + storage container)	40-60
Transportation cost (vehicle + preservation)	120-180
Feed processing cost	300-450
Compost treatment cost	150-250

7. Cost analysis of citrus residue treatment

<u>Collection costs</u>

Labour cost: the labour cost of collecting citrus residue in the citrus processing plant is assumed to be about 50-100 yuan per ton.

Collection tool cost: Suppose that the collection tool cost per ton of citrus residue is about 10-20 yuan.

<u>Transportation costs</u>

Vehicle transportation cost: ordinary truck transport citrus residue, assuming that the transportation cost per ton is about 80-120 yuan.

Packaging cost: In order to prevent the citrus residue from scattering during transportation, the packaging cost is assumed to be about 30-50 yuan per ton.

<u>Treatment costs</u>

Feed processing: when processing into animal feed, it is necessary to add some nutrients and preservatives. Assuming that the cost of feed processing per ton is about 250-400 yuan.

Extract essential oil and other components: extract essential oil and other components in citrus residue, with high equipment input and technical requirements, assuming that the treatment cost per ton is about 800-1200 yuan.

Table 14: Summary table of citrus residue treatment cost (own compilation of BTBU).

Cost project	Cost range (RMB / ton)
Collection cost (labour + tool)	60-120
Transportation cost (vehicle + packaging)	110-170
Feed processing cost	250-400
Processing cost of components such as extracted essential oil	800-1200

8. Cost analysis of corn straw and corn cob treatment

Collection costs

Labour cost: In rural areas, the labour cost for farmers to collect corn stalks and corn cobs is relatively low, but if it is collected on a large scale, they need to hire workers, assuming that the labour collection cost per ton is about 50-100 yuan.

Mechanical harvesting and collection costs: Using machinery for harvesting and collection can improve efficiency, but mechanical leasing or purchase costs are higher. Assuming that the cost of leasing a corn harvesting and collecting machine is 1000-2000 yuan per day, and the cost of spreading to a ton is about 30-80 yuan per ton according to the harvesting area and the collection amount.

Transportation costs

Vehicle transportation cost: ordinary trucks transport corn stalk and corn cob, assuming that the transportation cost per ton is about 80-120 yuan.

Handling and unloading cost: the loading and unloading of corn stalks and corn cob requires a certain amount of manpower and time, assuming that the loading and unloading cost per ton is about 20-40 yuan.

Treatment costs

Feed processing: Raw material needs to be crushed, fermentation and other treatments, assuming that the cost of feed processing per ton is about 150-250 yuan.

Fuel processing: the corn stalk and corn cob are processed into biomass fuel, and the equipment input and technical requirements are relatively high, assuming that the treatment cost per ton is about 200-350 yuan.

Table 15: Summary table of corn stalk and corn cob treatment costs (own compilation of BTBU).

Cost project	Cost range (RMB / ton)
Collection cost (labour + machinery)	80-180
Transportation cost (vehicle + handling)	100-160
Feed processing cost	150-250
Fuel processing cost	200-350

6.5 Market assessment

Agricultural organic waste has long been regarded as a by-product of agricultural production, such as crop straw, livestock and poultry manure, and agricultural products processing waste, which are often discarded or burned at will and cannot be properly handled. It not only occupies land resources, but also causes pollution to the environment. However, with the progress of technology and the enhancement of environmental awareness, these wastes are gradually becoming an important resource for agricultural circular economy and green development, which can be transformed into high-value organic fertilizer and bio-energy, thus significantly improving their economic benefits. This chapter aims to reveal the economic potential of agricultural organic waste resource utilization through a systematic revenue assessment.

6.5.1 Market demand analysis and product value evaluation

6.5.1.1 Market demand analysis

At present, the three main technologies widely used in the energy treatment process of organic solid waste are: thermal conversion (incineration, pyrolysis, gasification), bioconversion (anaerobic digestion / biomethylation and composting), landfill and gas recovery. Agricultural organic waste is rich in nutrients, including nitrogen, phosphorus, potassium and other essential elements for plant growth. Moderate use of organic waste can increase the rich organic matter in the soil, improve the soil structure, increase the stability of soil aggregates, significantly improve the ability of soil water and fertilizer conservation, promote the diversity and activity of soil microbial communities, and be beneficial to plant growth.

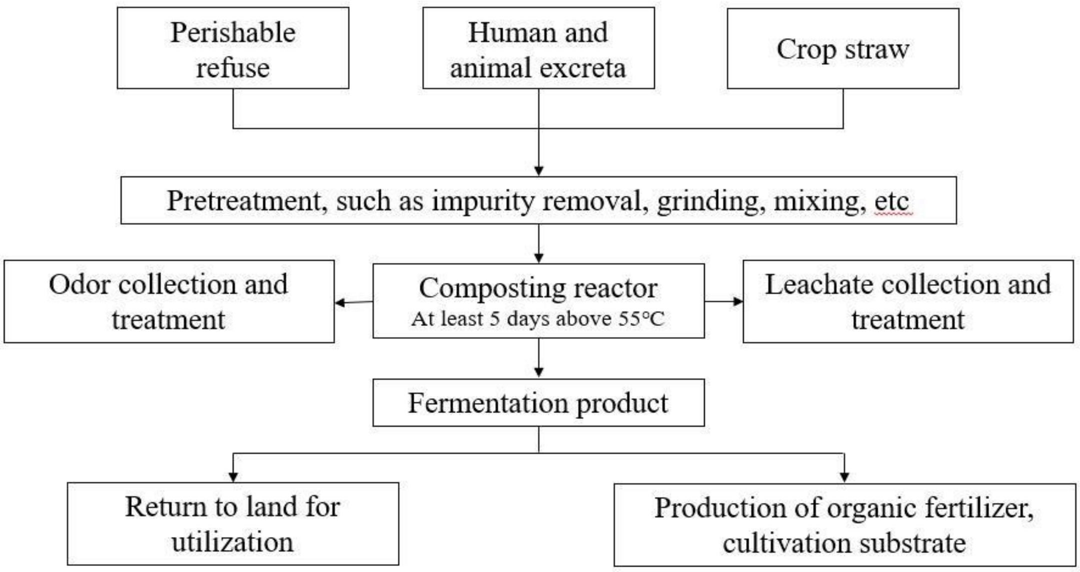

Figure 19: Schematic diagram of the reactor composting technology mode (own compilation of BTBU).

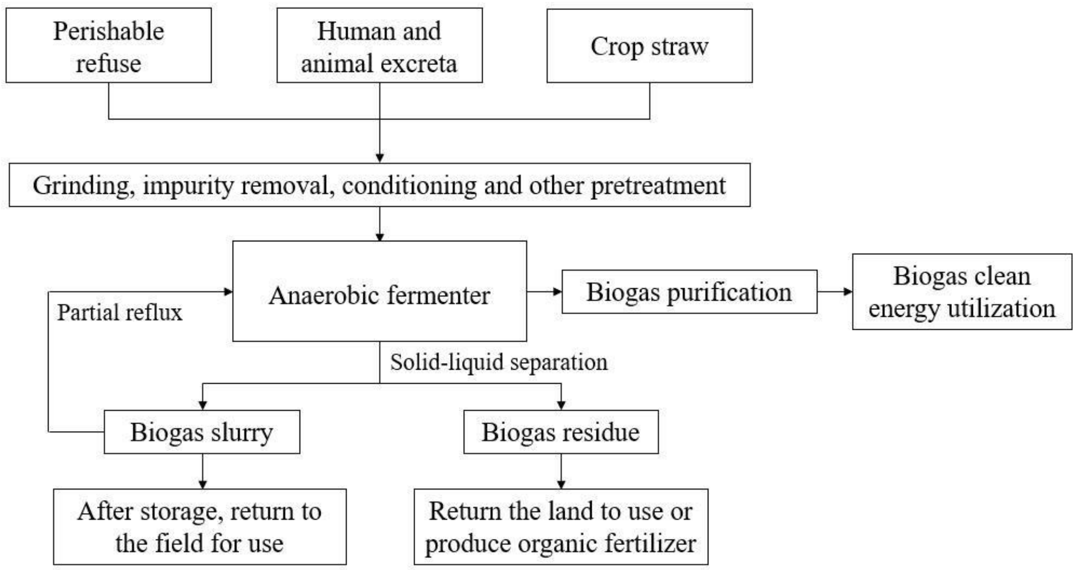

Figure 20: Schematic diagram of the cooperative treatment technology mode of anaerobic fermentation (own compilation of BTBU).

At present, organic waste is often used as organic fertilizer and bio-energy raw materials to realize the recycling of resources, reduce carbon emissions, and can also be used in the production of some high value-added products, which has a broad market prospect and potential application value.

Table 16: The resource utilization method of the main agricultural organic waste (own compilation of BTBU).

Agricultural organic waste	Annual production volume (100 million t)	Common resource recovery approach	Transform products
Crop straw	10	Fertilizer utilization (straw returning to the field), vaporization power generation	Organic fertilizer, bio-energy (such as biogas)
Livestock and poultry manure	40	anaerobic digestion	Biogas, organic Fertilizer
Tikitiki	1.2	Fermentation, extrusion method, damp and heat method	Feed additives, rubber additives

Edible fungus forage	0.3	The bacteria are reused	Organic fertilizers, biofuels, and food additives
Aquaculture wastewater	20	Microbiological technical handling	Breeding water recycling

6.5.1.2 Market value evaluation

1. Organic fertilizer

Orange stalk made into organic fertilizer has many advantages and is widely used. First of all, organic fertilizer can provide rich organic matter and nutrient elements, improve soil quality, increase soil water and fertilizer ability, improve soil structure increase soil ventilation and retention, is conducive to root growth and plant cultivation, secondly, organic fertilizer can promote soil microbial activity and biodiversity, maintain the stability of the soil ecosystem and health. Straw organic fertilizer is widely used in agricultural production, which can be directly applied in farmland or mixed with chemical fertilizer to improve soil fertility and crop yield; Organic fertilizer is also widely used in orchard, vegetable planting, flower breeding and other agricultural fields to provide nutrients for plant growth. Therefore, the organic fertilizer made from straw has a positive impact on the soil protection and the sustainable agricultural development.

2. Bioenergy

As a kind of renewable energy, bioenergy has the advantages of reducing carbon emissions and reducing energy costs. Agricultural waste can generate biogas through anaerobic fermentation technology, or it can produce bio-diesel, ethanol and other fuels through thermochemical treatment, which can replace some fossil energy. For agricultural equipment and facilities that rely on diesel or natural gas, the use of bioenergy can significantly reduce fuel expenditure, especially in the case of volatile energy prices, the cost of bioenergy is relatively stable, further improving the space for cost savings.

Taking straw as an example, the calorific value produced by 2 tonnes of straw combustion can be comparable to that produced by 1 ton standard coal combustion. The straw curing and forming as biomass fuel is included in the environmental protection fuel due to the small dust after combustion.

In the current agricultural market, the demand for organic fertilizers and bioenergy is gradually rising, and the market price also fluctuates. The rapid growth of the global population and the shift in dietary preferences have driven the growth of the global agricultural fertilizer market, which was worth $223.68 billion in 2024 and is expected to grow to $297.67 billion by 2032.

3. Utilization of feed and raw materials

Taking straw as an example, it is estimated that the nutritional composition of livestock contained in 4 jin of straw is equal to the same as that of 0.5 kg of grain. The straw can be crushed and fed to livestock, and it can also be made into high-density block feed, or the straw feed processing enterprises can make the straw feed, such as silage, ammonification, micro-storage or pellet. Straw can be used as industrial raw material, such as providing raw materials for paper industry; all kinds of light plates and insulation raw materials in construction industry, biodegradable environmentally friendly packaging buffer materials, woven ornaments; or extracting organic compounds such as polymer carbohydrates and xylitol from straw.

The conversion of agricultural organic waste into high value-added products for soil fertility improvement, soil remediation, bio-energy and other purposes, and the realization of waste treatment and high-value biological conversion, is helpful to explore a sustainable development model of ecological circular agriculture. Therefore, based on the resource utilization of these crop wastes, it can not only provide sustainable inputs for agriculture, but also create considerable market value.

With the promotion of green development and sustainable agricultural policy, the future market prospect of organic fertilizer and bioenergy is promising, and the price is expected to increase steadily. Especially in the background of increasing environmental pressure, the products with environmental benefits will be more competitive.

6.5.2 Direct economic benefits

The recycling of agricultural organic waste can not only generate benefits, but also significantly reduce the cost of traditional agricultural production, especially in terms of fertilizer and energy input.

6.5.2.1 Cost savings analysis

The analysis of the capital and operation cost of different solid waste energy technologies is shown in the table 17 The cost of capital is also affected by the quality of waste, the technology used, government subsidies, the prices of raw materials and other factors. Relatively speaking, the comprehensive treatment cost of developing countries is relatively low, and that of developed countries is higher.

Table 17: Related costs of energy utilization technologies for different organic solid waste (own compilation of BTBU).

Solid waste energy utilization technology	capital cost ($/ Tons of solid waste /year)	running cost ($/ Tons of solid waste /year)
burn	400~700	40~70
pyrolyzation	400~700	50~80
pneumatolysis	250~850	45~85
anaerobic digestion	50~350	5~35
Gas recovery landfill	10~30	1~3

The conversion of agricultural organic waste into organic fertilizers and bioenergy sources has achieved significant cost savings compared with the use of traditional chemical fertilizers and fossil energy sources. First of all, in terms of organic fertilizers, traditional fertilizers (such as nitrogen, phosphate and potassium fertilizers) are more expensive, and long-term use may lead to soil compaction and decreased fertility, which requires greater investment in soil remediation. Organic fertilizer can not only improve the organic matter content of the soil and the soil structure, but also reduce the amount of chemical fertilizer and save related expenses.

By comparing the cost of traditional treatment methods and using the transformation mode of agricultural organic waste resources, we can reduce the cost of waste treatment, such as transportation, landfill, incineration and other links, which can effectively reduce the direct production cost, and ultimately improve the overall economic benefits of agricultural production.

Analysis of grain production and income increase

Taking straw returning to the field as an example, the yield increased basically after the third year, with an average increase of 5%~10%, or even higher. In addition, crop straw returning to the field increases the nutrient input of the soil, and the amount of chemical fertilizer can be reduced by 15%~20%, not only the crop does not reduce production, but also the soil force will be improved. Scientific straw returning to the field is conducive to high and stable yield and reduction and efficiency of chemical fertilizer. In 2021, the amount of straw returned to rice, wheat and corn in China was about 400 million tons, and the nutrient content was equivalent to 11,407,100 tons (discounted purity amount), which was 20.8% of the total chemical fertilizer applied in China in 2022. In 2021, the average yield per unit area of the three major crops in China is about 427kg /mu, The national average purchase price is 2.67 yuan / kg, and the straw scientific return to the field is increased by 50~100 yuan /mu. At present, the chemical fertilizer input of the three major crops is about 150~200 yuan /mu, Science return to the field weight loss festival 20~40 yuan /mu. Straw returning to the field needs to increase the tillage and preparation work 1~2 times, such as stubble removal operation and deep turning or deep rotary tillage, generally only one more operation.20~30 yuan /mu, Deep turn or deep rotation 30~60 yuan /mu, Therefore, the operation cost of straw returning to the field is increased by 50~90 yuan /mu. After deducting the increased operation cost, straw returning to the field can promote crop yield increase and chemical fertilizer input reduction, so as to save cost and increase income.

In general, the resource utilization of agricultural organic waste can not only reduce the dependence on chemical fertilizers and fossil energy, but also effectively reduce the production cost, improve the sustainability of agricultural production, and bring long-term economic benefits to agricultural operators.

Conclusion

For the recycling of waste, farmers can collect agricultural organic wastes such as straw and livestock waste, and sell them to agricultural and rural cooperatives, biomass energy enterprises, etc., to obtain additional income sources.

Considering comprehensively, this transformation mode not only has great advantages in direct cost, but also brings the increase of hidden value by reducing the cost of waste disposal, improving environmental benefits and improving the quality of agricultural products. Therefore, compared with the traditional agricultural organic waste treatment mode, the comprehensive cost saving effect of using green low carbon cycle treatment mode is significant.

6.5.3 Assessment of environmental and social benefits

6.5.3.1 Ecological and environmental benefits

Agricultural organic waste resource utilization of pollutants to reduce emissions, alleviate the soil barren, secondary salinization, soil compaction, fertilizer dosage, improve the quality of cultivated land, improve soil fertility, promote ecological balance, enhance the soil drought resistance, help the healthy growth of plants, improve the sustainability of agricultural production, indirectly increase the long-term economic benefits of agriculture.

In addition, organic waste such as livestock and poultry waste will produce a large amount of CH in open storage and landfill and N_2 Greenhouse gases, such as O, leading to global warming. The discharge of sewage and wastewater may also lead to water body eutrophication, groundwater pollution, etc. Therefore, resource treatment can help reduce greenhouse gas emissions and water pollution, which can help alleviate global climate change and protect water resources.

6.5.3.2 Social benefits

Promote agricultural organic waste recycling efficient utilization of technology, promote ecology, environmental protection, green concept, help to clean production, green development, sustainable development and related ideas gradually implement to the specific production and living each link and decision-making, help to promote carbon reduction, pollution reduction, expanding green, form green production mode and way of life, promote the construction of beautiful China. At the same time, we will promote the concept of green consumption, constantly develop related industries, encourage more people to innovate and start businesses, create a large number of job opportunities, and increase related jobs, including waste collection, transportation, treatment, sales and other links. This will help to ease the pressure on rural employment, promote the prosperity of rural industries, and increase farmers income.

6.5.3.3 Sustainable development aspects

Although the implementation of the circular agriculture model requires some initial investment, such as the construction of anaerobic digestion facilities and composting treatment systems, this investment is cost-efficient in the long term. The recycling of agricultural organic waste is an important practice of circular economy. minimizing the discharge of waste is helpful to promote the development of agricultural circular economy and realize the "reduction, reuse and recycling" of resources. Adhering to the principles of fairness, sustainability and commonality, while paying attention to environmental protection, so as to realize the coordination and unity of economic, social and ecological benefits.

6.5.3.4 Added value

Establish from pollutant control to high value-added products production circulation system, according to the agricultural characteristics of different areas, can realize "livestock and poultry manure — organic fertilizer — agricultural products", "livestock manure — organic fertilizer — soil repair" such as a variety of ecological agriculture cycle mode, can adapt to different regional agricultural development, improve agricultural competitiveness, build a variety of ecological circulation system, realize the natural economic and social coordinated development, harmonious coexistence between man and nature, promote the ecological virtuous cycle and has an obvious application value.

6.6 The indicator of environmental economics

6.6.1 Emission reduction assessment

Climate change is a severe challenge facing the world, and greenhouse gas emissions are the main cause of climate change. To combat climate change, countries are taking measures to reduce greenhouse gas emissions. However, reducing greenhouse gas emissions is not only an environmental issue, but also a major issue concerning economic development and social well-being. This report explores the economic value of greenhouse gas emission reduction in order to provide a reference for relevant decisions.

6.6.1.1 Assessment of straw emission reduction

There are various ways to use straw, mainly including but not limited to returning straw to the field directly after crushing can increase soil organic matter content, improve soil structure and improve soil fertility. Feed: the straw is used as feed after treatment, which can supplement the crude fibre of livestock and reduce the feed cost. Fuel: Straw can be directly burned or processed into biofuel for heating, power generation, etc. Biomass energy: through anaerobic fermentation, pyrolysis and other ways, straw into biogas, bio-oil, biochar, etc. Paper raw materials: straw fibre can be used to make paper and board, etc. Other: straw can also be used in the production of bioplastics, biofertilizers and so on.

As an organic waste produced in agricultural production, its rational utilization is of great significance for environmental protection and sustainable development. The emission reduction of straw is mainly reflected in reducing greenhouse gas emissions and improving environmental quality. Straw burning is an important cause of air pollution and greenhouse gas emissions. By replacing fossil fuels by returning straw to the field and preparing biomass energy, greenhouse gas emissions such as carbon dioxide can be reduced. Straw returning to the field can increase the soil organic carbon content, improve the soil fertility, reduce the loss of soil carbon, so as to achieve the effect of carbon sequestration and emission reduction.

Straw burning will produce a large number of soot, sulfur dioxide, nitrogen oxide and other harmful substances, seriously polluting the air. The rational use of straw can effectively reduce air pollution and improve air quality.

The ashes and soot produced by the straw burning will pollute the water body, while returning the straw to the field can improve the soil structure, improve the soil water retention capacity, and reduce the soil erosion.

Straw burning will destroy the soil ecological environment, reduce the number of microorganisms in the soil, and affect the balance of the soil ecosystem. Straw returning to the field can increase the organic matter in the soil, which is conducive to the growth of soil microorganisms and promote the healthy development of soil ecosystem.

The specific measures of straw emission reduction include straw returning to the field: returning the straw directly to the field after crushing, increasing the content of soil organic matter, improving the soil structure, and improving the soil fertility. Straw preparation of biomass energy: straw into biogas, bio-oil and other biomass energy, to replace fossil fuels.

Straw production of biological fertilizer: turns straw into organic fertilizer to reduce the use of chemical fertilizer. Straw production of biomass materials: straw is used for the production of paper pulp, plate and other biomass materials.

Straw emission reduction is one of the most important measures to deal with climate change, which helps to slow down global warming. It can improve air quality, water environment and soil quality, and protect ecosystems. The rational utilization of straw can improve agricultural production efficiency, reduce production cost and realize the sustainable development of agriculture. Straw preparation of biomass energy can promote the adjustment of energy structure and reduce the dependence on fossil energy.

From the perspective of straw production, China is one of the countries with the most abundant straw resources in the world. According to the data, the annual amount of straw produced by crops in China reached 10.5010^{11} kg, of which the straw of major crops such as rice, wheat and corn accounts for a large proportion. However, although the abundant straw resources, its utilization rate is not high. According to the study, the utilization rate of crop straw in China is 69%, and there is still 3.2510^{11} kg of straw that has not been effectively used.

In the treatment of straw, China has adopted a variety of comprehensive utilization measures. At present, the utilization way of straw mainly includes fertilizer, feed, energy, raw material and base material and other "five modernization" mode. Specifically, straw fertilizer utilization is 390 million tons, accounting for 43.2%; feed utilization 170 million tons, accounting for 18.8%; and base material utilization 40 million tons, accounting for 4%.

The comprehensive utilization of straw, especially the energy utilization, can significantly reduce greenhouse gas emissions. The utilization of straw into biogas can reduce it by 208 million tons per year (CO_2e) Carbon footprint, compared with straw direct burning emission reduction 46.8%. In addition, measures such as straw returning to the field and biochar preparation can also effectively fix carbon, such as biochar sequestration of CO_2e of about 4.6310^{8} tons.

In the past decade, the average annual net greenhouse gas emission reduction contribution of straw comprehensive utilization is 7.010^{7} tons of carbon dioxide equivalent (CO_2e), in which the greenhouse gas emissions of open incineration and natural decomposition are 5.610^{7} tons of CO_2e, and the emission reduction of straw material utilization (including fertilizer, fuel, etc.) is 1.2610^{8} tons of CO_2e. Specifically, the emission reduction effect of fertilizer and fuel utilization is the most significant, with 7.910^{7} tons and 3.810^{7} tons of CO_2e, respectively.

6.6.1.2 Assessment of emission reduction of livestock manure

Livestock and poultry manure is rich in nitrogen, phosphorus and other nutrients, after harmless treatment, it can be used as fertilizer for agricultural planting. The specific methods include: compost return to the field: the livestock and poultry manure composting fermentation treatment, once rendered harmless in the crop fertilization period. Utilization of biogas slurry with integrated water and fertilizer: through the pressure system or the natural terrain drop, the biogas slurry is applied for agricultural cultivation according to the content of soil nutrients and the fertilizer requirements of crop types. Production of organic fertilizer: through the professional organic fertilizer production facilities will make solid manure into commercial organic fertilizer, through sales to achieve the use of feces.

Livestock manure can produce biogas by anaerobic fermentation. Biogas is a clean energy and can be used for power generation, lighting and as a clean fuel. In addition, hydrogen, electricity, biogas, ethanol, biodiesel and other energy sources can also be produced through thermochemical conversion and biochemical conversion. Livestock and poultry manure can be prepared together with other materials, and the used fungus residue can participate in composting and fermentation to produce organic fertilizer. In addition, the matrix disks and matrix soil can also be used to cultivate fruits and vegetables.

As an important by-product in agricultural production, the improper handling of livestock manure will bring serious environmental problems. Therefore, the emission reduction of livestock manure is of great significance to protect the environment, improve the ecology and protect human health.

The annual production volume of livestock and poultry manure in China is nearly 4 billion tons, and the utilization rate of resources reaches about 75%, but there are still nearly 25% of livestock and poultry manure that has not been used, and the pressure of livestock and poultry manure pollution exists for a long time. Main methods include storage of agricultural utilization and production of organic fertilizer. The manure treatment mode of live pigs, dairy cows and beef cattle is mainly stored for agriculture, accounting for more than 75%. The proportion of organic fertilizer reached about 65%. In addition, the fecal production of biogas is less, accounting for about 1% of the country.

6.6.1.3 Assessment of emission reduction of agricultural products processing waste

There are various ways to use agricultural products processing waste, mainly including: direct use: direct use of waste in agricultural fields, such as fertilizer or feed. For example, livestock manure can be used as fertilizer, while fruit and vegetable processing residues can also be used as animal feed. Matrix utilization: to convert waste into matrix for agricultural cultivation. For example, the biogas residue produced by anaerobic digestion can be used as soil amendments. To turn the waste into fertilizer for agricultural production. For example, both livestock manure and crop straw can be composted into organic fertilizer. Feed utilization: turn waste into feed for breeding industry. For example, fruit and vegetable processing remnants can be processed and used as animal feed. Through the deep processing technology, the waste is converted into high value-added products. For example, fruit processing remnants can extract protein and fat used for the production of other food or industrial products. Energy utilization: converting waste into energy, such as biomass fuels and biogas. For example, biogas produced by anaerobic digestion can be used as fuel for power generation or vehicle fuel. Material utilization: to convert waste into new materials, such as recycled plastic particles. For example, waste agricultural film can be processed into recycled plastic particles.

Agricultural products processing waste refers to all kinds of by-products and wastes produced in the process of agricultural products processing. China produces about 600 million tons of agricultural products processing waste every year. The total amount of grain processing by-products is about 210 million tons, and fruit and vegetable processing waste is about 260 million tons. Through anaerobic fermenters to treat livestock and poultry manure and tail vegetables and other agricultural wastes, the annual output of 294,000 tons, 26,000 tons biogas slurry, , 10.6 million ㎡ biogas, and the annual power generation can reach 21 million KWh. Reduced by 210 million tons of CO_2e.

6.6.2 Value of ecological services

Soil health and biodiversity are important components of ecosystems, which have irreplaceable roles in human well-being and ecological balance. However, soil health and biodiversity are often overlooked and their value is difficult to quantify. With the deepening of ecological civilization construction, the monetization assessment of soil health and biodiversity will not only help to improve its weight in decision-making, but also promote the coordinated development of ecological protection and economic development.

Significance of monetization assessment: Decision support: to provide a scientific basis for the formulation of ecological protection and restoration policies. Value embodiment: highlight the economic value of soil health and biodiversity, and improve their protection awareness. Incentive mechanism: establish a sound ecological compensation mechanism to encourage ecological protection behaviour. Performance evaluation: to evaluate the effectiveness of ecological protection projects and provide a basis for continuous improvement.

<u>Method of monetizing evaluation</u>

The monetization assessment methods of soil health and biodiversity used in this report mainly include:

Market value method:

(1) Direct market value method: to directly estimate the value of ecological service through the market transaction price.
(2) Alternative cost method: Estimate the cost of alternative ecological services.
(3) Cost avoidance method: Estimate the cost of avoiding ecosystem degradation.
(4) Production function method: the ecosystem services are regarded as the production factors and estimated through the production function model.
(5) Implicative value method: through questionnaires and other ways, to understand the publics willingness to pay for ecological services.
(6) Ecosystem service value evaluation model: use InVEST and other models to conduct a comprehensive evaluation of ecosystem services.
(7) Evaluation index system
(8) Soil health indicators: soil organic matter content, soil structure, soil enzyme activity, number of soil microorganisms, etc.
(9) Biodiversity indicators: species richness, species diversity, ecosystem diversity, etc.
(10) Ecosystem service value indicators: supply, regulation, support and cultural services, etc.

The evaluation process

1. Determine the evaluation objectives: to clarify the scope and purpose of the evaluation.
2. Data collection: collect soil, biological, social and economic related data.
3. Selection of indicators: Select the appropriate indicators according to the evaluation objectives.
4. Model construction: Establish the evaluation model and quantify the indicators.
5. Value assessment: A monetization assessment of ecosystem services.
6. Results analysis: Analyse the evaluation results and draw conclusions

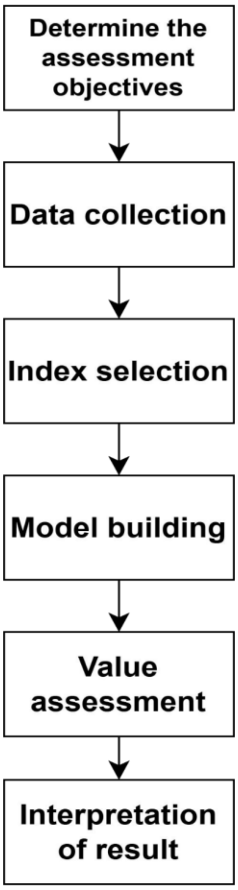

Figure 21: Evaluation Flow Chart (Own compilation of BTBU).

6.6.2.1 Monetization assessment of soil health and biodiversity improvement caused by straw utilization

Straw returning technology has significantly improved the soil health level by increasing the content of soil organic matter, improving soil structure and improving soil fertility. For example, straw returning to the field can reduce soil bulk density, improve soil mass structure, increase soil porosity, and increase soil organic matter, nitrogen, and phosphorus content. In addition, straw returning to the field can also promote microbial vitality and crop root development, so as to improve soil bioactivity.

Straw returning to the field has a significant positive impact on soil microbial diversity. The study shows that straw returning to the field can significantly increase the soil bacterial diversity, and the effect is more significant at high nitrogen levels. In addition, straw returning to the field can also regulate the metabolic function and structure of soil microbial communities and improve soil quality. No-till straw cover measures also showed positive effects on soil microbial diversity, increasing the capacity of the soil to utilize carbon sources.

At present, the methods of monetizing the ecological benefits of straw comprehensive utilization project mainly include LCA method (life cycle assessment method) and carbon dioxide shadow price method. These methods can transform the ecological benefits into specific economic value, so as to provide a scientific basis for policy making and project investment. Through the monetization calculation of the net emission reduction benefit of the straw pyrolysis and gasification project by LCA method and carbon dioxide shadow price, the quantitative estimation of the ecological value of the comprehensive utilization project of straw can be realized.

Straw utilization has a significant monetization value for the improvement of soil health and biodiversity. Through scientific evaluation methods, these ecological benefits can be transformed into specific economic values to provide strong support for the sustainable development of agriculture.

6.6.2.2 Monetization assessment of soil health and biodiversity improvement caused by livestock manure utilization

Livestock and poultry manure is rich in organic matter, nitrogen, phosphorus, potassium and other nutrients, which can significantly improve soil fertility and improve soil structure after application. For example, chicken manure, as the base material of organic fertilizer, can improve soil quality and improve crop yield. In addition, returning livestock and poultry manure can loosen the land, increase the content of soil organic matter, promote soil microbial activities, and prevent cultivated land compaction and soil acidification.

The application of livestock manure can reduce the amount of chemical fertilizer used, thus saving the cost of agricultural production. The application of livestock manure can reduce the amount of agricultural fertilizer by about 30,000 tons and save 60 million yuan.

The application of livestock and poultry manure can improve soil nutrients, promote crop growth, and improve the yield and quality. Through the construction of planting and breeding cycle demonstration site, the planting industry can radiate to 11,500 mu, and the annual income is expected to increase by more than 10 million yuan.

Application of livestock manure can improve the microbial diversity, but also change the physical and chemical properties of soil, and directly or indirectly affect the composition and structure of soil microbial communities. For example, the soil microbial diversity was improved after the application of poultry feces.

The application of livestock manure helps to maintain ecosystem function and prevent land degradation. For example, grazing along with livestock trampling and excrement decomposition can directly or indirectly change the soil structure and nutrient accumulation, enhance the net soil nitrogen mineralization and nitrogen nitrification rates, and improve the effectiveness of soil nutrients.

The rational use of livestock and poultry manure can reduce the occurrence of diseases and insect pests. For example, antibiotics, hormones and other substances in livestock and poultry manure can kill parasitic eggs and pathogenic bacteria and prevent major animal outbreaks.

The resource utilization of livestock and poultry manure not only reduces the use of chemical fertilizer, but also improves the yield and quality of crops, bringing significant economic benefits. Through the construction of harmless treatment and resource utilization facilities of livestock and poultry manure, 60 million yuan can be saved every year, and the planting industry can be increased by more than 10 million yuan.

The resource utilization of livestock and poultry manure has improved the rural production and living conditions and ecological environment, and improved the quality of life of farmers. As a high-quality farm fertilizer, marsh fertilizer can effectively improve the soil ecology, loosen the land, increase the content of soil organic matter, promote soil microbial activities, improve soil fertility, and prevent farmland consolidation and soil acidification.

The rational use of livestock and poultry manure reduces environmental pollution and prevents groundwater nitrate pollution and surface water phosphorus pollution. For example, the appropriate amount of nitrogen, phosphorus, potassium and other nutrients in livestock and poultry manure can effectively improve soil fertility, improve soil physical and chemical characteristics, and promote the growth of crops.

The rational use of livestock manure can not only significantly improve soil health and biodiversity, but also bring significant economic, social and environmental benefits. Through scientific management and technical guidance, these benefits can be maximized and sustainable agricultural development can be realized.

6.6.2.3 Monetization assessment of soil health and biodiversity improvement caused by the utilization of agricultural products processing waste

Agricultural product processing waste has a significant monetization value for the improvement of soil health and biodiversity. First, healthy soil is the basis of biodiversity, which in turn can promote soil health and form a virtuous cycle. By screening and cultivating efficient bacteria species and developing biological agents, we can build "fertile soil" microbial communities, improve soil biodiversity, and inhibit soil-borne diseases, so as to play a greater role in the farmland ecosystem.

Improving soil biodiversity and crop diversification is an important way to ensure the sustainable development of agriculture. Some strategies, such as protective agriculture and diversified cultivation, can enhance soil biodiversity and ecosystem function by enhancing niche complementarity. For example, the introduction of phages specifically targeting infected pathogens in the rhizosphere soil can greatly reduce the number of pathogens, weaken their competitiveness in the rhizosphere, provide conditions for the growth of other microorganisms, and restore and enhance the diversity of microbial communities in the rhizosphere.

Reasonable agricultural management measures and planting system serve agricultural production by regulating beneficial microorganisms, such as crop rotation, no-tillage and covering crops, which can regulate the diversity and biological function of soil microorganisms and improve crop productivity. In addition, besides providing nutrients, organic management promotes ecosystem versatility, such as biodiversity conservation, soil and water quality improvement, and climate mitigation.

In terms of monetization evaluation, the environmental value evaluation method (environmental economic evaluation technology) can conduct quantitative evaluation of the goods or services provided by the environment through certain means, and can usually be characterized in the form of money. The value of using agricultural land soils to capture carbon emissions is estimated at $96- $480 billion per year. This suggests that the sustainability and economic benefits of agricultural production can be significantly enhanced by improving soil health and biodiversity.

The improvement of soil health and biodiversity caused by agricultural products processing waste not only contributes to the sustainable development of agriculture, but also has significant economic value. Through scientific management and rational agricultural practices, soil health and biodiversity can be double improved, and their economic contribution can be quantified through monetization assessment methods.

6.7 Risk assessment

The rational utilization of agricultural organic waste is of great significance to realizing the sustainable development of agriculture, reducing environmental pollution and improving the efficiency of resource utilization. However, in the process of resource investigation and economic evaluation of agricultural organic waste, there are also a series of risks. Therefore, risk evaluation is crucial in the investigation and economic evaluation of agricultural organic waste resources.

First of all, with the emphasis on the sustainable agricultural development and the increasing demand for resource recycling, the treatment technology of agricultural organic waste is also constantly developing and innovating. However, the introduction of various technologies is often accompanied by certain risks, so a comprehensive assessment of technical risks is of great significance to ensure the successful implementation of projects and the effective use of resources, and can help to find the possible problems in the application process of technology in advance. For example, by identifying equipment failure, immature processing technology, or the risk of unsuitable new technology, can make enterprises or relevant institutions in advance layout, take measures to avoid technical problems because agricultural organic waste cannot effectively be converted into organic fertilizer, biomass energy and other useful resources, so as to ensure the sustainability and efficiency of resource utilization.

Secondly, in terms of the market, it can help enterprises to cope with the market uncertainty. In view of the price fluctuation and the demand instability of products after agricultural organic waste treatment, a comprehensive and in-depth assessment of market risks can enable enterprises to predict risks in advance and establish a risk early warning mechanism, so as to reasonably plan the production scale and product structure.

Moreover, with the rapid development of agriculture, the amount of agricultural organic waste is also increasing. Agricultural organic waste has the characteristics of large quantity, wide distribution and complex composition. If these wastes are not properly treated, they will cause serious pollution to the environment. Considering the importance of environmental protection, it is necessary to pay attention to environmental assessment and take effective environmental protection measures to prevent environmental risks while conducting resource investigation and economic assessment of agricultural organic waste. As improper treatment of agricultural organic waste may lead to secondary pollution and environmental problems such as soil quality decline and ecological damage, risk assessment can enable enterprises to pay attention to these potential hazards and adopt appropriate environmental protection treatment technologies and supervision measures to avoid irreparable damage to the environment.

Finally, at the policy and regulation level, the significance of risk assessment is also very high. The treatment and utilization of agricultural organic waste is widely influenced by national and local policies, and changes in policies and regulations and changes in supervision may have a significant impact on the development direction of the whole industry, the business strategy of the enterprise and the economic benefits of the project. By accurately assessing policy risks, paying close attention to policy dynamics and timely adjusting business strategies, enterprises need to adapt to policy changes, ensure their own legal and compliant operation, ensure the smooth progress of the project and the sustainable development of the industry, and avoid losses due to violation of regulations or failure to comply with the policy adjustment. This risk assessment provides the decision reference for the effective utilization of agricultural organic waste.

6.7.1 Risk type identification

6.7.1.1 Technical risks

Equipment failure: The treatment of agricultural organic waste requires the use of a variety of professional mechanical equipment, such as crusher, fermenter, dryer, etc. These devices may fail during operation, affecting the processing progress and effect. At the same time, the repair and maintenance of the equipment also need a certain cost and time.

Immature processing technology: At present, there are many kinds of agricultural organic waste treatment technologies, but some of them are still in the stage of research and development or pilot, and there are problems such as technical instability and poor treatment effect. In addition, the reliability and stability of the technology also affect its applicability. In agricultural production, the generation of waste is persistent and uncertain, and requires the treatment technology to operate stably and reliably. If the treatment technology often fails in the practical application or the treatment effect is unstable, it will affect the normal progress of agricultural production and the timely treatment of waste.

The applicability of the new technologies: On the one hand, new technologies may face challenges of compatibility with existing agricultural production systems and waste disposal processes. Agricultural production has certain regional and seasonal characteristics, and the type, quantity and agricultural production mode of agricultural organic waste vary in different regions. If new technologies are not well adapted to these specific conditions, it is difficult to play a role in practical application. On the other hand, the cost-effectiveness of new technologies is also a key factor for applicability. Although new technologies often bring higher processing efficiency and better environmental benefits, if the implementation cost is too high, including equipment investment costs, operation and maintenance costs, technical training costs, it may deter enterprises, especially small agricultural enterprises or farmers.

6.7.1.2 Market risks

Product price fluctuations. Agricultural organic waste can produce a variety of products after treatment, such as organic fertilizer, biomass energy, etc. However, the market price of these products is affected by many factors, such as market supply and demand relationship, raw material prices, policies and regulations, etc., which has a large risk of fluctuation. For example, when the supply of organic fertilizer exceeds the demand on the market, the price may fall, thus affecting the economic benefits of enterprises.

Unstable market demand: Although there is a certain market demand, there is uncertainty about the growth rate and scale of market demand. On the one hand, consumer awareness and acceptance of organic products may affect the market demand for products such as organic fertilizers; on the other hand, changes in policies and regulations may also have an impact on the market demand for products such as biomass energy.

6.7.1.3 Environmental risks

Secondary pollution: In the treatment process of agricultural organic waste, if the treatment technology is not appropriate or poor management, secondary pollution may occur, such as waste water, waste gas, waste residue, etc. If these secondary pollutants are discharged directly without effective treatment, they will cause serious pollution to the environment.

Soil quality risk: Some components of agricultural organic waste, such as heavy metals and pesticide residues, are directly returned to the field or used for the production of organic fertilizer, which may have adverse effects on soil quality, and then affect the growth and quality of crops.

Risk of ecological damage: In the treatment process of agricultural organic waste, if the land resources are unreasonably developed and utilized, it may destroy the ecological environment and affect the ecological balance.

6.7.1.4 Policy risks

Policy changes: The treatment and utilization of agricultural organic waste is greatly affected by national and local policies. National and local governments may adjust the policies on the treatment and utilization of agricultural organic waste according to the needs of economic development, environmental protection and other aspects. Policy changes may directly affect the feasibility of the project and the economic benefits of the enterprise, and have a significant impact on the operation and development of the enterprise.

Additionally, the supervision was strengthened. With the improvement of environmental awareness, the governments supervision of the treatment and utilization of agricultural organic waste may be continuously strengthened. Companies need to invest more money and energy to meet regulatory requirements, which will increase their operating costs. At the same time, the strengthening of supervision may also have certain restrictions on the production and operation activities of enterprises.

6.7.2 Assessment of the likelihood and impact degree of risk occurrence

6.7.2.1 Technical risk assessment

Due to the continuous development and innovation of agricultural organic waste treatment technology, the possibility of technical risk occurrence is relatively high. Especially for some new technologies, they may face more technical problems and challenges in their practical application. If technical risks occur, it may lead to poor waste disposal effect, and affect the economic and social benefits of enterprises. Serious technical failures may even lead to enterprises to stop production, resulting in large economic losses.

6.7.2.2 Market risk assessment

Market price fluctuation and demand instability are common phenomena in the market economy, so the possibility of market risk is also high. Market price fluctuations and unstable demand may affect the sales revenue and profits of enterprises. If market demand drops sharply, enterprises may face problems such as product backlog and capital turnover difficulties.

6.7.2.3 Environmental risk assessment

If enterprises do not pay attention to environmental protection in the process of dealing with agricultural organic waste, environmental risks are more likely to occur. Once environmental risks occur, they will cause serious pollution to the environment and affect the social image and sustainable development of enterprises. At the same time, companies may also face huge environmental protection fines and governance costs.

6.7.2.4 Policy risk assessment

Policy changes are uncertain, and the possibility of policy risk is also high. Policy changes may force companies to constantly adjust their product mix, business strategies and development direction. If the policy adjustment is bad for enterprises, enterprises may need to make a major strategic adjustment, or even face a survival crisis. Moreover, the policy risks may have a significant impact on the economic benefits of the project. Policy changes may lead to less revenue and more cost of the project, thus reducing the profitability of the project.

6.7.3 Risk response measures

6.7.3.1 Technical risk countermeasures

1. Strengthen technological research and development and innovation: In order to solve the problems such as immature technology treatment and application of new technology, enterprises should increase the investment in the research and development of agricultural organic waste treatment technology, and constantly improve the technical level and treatment effect. First, strengthen the combination of technology research and development with actual demand, fully consider the characteristics of agricultural production and the actual situation of waste disposal, actively cooperate with scientific research institutions, introduce advanced technology and equipment, develop more targeted and applicable new technologies, and reduce technical risks. The second procedure is to carry out pilot and demonstration of processing technology, in different regions and different types of agricultural production, to verify the applicability and feasibility of new and old technologies, and to adjust and optimize according to the actual situation. At the same time, the establishment of demonstration projects can demonstrate the advantages and feasibility of new technologies and enhance market confidence.
2. Establish the equipment maintenance and management system. The enterprise shall establish and improve the equipment maintenance and management system, and shall check and maintain the equipment regularly to ensure the normal operation of the equipment. At the same time, a certain amount of spare equipment can be reserved to deal with the emergencies of equipment failure.
3. Strengthen the technical personnel training and technical evaluation feedback mechanism. Carry out extensive technical training to help enterprises and farmers to understand and master the processing technology, and improve the application level and effect of the technology. Establish technology evaluation and feedback mechanism, timely collect and analyse the problems and experience in the application process of technology, to provide a basis for further improvement and improvement of technology.

6.7.3.2 Market risk response measures

1. Strengthen market research and analysis: Enterprises should pay close attention to market dynamics, strengthen market research and analysis, and timely understand the relationship between market supply and demand and price trends. Adjust the product structure and production plan according to the market demand to reduce the market risk.
2. Expand sales channels. Enterprises should actively expand sales channels and establish a diversified sales network. In addition to the traditional sales channels, we can also expand the sales scope of our products through e-commerce, cooperative sales and other ways.

6.7.3.3 Environmental risk response measures

1. Adopt environmental protection treatment technology: Enterprises should choose environmental protection and efficient treatment technology to ensure that the waste will not produce secondary pollution in the process of treatment. At the same time, strengthen the environmental monitoring and management of the processing process, timely find and solve environmental problems.
2. Strengthen soil quality monitoring: When returning agricultural organic waste to the field or for the production of organic fertilizer, enterprises should strengthen the monitoring of soil quality to ensure that the soil quality meets the relevant standards. If any soil quality problems are found, timely measures should be taken to repair them.
3. Strengthen publicity and education: Through various forms to strengthen the publicity and education of agricultural organic waste treatment, improve the environmental awareness of farmers and enterprises, and guide them to actively participate in the treatment and utilization of agricultural organic waste.

6.7.3.4 Policy and risk response measures

1. Pay close attention to policy changes: Enterprises should pay close attention to the changes in the national and local policies, and timely understand the direction and content of the policy adjustment. Through the establishment of policy information collection channels and regular analysis of policy dynamics, we can provide timely and accurate policy information for enterprise decision-making, adjust the business strategy and development direction of enterprises according to the policy changes, and reduce policy risks.
2. Strengthen communication and cooperation with government departments. Enterprises should actively communicate and cooperate with the government departments to win the support and help of the government. By participating in the policy making process and putting forward reasonable suggestions, we can create a good policy environment for the development of enterprises. At the same time, abide by the national and local policies and regulations, standardize the business behaviour of enterprises.
3. Improve the adaptability of the enterprise itself: Enterprises should constantly improve their own adaptability and enhance their ability to resist policy risks. By strengthening technological innovation, optimizing the management process and expanding market channels, the core competitiveness of enterprises can be improved and the impact of policy risks on enterprises can be reduced.

6.8 Policy impact

6.8.1 Overview of national policy

National policies play an important role in guiding and supporting the treatment of agricultural organic waste. Here are some of the main topics of the national policy:

1. . Laws and regulations: The state has formulated a series of laws and regulations, such as the Environmental Protection.
   Environmental Pollution by Solid Waste clarify the legal requirements and responsibilities for the treatment of agricultural organic waste. In 2022, the state issued the Action Plan for Agricultural and Rural Pollution Control (2021-2025), continuing to improve the rural living environment and prevent and control agricultural non-point source pollution, enhancing farmers sense of gain and happiness, and providing strong support for rural ecological revitalization.
2. Objectives and planning: The government has formulated relevant objectives and plans to promote the effective treatment and resource utilization of agricultural organic waste. These goals usually include reducing waste emissions, improving resource utilization, and improving the quality of the rural environment.
3. Financial support: The state provides financial support through financial policies to encourage and support the construction and operation of agricultural organic waste treatment projects. This includes subsidies, loan incentives, and tax breaks.
4. Technology promotion: The government actively promotes advanced agricultural organic waste treatment technologies and modes, provides technical guidance and training, and promotes technological innovation and application.
5. Supervision and law enforcement: Strengthen the supervision and law enforcement of agricultural organic waste treatment, ensure the implementation of relevant laws and regulations, and prevent environmental pollution and illegal acts.
6. Policy incentives: Formulate incentive policies to encourage farmers and agricultural enterprises to actively participate in the treatment and resource utilization of agricultural organic waste, such as giving awards and honorary titles, etc.
7. Collaborative governance: Emphasize the collaborative governance of the government, enterprises, farmers and all social parties to form a joint force and jointly promote the treatment of agricultural organic waste.
8. International cooperation: Actively participate in international cooperation and exchanges, draw on international advanced experience and technology, and promote the improvement of Chinas agricultural organic waste treatment level.

Through the guidance and support of national policies, it can promote the rational treatment and resource utilization of agricultural organic waste, realize the sustainable agricultural development, protect the rural ecological environment, and improve the quality of life of farmers. At the same time, the continuous improvement and implementation of policies also requires the joint efforts and active participation of all parties.

In 2019, the general office of agricultural NongCunBu about comprehensive utilization of straw notice points out that to adhere to local conditions, agricultural priority, local, near the government guidance, market operation, technology support, to improve the utilization system, supporting policies, strengthen safeguard measures to promote means, stimulate straw returning, from the field, processing using market main body vitality, establish and improve the formation of the interests of the government, enterprises and farmers tripartite “win-win " link mechanism, promote a rational layout, multiple utilization of industrialization development pattern, constantly improve the level of comprehensive utilization of straw. In the "14th Five-year plan" circular economy development plan, it is pointed out that the comprehensive utilization rate of crop straw will be kept above 86% by 2025.

In 2023, the Guiding Opinions of the Ministry of Agriculture and Rural Affairs of the National Standards Commission on Promoting the Construction of the Standard System for Resource Utilization of Livestock and Poultry Waste was put forward, which clarified the basic principles of livestock manure treatment: strengthening top-level design; focusing on coordination and unity; adhering to integrity and innovation; and highlighting the transition from treatment to use.

6.8.8.1 Local policy support

At the local level, governments at all levels have also introduced a series of policy measures to support the treatment of agricultural organic waste. The introduction of these policies not only provides a policy guarantee for the treatment of agricultural organic waste, but also provides more development opportunities for related enterprises and farmers.

Taking Hunan Province as an example, the province issued the "Notice on Further Promoting the Resource Utilization of Livestock and Poultry Waste below the Scale", clearly proposing to strengthen the treatment and resource utilization of agricultural organic waste and improve the comprehensive utilization rate of agricultural waste. The province has also set up a special fund to support the construction and operation of agricultural organic waste treatment and resource utilization projects.

Weifang city has also issued the "Weifang Interim Measures for the Management of Agricultural Waste", proposing to establish and improve the agricultural organic waste treatment and resource utilization system, strengthen the management of the collection, transportation, treatment and utilization of agricultural organic waste, and improve the level of the treatment and resource utilization of agricultural organic waste.

In addition, some local governments have encouraged enterprises and farmers to carry out agricultural organic waste treatment and recycling work through fiscal subsidies and tax incentives. For example, Hangzhou gives certain financial subsidies to enterprises that carry out agricultural organic waste treatment and resource utilization, and gives certain tax incentives to enterprises that purchase agricultural organic waste treatment equipment.

In short, the policy support of the local government provides a strong guarantee for the treatment and resource utilization of agricultural organic waste, and also provides more development opportunities for related enterprises and farmers.

6.8.9 Policy objectives and priorities

Under the policy background, Chinas policy objectives and priorities of agricultural organic waste treatment mainly include the following aspects:

1. **Resource recycling**

In 2016, the Plan on promoting the Pilot Utilization of Agricultural waste resources pointed out that the main task of the pilot utilization of agricultural waste resources is to actively explore the effective technical path, and the second is to explore the comprehensive utilization mode. Through policy guidance, we should promote the resource utilization of agricultural organic waste, transform the waste into organic fertilizer, energy and other resources, realize the recycling of resources, reduce the dependence on external resources, and improve the sustainable development ability of agriculture.

2. **Environmental protection**

According to the Guidance on the Comprehensive Utilization of Bulk Solid Waste during the 14th Five-Year Plan period, it is necessary to promote the green, high efficiency, high quality, high value and large-scale utilization of large solid waste, improve the comprehensive utilization level of large solid waste, help the construction of ecological civilization, and provide strong support for high-quality economic and social development. One of the policy objectives is to reduce the environmental pollution caused by agricultural organic waste. Through reasonable treatment and disposal methods, reduce the discharge of harmful substances in waste, protect soil, water and air quality, and maintain ecological balance.

3. **Sustainable development of agriculture**

Promoting the effective treatment of agricultural organic waste is helpful to improve soil quality, improve soil fertility, and promote the growth of crops and yield improvement. At the same time, reduce the negative impact of waste on the agricultural ecosystem, and realize the sustainable development of agriculture.

4. **Rural ecological construction**

The policy focuses on the ecological construction in rural areas, improving the rural environment of agricultural organic waste, improving the quality of life of rural residents and promoting the development of rural economy by strengthening the treatment of agricultural organic waste.

5. **Technological innovation and promotion**

Encourage and support the research and development and innovation of related technologies, promote advanced agricultural organic waste treatment technology and equipment, improve the efficiency and quality of treatment, and reduce treatment costs.

6. **Policy support and incentives**

We will formulate relevant policies, provide financial subsidies and tax incentives, encourage farmers and enterprises to actively participate in the treatment and utilization of agricultural organic waste, and form a good social atmosphere.

7. **Regulation and law enforcement**

Strengthen the supervision of the treatment of agricultural organic waste, establish a sound monitoring system and law enforcement mechanism, ensure the effective implementation of policies, and prevent improper disposal and discharge of waste.

8. **Improving public awareness**

Through publicity and education and other means, improve the public awareness of the importance of agricultural organic waste treatment, enhance environmental awareness, and promote public active participation and support for related work.

To sum up, the goal of Chinas policy for agricultural organic waste treatment is to realize resource recycling, environmental protection and sustainable agricultural development, focusing on technological innovation, policy support, supervision and law enforcement, and public awareness improvement. The implementation of these policy objectives and priorities will help to promote the development of agricultural organic waste treatment in China, and realize the green development of agriculture and ecological civilization construction.

6.8.10 Impact of the policy on agricultural organic residue disposal

1. **The impact of policies on handling technological innovation**

Promote processing technology innovation:

Scientific and technological innovation supports the construction of a strong agricultural country. In 2022, the CPC Central Committee and the State Council issued the opinions on accelerating the innovation of Agricultural Science and Technology and continuously enhancing the supply guarantee capacity of agricultural products. The policy support and guidance can stimulate scientific research institutions and enterprises to invest in the research and development of agricultural organic waste treatment technology. Encourage the development of more efficient and environmentally friendly treatment technologies, such as biological treatment and pyrolysis and gasification, through the establishment of scientific research projects and providing financial support. Innovation in these technologies can not only improve the efficiency of waste treatment, but also reduce treatment costs and environmental pollution.

Promote the change of treatment mode

Policies can guide the transformation of agricultural organic waste treatment from traditional incineration, landfill and other ways to resource utilization. For example, encourage the development of biogas projects to convert waste into clean energy; promote composting technology, produce organic fertilizer; support biomass power generation, realize the energy utilization of waste, etc. These changes in treatment models can not only reduce waste emissions, but also create economic benefits and promote the sustainable development of agriculture.

2. **The impact of policies on handling industrial development**

Promote the innovation and application of treatment technology

Policies can encourage enterprises and scientific research institutions to carry out research and development of agricultural organic waste treatment technology by providing financial support and research and development subsidies. This helps to promote continuous innovation in processing technology, improve processing efficiency and quality, and reduce processing costs.

Guide industrial investment and development

Relevant policies issued by the government can attract social capital to invest in the agricultural organic waste treatment industry. For example, giving policies and measures such as tax incentives and loan support can stimulate the investment enthusiasm of enterprises, promote the construction and operation of processing facilities, and promote the large-scale development of the industry.

Standardize the treatment market order

Policies can formulate relevant standards and norms, strengthen the supervision of agricultural organic waste treatment enterprises, ensure that the treatment process meets the environmental protection requirements, and prevent secondary pollution. This will help to standardize the market order, improve the overall level of the industry, and protect the public interest.

Promote industrial structure adjustment

Policies can guide the agricultural organic waste treatment industry to the direction of specialization, scale and intensification. By encouraging enterprises to integrate and reorganize, improve the industrial concentration degree, optimize the allocation of resources, and realize the sustainable development of the industry.

Promote the development of circular economy

Agricultural organic waste treatment is an important part of circular economy. Policy support can promote the resource utilization of waste, convert the waste into useful products such as energy and fertilizers, realize the recycling of resources, and reduce the pressure on the environment.

International cooperation and exchange

Policies can support international cooperation and exchange in the field of agricultural organic waste treatment, introduce foreign advanced technology and experience, and improve the level of Chinas treatment industry. At the same time, it can also promote Chinese processing enterprises to go out and participate in the international market competition.

Address climate change

The treatment of agricultural organic waste can reduce greenhouse gas emissions, which is a positive response to climate change. Policy guidance can encourage enterprises to adopt a more environmentally friendly approach and improve the effect of carbon emission reduction.

To sum up, the policy has many effects on the development of the agricultural organic waste treatment industry. Through the policy support and guidance, it can promote the innovation of treatment technology, promote the healthy development of the industry, and realize the win-win situation of the resource utilization of agricultural organic waste and environmental protection.

3. The impact of policies on farmers participation in the treatment

The impact of Chinas policy on agricultural organic waste treatment is multifaceted, including the impact on farmers participation in the treatment. The formulation and implementation of policies can affect the enthusiasm and behaviour of farmers to participate in agricultural organic waste disposal in various ways.

First, policies can provide economic incentives to encourage farmers to participate in waste disposal. For example, the government can provide subsidies or incentives to encourage farmers to adopt environmentally friendly waste disposal methods, such as compost, and biogas digesters. These economic incentives could reduce the cost of farmers to of waste and increase their willingness to participate.

Secondly, the policy can strengthen the supervision and law enforcement of agricultural organic waste treatment. By formulating strict regulations and standards, the government can require farmers to dispose of waste in prescribed ways to reduce environmental pollution and resource waste. At the same time, strengthening law enforcement can ensure the effective implementation of policies and punish violations, so as to improve farmers awareness and responsibility of environmental protection.

In addition, policies can provide technical support and training to help farmers master effective waste disposal methods and skills. The government may organize training courses, demonstration projects and technology promotion activities to teach farmers the knowledge and technology of waste disposal and improve their disposal capacity and level. This will help farmers to better participate in waste disposal and achieve better results.

The impact of policy on farmers participation in treatment is also reflected in improving farmers environmental awareness and sense of responsibility. Through publicity and educational activities, the government can popularize the importance of environmental protection to farmers and make them realize the impact of waste disposal on the sustainable agricultural development and the ecological environment. This will stimulate farmers awareness of environmental protection, encourage them to actively participate in waste disposal, and contribute to environmental protection.

Finally, the policy stability and continuity are also very important for farmers to participate in the treatment. If policy changes frequently or lacks continuity, farmers may feel uncertain about the prospects of waste disposal, thus affecting their enthusiasm for participation. Therefore, the government should formulate long-term and stable policies to provide clear guidance and support for farmers and give them the confidence and motivation to participate in waste disposal.

In conclusion, policies have important implications for farmers participation in agricultural organic waste disposal. By providing economic incentives, enhancing regulatory enforcement, providing technical support and training, enhancing environmental awareness, and maintaining the stability and continuity of policies, governments can effectively promote farmers participation in waste disposal and achieve the goals of sustainable agricultural development and environmental protection.

6.8.11 Challenges and problems of policy implementation

1. The difficulty of policy implementation

According to the Action Plan for the Tough Battle against Agricultural and Rural Pollution (2021-2025), the difficulty of policy implementation is mainly reflected in the following aspects:

Lack of effective supervision mechanism

Although China has issued a series of policies to regulate the treatment of agricultural organic waste, but in the actual implementation process, due to the lack of effective supervision mechanism, leading to some enterprises and individuals illegally discharge organic waste, serious pollution of the environment.

Limited technical level

At present, Chinas technical level in agricultural organic waste treatment is still relatively limited, and the lack of advanced treatment technology and equipment, resulting in unsatisfactory treatment effect and low utilization rate of resources.

Insufficient capital investment

Agricultural organic waste treatment requires a large amount of capital investment, including equipment purchase, technology research and development, personnel training and other aspects. However, due to the lack of capital investment, the construction of agricultural organic waste treatment facilities in some areas lags behind, which cannot meet the actual demand.

Farmers weak awareness of environmental protection

Farmers are the main producers of agricultural organic waste, but due to the weak awareness of environmental protection and the lack of attention to organic waste treatment, a large number of organic waste is piled up at will, which seriously affects the quality of rural environment.

Poor policy publicity

Although China has issued a series of policies to regulate the treatment of agricultural organic waste, some enterprises and individuals do not understand the content of the policy and cannot deal with it according to the policy requirements.

In order to solve the difficulty of policy implementation, the following measures need to be taken:

Strengthen supervision

Establish and improve the effective supervision mechanism, strengthen the supervision of agricultural organic waste treatment, severely crack down on illegal emissions, and ensure the effective implementation of policies.

Improve the technical level

increase the investment in the research and development of agricultural organic waste treatment technology, introduce advanced treatment technology and equipment, and improve the treatment effect and resource utilization rate.

Increase capital input: The government should increase capital investment in the construction of agricultural organic waste treatment facilities, encourage the participation of social capital, and jointly promote the development of agricultural organic waste treatment industry.

Improve farmers awareness of environmental protection

Strengthen the publicity and education of environmental protection for farmers, improve their awareness of environmental protection, and guide farmers to actively participate in the treatment of agricultural organic waste.

Strengthen policy publicity

The government should strengthen the publicity of agricultural organic waste treatment policies, improve the understanding of enterprises and individuals on the policy content, and ensure the effective implementation of the policies.

2. **Technical bottlenecks and limitations**

In the process of policy implementation, technical bottlenecks and limitations are an important challenge. In the treatment of agricultural organic waste, although China has formulated a series of policies to promote the development and application of related technologies, there are still some technical problems to be solved in practice.

First of all, Chinas agricultural organic waste treatment technology is relatively backward, the lack of efficient, environmental protection, economic treatment technology. At present, the treatment of agricultural organic waste in China mainly adopts traditional methods such as landfill, incineration and composting, which have problems such as low treatment efficiency, serious secondary pollution and waste of resources.

Secondly, Chinas agricultural organic waste treatment technology research and development and application lack of financial support. Because the research and development and application of agricultural organic waste treatment technology need a large amount of capital investment, and the Chinese government has relatively little investment in this aspect, leading to the slow development and application of related technologies.

Finally, the popularization and application of agricultural organic waste treatment technology in China lack of effective policy support. Because the promotion and application of agricultural organic waste treatment technology needs the government to issue the relevant policy support, and the Chinese government has relatively little policy support in this respect, resulting in the promotion and application of related technologies is difficult.

In order to solve the problems above, the Chinese government needs to increase the capital investment in the research and development and application of agricultural organic waste treatment technology, introduce relevant policy support, strengthen the promotion and application of relevant technologies, improve the level and efficiency of Chinas agricultural organic waste treatment technology, and promote the sustainable development of Chinas agriculture.

3. Imperfect market mechanism

The imperfect market mechanism is an important challenge facing Chinas policy in the treatment of agricultural organic waste. At present, Chinas agricultural organic waste treatment market is still in the primary stage, the market mechanism is not sound enough, and there are some problems.

First, the market subject is single. At present, Chinas agricultural organic waste treatment mainly depends on the input of the government and enterprises, the market subject is relatively single and lacks of diversified market participation. This leads to insufficient market competition, low efficiency of resource allocation, and it is difficult to meet the needs of agricultural organic waste treatment.

Secondly, the market price formation mechanism is unreasonable. Due to the single market subject, insufficient market competition, the price formation mechanism of agricultural organic waste treatment is unreasonable, and the price cannot reflect the market supply and demand relationship and the degree of resource scarcity. This leads to the high cost of agricultural organic waste treatment, and the low enthusiasm of enterprises and farmers, which affects the implementation effect of the policy.

In addition, the market regulation is not in place. At present, there are still some loopholes in the market supervision of agricultural organic waste treatment in China, and the supervision is not in place, leading to some enterprises and individuals illegal treatment of agricultural organic waste, affecting the environmental quality and people´s health.

In order to solve the problem of imperfect market mechanism, our government should take the following measures:

First, we need to foster diversified market entities. The government should encourage social capital to participate in the treatment of agricultural organic waste, cultivate diversified market subjects, improve the degree of market competition, and promote the improvement of resource allocation efficiency. Second, we will improve the market-price-setting mechanism. The government should establish and improve the market price formation mechanism for agricultural organic waste treatment, reasonably determine the price, reflect the relationship between market supply and demand and the degree of resource scarcity, and improve the enthusiasm of enterprises and farmers. Third, we will strengthen market oversight. The government should strengthen the supervision of the agricultural organic waste treatment market, establish and improve a sound supervision system, strengthen the supervision of enterprises and individuals, severely crack down on the illegal disposal of agricultural organic waste, and ensure the environmental quality and the health of the people.

In short, the imperfect market mechanism is an important challenge facing Chinas policy in the treatment of agricultural organic waste. The government should take effective measures to cultivate diversified market entities, improve the market price formation mechanism, strengthen the market supervision, promote the perfection and perfection of the market mechanism, and improve the efficiency and quality of agricultural organic waste treatment.

6.8.12 Future policy prospects and recommendations

1. Policy adjustment and improvement

In the future, the impact of Chinas policies on agricultural organic waste treatment will continue to play an important role. In order to better cope with the challenge of agricultural organic waste treatment, the policies need to be constantly adjusted and improved. The following are some suggestions for policy adjustment and improvement:

Strengthen the construction of laws and regulations

Formulate and improve relevant laws and regulations, clarify the responsibilities and obligations of agricultural organic waste treatment, and strengthen the punishment for violations.

Increase financial input

Increase financial support for the treatment of agricultural organic waste, encourage enterprises and farmers to adopt environmental protection technology and equipment, and improve the efficiency and quality of treatment.

Promotion of green agriculture

Strengthen the publicity and promotion of green agriculture, encourage farmers to adopt ecological planting and breeding methods, and reduce the generation of agricultural organic waste.

Establish and improve the recycling system

Establish and improve the agricultural organic waste recycling system, strengthen the classification and collection of waste, and improve the recycling rate.

Strengthen technology research and development

Increase investment in the research and development of agricultural organic waste treatment technology, encourage enterprises and scientific research institutions to cooperate, and develop more efficient and environmentally friendly treatment technologies.

Improve the public awareness

Strengthen the publicity and education to the public, improve the public awareness and awareness of agricultural organic waste treatment, and encourage the public to actively participate in the waste treatment work.

In short, the future policy adjustment and improvement need to consider various factors, strengthen the construction of laws and regulations, increase financial investment, promote green agriculture, establish and improve the recycling system, strengthen technology research and development and improve the implementation of public awareness, will help promote the healthy development of agricultural organic waste disposal work, realize the goal of agricultural sustainable development.

2. Strengthen supervision and evaluation

Strengthening supervision and evaluation is the key link to ensure that Chinas policies have a positive impact on agricultural organic waste treatment. Here are some specific suggestions:

Establish and improve the supervision system

The government should establish a sound supervision mechanism, clarify the responsibilities and authority of each department, and strengthen the supervision of the whole process of agricultural organic waste treatment. At the same time, we will strengthen law enforcement and severely crack down on violations of laws and regulations.

Strengthen monitoring and evaluation

Establish a monitoring system for agricultural organic waste treatment, and regularly evaluate the treatment effect. Through the monitoring data, find out the problems in time and take corresponding measures to solve them.

Improve the supervision ability

Strengthen the training of supervision personnel, and improve their professional level and supervision ability. At the same time, the necessary monitoring equipment and technical means should be equipped to make the supervision more scientific and accurate.

Strengthen social supervision

Encourage the public to participate in the supervision of agricultural organic waste treatment, establish a reporting system, and expose and punish violations of laws and regulations.

Establish an information disclosure system

The government should timely disclose the relevant policies, regulations and standards for the treatment of agricultural organic waste, as well as the information of the processing enterprises, and accept social supervision.

Strengthen the supervision of treatment enterprises

Conduct strict qualification examination of enterprises engaged in agricultural organic waste treatment to ensure that they have the corresponding technical and management capabilities. At the same time, we should strengthen the daily supervision of enterprises and urge them to deal with them in strict accordance with the relevant standards and norms.

Promote industry self-discipline

Encourage the agricultural organic waste treatment industry to establish self-discipline organizations, formulate industry norms and standards, strengthen industry self-discipline, and improve the overall level of the industry.

Strengthen international cooperation and exchanges

Actively participate in international cooperation and exchanges, learn from the advanced foreign regulatory experience and technologies, and improve Chinas regulatory level.

By strengthening supervision and evaluation, we can ensure the effective implementation of agricultural policies on agricultural organic waste treatment, promote the sustainable development of agriculture and protect the ecological environment.

3. Promoting public participation and awareness improvement

In order to promote public participation and awareness of agricultural organic waste disposal, we can start from the following aspects:

<u>Strengthen environmental education</u>

Popularize the importance and methods of agricultural organic waste disposal to the public through schools, communities and media channels. Prepare relevant teaching materials and publicity materials, and hold environmental protection lectures and training activities to improve the public´s understanding and understanding of environmental protection issues.

<u>Establish a public participation mechanism</u>

The government can establish a public participation platform, such as advisory committees and hearings, so that the public can participate in the process of policy formulation and project implementation. Encourage the public to make opinions and suggestions, and promote the communication and interaction between the government and the public.

<u>Carry out environmental protection publicity activities</u>

Organize various publicity activities through important environmental protection festivals, such as environmental protection exhibitions, artistic performances and volunteer activities. Through these activities, the public will pay attention to environmental issues and stimulate their environmental awareness and responsibility.

<u>Strengthen information disclosure</u>

The government should timely disclose the relevant policies, regulations and project progress of agricultural organic waste treatment, so that the public can understand the work trends of the government. At the same time, an environmental information disclosure platform will be established to facilitate public inquiry and supervision.

<u>Promote environmental protection technologies and products</u>

Promote advanced agricultural organic waste treatment technologies and products through demonstration projects and subsidy policies. We will encourage enterprises and research institutions to carry out technological innovation and develop more environmentally friendly and efficient treatment methods and equipment.

<u>Establish an incentive mechanism</u>

To commend and reward the public and enterprises that actively participate in the treatment of agricultural organic waste, such as issuing honorary certificates of environmental protection and providing tax incentives, etc. Encourage more people to get involved in environmental action.

Strengthen international cooperation

Actively participate in international environmental protection cooperation and exchanges, and learn from the advanced experience and technologies of other countries and regions. Through international cooperation, promote the improvement of China´s agricultural organic waste treatment level.

Improve farmers awareness of environmental protection

Strengthen environmental protection education and training for farmers, and improve their understanding and skills of agricultural organic waste treatment. Farmers are encouraged to adopt environmentally friendly farming and breeding methods to reduce waste production.

Cultivate environmental protection volunteer team

Organize and train environmental protection volunteer team, and carry out environmental protection publicity, supervision and service activities. Volunteers can play an active role in communities, schools and rural areas to promote public participation and awareness.

Strengthen supervision and law enforcement

The government should strengthen the supervision and law enforcement of agricultural organic waste disposal, and severely crack down on illegal waste discharge and disposal behaviours. At the same time, a reporting mechanism will be established to encourage the public to report illegal activities.

Through the implementation of the above measures, it can effectively promote public participation and awareness, promote the smooth development of agricultural organic waste treatment in China, and make contributions to the construction of a beautiful China.

7 Conclusion

By the literature review as well as the first and second round of expert interviews, we got valuable insights. The implementation of the methods was successful and the intermediate results confirm the research strategy.

The general feedback of the experts on the European side can be summarized in key points:

1. Agricultural residues are currently undervalued and experts expressed a strong need for innovative uses of agricultural residues.
2. Value chains that add value are strongly preferred
3. PHA, PHA applications and MP were seen as promising targeted end products.
4. Legislation can be a major driver or a critical barrier to the market potential of PHA and MP.
5. Price is a major challenge for the competitiveness of PHA and MP
6. There are several limitations and potential barriers to be considered for valorisation and end products.
7. The market potential of PHA and MP end products is generally considered to be very high.

This feedback shows that the challenges/barriers we are addressing in this project are well known and that there is a high level of interest in finding solutions within the industry. In the following, the most important results of Delphi I and Delphi II are divided into 4 sections as done before.

Valorisation

As a result of the first round of stakeholder interviews, experts stated that the current valorisation processes for agricultural by-products aim to enhance their value, with benefits including environmental and economic gains. Satisfaction is often low due to profitability, legislation, and unequal campaigns, but it improves when environmental concerns or profit strategies are prioritized. Experts expect increased profits through ideal valorisation processes focusing on high added value and simplicity in logistics. Potential pathways include organic fertilizer, protein products, green hydrogen, and animal nutrition additives. Supportive factors include financial aid, favorable legislation, and effective networks. Challenges include transportation costs, volume management, processing difficulties, climate change impacts, and restrictive legislation. Collaboration between research institutions, universities, and companies is crucial, and innovative solutions like insect-based food and microorganism transformations are explored. The economic and market situation of production, along with farmer involvement, is vital for successful valorisation scenarios. The industry explores innovative solutions like insect-based food and microorganism transformations for added value.

In agreement with the previous results, experts in the second round of Delphi interviews have expressed a strong need for innovative uses of agricultural residues, highlighting the potential for significant economic benefits. It is expected that effective valorisation strategies will lead to increased profitability by creating new uses for agricultural by-products, particularly in industries such as tomatoes where under-utilisation is widespread. In addition, increasing producer loyalty and marketability through effective valorisation initiatives is considered essential. However, experts also highlighted concerns about uneven profitability and the need for supportive legislation, advocating harmonised regulations to facilitate the valorisation process. The demand for sustainable practices within the food industry further reinforces the favourable environment for valorisation efforts, indicating a critical driver for advancing the circular economy in agriculture.

PHA

Experts in the first round of Delphi interviews expect PHA products to be GMO-free, prioritize 100 % PHA for optimal biodegradability, and foresee a decrease in PHA cost to €2.5/kg within the next 5 years. Market potential is high in agriculture and horticulture, with soil or compostable properties desired. Limitations include high production costs, scalability challenges, ecological concerns, quick degradation in soil or water, and limited feedstock availability. The agricultural industry is open to a small added cost for biodegradable PHA, presenting opportunities with favourable legislation and subsidies. Suitable applications include mulching films, vine clips, grow bags, blends, and twines, while some applications like flexible twine, injection products, plant pots, and PHB mulch films are deemed unsuitable.

The results the second round of Delphi interviews show a collective eagerness among stakeholders to improve the material properties and processing capabilities of PHA products. There is a consensus that reducing the high initial cost of production is critical to ensuring PHA's competitiveness with conventional plastics. In addition, clarity on the regulatory framework for PHA products is sought to facilitate market entry and consumer acceptance. Despite these challenges, stakeholders estimate a significant market potential for PHA, particularly in agricultural and food packaging applications. Growing consumer preference for sustainable materials is expected to drive demand for PHA, provided that advances in biopolymer technology can optimise production processes and scalability.

PHA-Applications

Experts anticipate that bio-based and bio-degradable PHA applications should be cost-effective, durable, and meet agronomic needs while saving time. However, current attempts with "bio" plastics have led to increased prices and consumer perceptions. Regarding PHA application quality, experts emphasize the importance of materials being free from harmful contamination, with purity considered less decisive. While customers may be willing to pay more for bio-based and biodegradable PHA applications, tight profit margins in the industry necessitate new business plans for guaranteed profits. Limitations include the decisive factor of pricing, the need for favourable legislation, and concerns about by-product availability. Supportive legislation, further research, and interest in biodegradable plastics in agriculture are seen as potential solutions, with specific applications like biodegradable bags and pots for plant cultivation suggested. Despite environmental benefits, challenges include higher prices, machinery requirements, stable supply needs, and issues with recycling processes. Experts find certain applications, such as mulch films, horticultural pots, twines, and more, generally suitable, but scepticism arises due to cost and performance concerns. Additionally, suggestions for biodegradable pots, weed fabrics, and other applications are noted, while certain applications like bio-packaging and pots in intensive production cycles are deemed unsuitable.

MP

Experts of the first round of Delphi interviews anticipate unproblematic protein quality in extracted proteins but recognize potential uric acid issues in MP. Quality-inhibiting factors for MP include microbial risks, contamination, toxicity, and anti-nutritional factors. Despite concerns about fermentation, texture, and practical conditions, experts view MP as practically similar to conventional proteins. While AgriLoop's chosen residues/by-products are deemed generally relevant and suitable, the changing quality of agricultural residues poses challenges. Major limitations include pricing factors, legislative constraints, challenging processes, and logistical difficulties, with experts expressing optimism about potential legislative changes. Scalability is considered good in terms of coproduct availability, but technological capacity, contamination, and investment costs may limit scalability. Experts doubt customer acceptance in food applications due to the well-known nature of conventional proteins, and price convergence between microbial and conventional proteins is expected, with a 5-10 % price increase accepted in commercial volumes and potential future cost decreases. The market potential for MP is considered very high, especially in animal feed, plant fertilizers, and human nutrition, with MP seen as 100 % replacements for conventional proteins in animal nutrition. While arthropods are deemed usable for human food, MP are viewed as less suitable. Animal feed is unanimously seen as the most suitable application, with potential in the food industry, plant fertilizers, and pet food, while challenges include energy costs, functionality, and pricing.

The results of the second round confirm those of the previous round. Experts recognised the significant potential of MP, particularly in feed applications, positioning it as a sustainable alternative to traditional protein sources such as fishmeal. Stakeholders emphasised the need for competitive pricing for MP to gain market share, as well as ongoing research to address sensory and textural concerns. There is an optimistic outlook for consumer acceptance of alternative proteins, particularly among environmentally conscious younger generations. However, regulatory hurdles remain a significant barrier to the integration of MP into human food products. Overcoming these barriers could unlock significant market opportunities, particularly as demand for sustainable food options increases. In addition, partnerships with feed manufacturers are seen as essential to accelerate market entry and establish MP as a mainstream protein source.

Looking at the Chinese market assessment provides a comprehensive assessment of China's agricultural landscape, highlighting the challenges and opportunities associated with the management and use of agricultural organic residues. As agricultural production contributes significantly to China's economy, there is a growing need for sustainable solutions to manage by-products such as crop straw, livestock manure and food processing waste. The report highlights the underutilisation of these by-products, with issues such as low recycling rates, high treatment costs and insufficient technological support. The report also outlines the potential of agricultural by-products for bioenergy production, animal feed and organic fertilisers, and suggests that improved infrastructure, technological innovation and policy support can unlock significant environmental and economic benefits. Finally, the analysis calls for increased efforts to improve waste management systems, reduce environmental impacts and promote a circular economy approach within the agricultural sector.

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Data Management Plan follow-up

N°	Dataset name	Open Data	Closed Data	Means of dissemination	Maximum delay before access	Data set access
1	WP1.1_ECOZEPT_BS	Results of interviews conducted with different types of stakeholders (data of experts' assessment will be collected) in Workpackage 1 Task 1.1	A pseudonymized data set containing sensitive personal data (GDPR)	Scientific and popularized publications, conferences, various dissemination and capacity-building events	Once published and at the latest 2 years after the end of the project	Ecozept intern data
2	WP1.1_INRAE_PB	Collection of interviews containing expert knowledge on agricultural waste valorization, annotated using the Delphi I method and associated with pseudonymized stakeholders	A pseudonymized data set containing sensitive personal data (GDPR)	Scientific and popularized publications, conferences, various dissemination and capacity-building events	Once published and at the latest 2 years after the end of the project	https://doi.org/10.57745/91BXIY

Table 18: Summary of the main information regarding the data produced for this deliverable.

This table above sums up the main information regarding the data produced for this deliverable, where is it stored and are the specific rules to respect concerning access, publication and FAIR principles.

N°	Dataset name	Owner	Name of the current contact	IPR issues	Use of third-party	Restrictions on data sharing (Y/N)
1	WP1.1_ECOZEPT_BS	Ecozept	Jan Linck	Require data transfer contract with chinese partners for closed data	no	Yes, compliance with GDPR (see closed data)
2	WP1.1_INRAE_PB	INRAE	Pierre Bisquert	Require co-responsible contract for personal data treatment to be signed between INRAE and ECOZEPT	no	Yes, compliance with GDPR (see closed data)

Table 19: Summary of main information regarding potential Intellectual property protection or GDPR issues.

This table above sums up the main information regarding potential Intellectual property protection or GDPR issues.

Annex I. Guidelines for the first round of AgriLoop stakeholder interviews according to the Delphi method

Research questions:

1. What are the general market opportunities for PHA/MP?
2. What are stakeholders’ expectations regarding the valorisation/the function of PHA/MP?
3. What are the actual and potential limits/barriers for the current valorisation / PHA/MP?

Table 1: Examined feedstock (in line with examined residue streams of DSS+):

Apple
Tomato
Grape
Potatoes
brewer's spent grains

Table 2: Examined end-products

Raw material	**Sub-category**
PHA	mulch films
	horticultural pots
	twines
	growth protectors
	greenhouses
	nets
	grow/seedling bags
Microbial proteins (for animal feed)	
Extracted proteins (for animal feed)	

Table 3: List of stakeholder groups

Stakeholder category	**Sub-group**	**Feedstock/end-product**
Suppliers of residual streams	Arable farmers, horticulture businesses and plant production as far as they produce or re-use by-products themselves	All feedstock (Table 10)
	Food processors	All feedstock (Table 1)
	Traders by-products	All feedstock (Table 1)
Converters, traders and processors of PHA	Converters and users of bioplastics	PHA applications (Table 11
Feed traders and processors of microbial and extracted proteins	Feed traders	Microbial and/ or extracted proteins
	Feed processors	Microbial and/ or extracted proteins
Potential users of microbial and extracted proteins	Livestock farmers	Microbial and/ or extracted proteins
Potential users of PHA applications	Arable farmers/ horticulture businesses; applied practical research (national research centers, e.g. Landesanstalten in Germany)	PHA applications (Table 2)

First page for all the following interview guidelines

AgriLoop stakeholder survey – Delphi round 1: Market opportunities, stakeholders' expectations, potential limits and barriers of PHA, microbial and extracted proteins

Last updated 17/07/2023

AF: Important hints The interviewees will have to sign the consent form if they agree to participate in the study. Please make sure that he or she has received the lime survey link and agreed to the terms before the interview. If it is not the case, remind the expert to open the e-mail and click on the link to fill in their personal information and agree to the displayed terms. In case the interviewee cannot respond to the question asked, you should first ask him or her if another person within her or his company could answer this question and who it would be. If no one can answer the question, just document it in the records that they do not know the answer.

Name:	Organisation:	Job:
Date:	Country:	Residue-stream/ application:
Website of company Interviewer: *Only for interview administration. Results will be treated anonymously.*		

Formatting guide

Green: adaptions for the individual expert

Introductory words (can be adapted freely according to stakeholder groups)

The AgriLoop project aims at eco-efficiently upgrading underexploited residues into a portfolio of high added-value bio-products. We will develop processes to convert a range of agri-residues (e.g. tomato, potato, livestock sectors) into extracted and microbial proteins, bio-based and bio-degradable material to be used for feed and materials applications, especially by the farming sector without competing with food supply. We are now identifying market opportunities including limitations and try to identify expectations of stakeholders within the value chain.

We thank you very much that you are taking time for this interview. It is important for us to get insights from professionals of the sector. You can obtain a free copy of the resume of this study.

I will document this interview in written form by typing your answers directly into a document and your answers will of course be treated confidentially.

In the AgriLoop project, Ecozept/DSS+ is responsible for the market studies. If you have in-depth questions about the technologies, we are happy to clarify these in consultation with the project partners after the interview.

Is the procedure clear to you? Do you have any questions? Then I will directly start with the first question.

I. *Questionnaire 1 for arable farmers/ horticulture businesses/ plant production / food processors (= suppliers of residual streams)*

Block "Introduction and ice breaker":

1. To begin with, please briefly describe your company and your position within the company.
2. Which type of residue stream (apple, tomato, grape, potatoes, or brewer's grains) do you deal with in your company?

Block "strengths and challenges"

3. How do you currently valorize your agricultural by-products of apple-/tomato-/grape-/potato processing/brewer's grains (see Table 1)? (Q6) (additional question)
4. Which are the strengths and advantages in the current valorisation of by-products of apple-/tomato-/grape-/potato processing/brewer's grains ? (Q7)
5. Please describe your challenges regarding the valorisation of your agricultural by-products from apple-/tomato-/grape-/potato processing /brewer's grains (Q34) as of today, e.g.:
   - Transportation
   - Logistics of the required volumes (e.g. storage, regional distribution)
   - Oxidation/ chemical deterioration
   - Smells
   - Limitation for use as fertilizer / as compost component
   - Processing difficulties due to chemical composition (e.g. high lignin content of grape stalk)
   - Limited seasonal availability of feedstock/ poor continuity throughout the year
   - Legislative issues
   - Other ______________
6. How could these challenges be overcome? (Q36)

Block "current structures"

7. When you provide your agricultural by-products for this valorisation pathway, how much do you get paid (*important: ask exactly for which unit the price applies, e.g., per ton wet material, per ton dry material, per cubic meter, etc.)*? Who organizes the transport of the by-products? Who pays for the transportation of the by-products? (Q29)
8. How satisfied are you with your current valorisation of apple-/tomato-/grape-/potato processing/brewer's grains (see Table 1)? Why? (Q8.1) E.g., regarding
   - Profitability
   - Legislation
   - Traditional reasons
   - Personal relationships
   - Effort
   - Other ______________
9. Are you aware of other alternative valorisation pathways that might be better than the current one? (Q8) Yes – No if Yes: Which ones?

Block "expectations"

10. Which would be your ideal solution for the valorisation of your by-products of apple-/tomato-/grape-/potato processing /brewer's grains (see Table 1)? Could you explain, why? (Q8.2) *(Internal remark: if interviewee does not know any other pathways, give examples like conversion in plant proteins, re-use as manure on the farm, produce mulch-films for application on own farm, etc.)*
11. What kind of support would you need for this ideal valorisation of the by-products of apple-/tomato-/grape-/potato processing /brewer's grains (see Table 1)? (Q8.3) E.g.,
    - Financial support

- Organizational support
- Supportive legislative framework
- Support regarding contact persons/ network/ supply structures
- Other _____________

12. What are your expectations regarding the valorisation of by-products from apple-/tomato-/grape-/potato processing /brewer's grains (see Table 1)? (Q8.4) E.g., regarding
    - Effort
    - Benefits
    - Other ___________

Block „Outlook and perspectives"

13. Do you observe any new interesting solutions in the area of valorisation of by-products from apple-/tomato-/grape-/potato processing /brewer's grains in your professional environment? (Q8.5)
14. In your opinion, where is the development going regarding the use of the by-products from apple-/tomato-/grape-/potato processing /brewer's grains? (Q8.6)

II. Questionnaire 2 for traders, processors, converters of the end-product PHA

Block "Introduction and ice breaker":

1. To begin with, please briefly describe your company and your position within the company.
2. Which type of residue stream (apple, tomato, grape, potatoes or brewer's grains) do you deal with in your company? OR Which material/ end products (mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from PHA) do you manufacture in you company?

Block 1: Market opportunities

3. How do you assess the market potential of mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from PHA; see Table 2? How do you assess it compared to conventional materials? (Q9)
4. Which factors determine market potential of mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags of PHA predominantly? (Q10), e.g.:
    - Logistics
    - Price
    - Legislation
    - Availability of by-products
    - Etc.
5. In how far do you think that mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2) are the best application of PHA in agriculture? (Q12)
6. Which other applications of PHA are attractive in terms of functionality (e.g., mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags, etc.)? (Q13)
7. For which agricultural applications is PHA not suitable? Why? Which functions are missing? (Q14)

Block 2: Stakeholders' expectations

8. Which functions does PHA as material has to fulfill for use in agricultural applications like mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2)? (Q23)
    - material description:
    - The way consumers use it:
    - Its expected service life:
    - Key features appreciated by consumers:
    - Key features appreciated by industries:
    - Ability to print on the material; example: Printability is key.
    - Etc.
9. Which expectations to mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags of PHA do you have regarding its quality? (Q24)
10. In how far is contamination of the material an issue?
11. In case you produce composite products: Which degree of purity do clients ask for mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags? Does it have to consist from 100 % PHA? Could it partwise be supplemented with, e.g., cellulose? (Q25)
12. How do you assess price development of PHA applications for agriculture, in this case for mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2)? On which factors does the price development depend? (Q28)

Block 3: Limits and barriers

13. Please describe the challenges regarding the application of mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2) from PHA, e.g.:
    - seasonal availability of agricultural by-products
    - regional distribution of agricultural by-products
    - prices
    - transportation
    - allocation of feedstock
    - availability of feedstock
    - processing difficulties
    - scalability, etc. (Q34)
14. How could these challenges be overcome? (Q36)
15. How fast could scalability of PHA applications from agricultural residues like mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags take place in your opinion? (Q38)

III. *Questionnaire 3 for arable farmers/ horticulture businesses as users of the end-product PHA applications (mulch films etc. according to Table 2)*

Block "Introduction and ice breaker":

1. To begin with, please briefly describe your company and your position within the company.
2. Which products made of plastic (mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags) do you use in your farm/ business?

Block 1: Market opportunities

3. In how far are bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2) from agri-residues a better solution than products from petrochemicals for you? (Q3)
4. Which further advantages do bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues have for you?(Q4)
5. Which disadvantages do they have? (Q5)
6. In how far do you think that bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2) are the best application from agri-residues in agriculture? (Q12)
7. Which other bio-based and bio-degradable applications from agri-residues are attractive to you in terms of functionality (like, e.g., mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags; see Table 2)? (Q13)
8. For which agricultural applications are applications from agri-residues not suitable for you? Why? Which functions could not be fulfilled compared to conventional materials? (Q14)

Block 2: Stakeholders' expectations

9. Which functions do bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues have to fulfill for you? (Q23 ff) (e.g., resistance to weather conditions/ snow/ humidity/ high solar radiation, material must last at least 6 months, etc.)
    - material description:
    - expected service life:
    - expected resistance of the material; example: resistance at all point of the value-chain (production, logistics, home storage)
    - Technical requirements related to appearance; example: transparency is not an issue.
    - Etc.
10. In how far is contamination of the material an issue? (Q26)
11. Which degree of purity do you need for mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags? Does it have to consist from 100 % PHA as material? Could it partwise be supplemented with, e.g., cellulose? (Q25)
12. Under which circumstances would you be willing to pay a higher price for bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues than for conventional materials? (Q27)

Block 3: Limits and barriers

13. Please describe the challenges for the use of bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues for you. (Q34)
14. How could these challenges be overcome? (Q36)

Block 4: Outlook and perspectives

15. Do you observe any new interesting solutions in the area of bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues in your personal surrounding? (Q8.5)
16. In your opinion, where is the development going with regard to the application of bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues? (Q8.6)

IV. Questionnaire 4 for feed traders and processors of the end-product extracted and microbial proteins

Block "Introduction and ice breaker":

1. To begin with, please briefly describe your company and your position within the company.
2. Which type of residue stream (apple, tomato, grape, potatoes or brewer's grains) do you deal with in your company? OR Which material/ end products (mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, growth/seedling bags from PHA) do you manufacture or trade in you company?

Block 1: Market opportunities

3. To which extent could extracted/ microbial proteins fulfill the same purpose as conventional proteins? (Q16)
4. Which functions could extracted/ microbial proteins not fulfill compared to conventional proteins? (Q17)
5. What do you consider to be the best use of extracted/ microbial proteins regarding their functionality (e.g., feed for aquaculture)? (Q18)
6. Which other applications (besides feedstuff) of extracted/ microbial proteins are attractive to you in terms of functionality? (Q19)
7. Which applications are inappropriate for the use of extracted/ microbial proteins? (Q20)
8. In which markets can these proteins be applied? (Q21)
9. How do you assess the market potential for extracted/microbial proteins? (Q22)

Block 2: Stakeholders' expectations

10. Which expectations to extracted/ microbial proteins do you have regarding quality, e.g. regarding:
    - microbial risks
    - contamination
    - toxicity
    - anti-nutritional factors
    - minimum quantities of certain ingredients
    - etc. (Q31)
11. How do you assess the qualities of extracted/microbial proteins compared to conventional proteins? (Q32)
12. Which expectations regarding the qualities of agri-residues as feedstock for processing of extracted/ microbial proteins do you have? (Q32.1)

Block 3: Limits and barriers

13. How does the geographical distribution of agricultural residues (Table 1) influence the production of extracted/microbial proteins? (Q39)
14. How could this logistical challenge be overcome? (Q40)
15. Which other factors limit the market potential of extracted/microbial proteins, e.g.:
    - availability of extracted/microbial proteins as feedstuff
    - legislation
    - consumer acceptance
    - price
    - processing technology
    - infrastructural issues
    - logistics
    - allocation of feedstock
    - competition

- scalability, etc.? (Q45)

16. How do you assess the costs of conventional proteins compared to extracted/ microbial proteins? (Q41)
17. On which factors does the price of extracted/ microbial proteins depend? (Q42)
18. How do you assess the future development of prices for extracted/ microbial proteins? (Q43)
19. How do you assess the legislation regarding approval of extracted/ microbial proteins as feed (e.g., preferential treatment of extracted/ microbial as feed, impediment of extracted/ microbial as feed, etc.)? (Q44)
20. How do you assess the scalability of extracted/ microbial proteins from agricultural residues? (Q46)
21. What does the scalability depend on? (Q47)
22. How does scalability limit today's market success of extracted/ microbial proteins? (Q48)

V. *Questionnaire 5 for potential users of the end-product extracted/ microbial proteins (=livestock farmers and aquaculture)*

Block "Introduction and ice breaker":

1. To begin with, please briefly describe your company and your position within the company.
2. Which types of extracted/ microbial proteins do you use in your farm/ business?

Block 1: Market opportunities

3. Which proteins do you currently use for your purpose? (Q15)
4. To which extent could extracted/ microbial proteins fulfill the same purpose? (Q16)
5. What do you consider to be the best use of extracted/ microbial proteins regarding their functionality? (Q18)
6. Which other applications (besides feedstuff) of extracted/ microbial proteins are attractive to you in terms of functionality? (Q19)
7. Which applications are inappropriate for use of extracted/ microbial proteins? (Q20)
8. How do you assess the market potential of extracted/ microbial proteins (Q22)?

Block 2: Stakeholders' expectations

9. Which expectation to extracted/ microbial proteins do you have regarding quality, e.g.:
    - regarding microbial risks
    - contamination
    - toxicity
    - anti-nutritional factors
    - nutritional qualities
    - amino acid profile
    - digestibility
    - feed conversion ratio
    - minimum quantities of certain ingredients, etc. (Q31)
10. How do you assess these qualities compared to conventional proteins? (Q32)
11. Under which circumstances would you be willing to pay a higher price for extracted/ microbial proteins than for conventional feedstock? (Q33)

Block 3: Limits and barriers

12. Which factors limit the market potential of extracted/microbial proteins, e.g.:
    - availability of extracted/microbial proteins as feedstuff
    - legislation
    - consumer acceptance
    - price
    - processing technology
    - infrastructural issues
    - logistics
    - allocation of feedstock
    - competition
    - scalability, etc.? (Q45)
13. How do you assess the costs of conventional proteins compared to extracted/ microbial proteins? (Q41)
14. On which factors does the price of extracted/ microbial proteins depend? (Q42)
15. How do you assess the future development of prices for extracted/ microbial proteins? (Q43)
16. How do you assess the legislation regarding approval of extracted/ microbial proteins as feed (e.g., preferential treatment of extracted/ microbial as feed, impediment of extracted/ microbial as feed, etc.)? (Q44)

Block 4: „Outlook and perspectives“

17. Do you observe any new interesting solutions for the use of extracted/ microbial proteins in your personal surrounding? (Q22.1)
18. In your opinion, where is the development going with regard to the use of extracted/ microbial proteins? (Q22.2)

Last page for all of the interview guidelines above

We are already approaching the end of our interview. I only have some last organizational questions for you.

1. Are there aspects about the topic of the interview that are relevant for you but that we did not consider in our interview? Could you specify them please?

2. Do you know further experts about the topic of the interview who would be interested to participate in the survey?

3. Are you interested in receiving a summary of the results of this study? This document will of course not disclose any confidential information. If yes, I would need your e-mail address, please: ___________________________

The interview is now over. We thank you for your participation.

Postscript of the interview
Anything particularly noticeable during the interviews? E.g. Interruption, tense discussion atmosphere? Did the interviewee give relevant information after the official end of the interview? If so, please note it in the postscript section

Annex II. Guidelines for the second round of AgriLoop stakeholder interviews according to the Delphi method

Research questions:

4. What are the general market opportunities for xyz?
5. What are stakeholders' expectations regarding the valorisation/the function of xyz?
6. What are the actual and potential limits/barriers for xyz?

Table 1: Examined feedstock (in line with examined residue streams of DSS+):

Apple
Tomato
Grape
Potatoes
Brewer's grains

Table 2: Examined end-products

Raw material	**Sub-category**
PHA	mulch films
	pots
	twines (=Bindegarne)
	growth protectors (=Wuchshüllen)
	greenhouses
	nets
	grow/seedling bags
Microbial proteins (for animal feed)	
Extracted proteins (for animal feed)	
Bioproteins for food	

Table3: List of stakeholder groups

Stakeholder category	**Sub-group**	**Feedstock/end-product**
Suppliers of residual streams	Arable farmers, horticulture businesses and plant production as far as they produce or re-use by-products themselves	All feedstock (Table 1)
	Food processors	All feedstock (Table 1)
	Traders' by-products	All feedstock (Table 1)
Converters, traders and processors of PHA	Converters and users of bioplastics	PHA applications (Table 2)
Feed traders and processors of microbial and extracted proteins	Feed traders	Microbial and/ or extracted proteins
	Feed processors	Microbial and/ or extracted proteins
Potential users of microbial and extracted proteins	Livestock farmers	Microbial and/ or extracted proteins
Potential users of microbial and extracted proteins for food	Food industry, producers of protein food	Microbial and/ or extracted proteins
Potential users of PHA applications	Arable farmers/ horticulture businesses; applied practical research (national research centers, e.g. Landesanstalten in Germany)	PHA applications (Table 2)

First page for all the following interview guidelines

AgriLoop stakeholder survey – Delphi round 1: Market opportunities, stakeholders' expectations, potential limits and barriers of PHA, microbial and extracted proteins

Last updated 23/08/2024

AF: Important hints
The interviewees will have to sign the consent form if they agree to participate in the study. Please make sure that he or she has received the lime survey link and agreed to the terms before the interview. If it is not the case, remind the expert to open the e-mail and click on the link to fill in their personal information and agree to the displayed terms. In case the interviewee cannot respond to the question asked, you should first ask him or her if another person within her or his company could answer this question and who it would be. If no one can answer the question, just document it in the records that they do not know the answer.

Name:	Organisation:	Job:
Date:	Country:	Residue-stream/ application:
Website of company Interviewer: *Only for interview administration. Results will be treated anonymously.*		

Formatting guide

Green: adaptions for the individual expert

Introductory words (can be adapted freely according to stakeholder groups)

In our Horizon 2020 project "AgriLoop" (https://www.agriloop-project.eu/) powerful partners such as NOVA Institute, Wageningen Research and University of Gent work on developing processes to convert agri-residues into extracted and microbial proteins as well as bio-based and biodegradable materials. We are now identifying market opportunities including limitations and try to identify expectations of stakeholders within the value chain.

Thank you very much for taking time for this interview. It is important for us to get insights from professionals of the sector. You can obtain a free copy of the resume of this study.

I will document this interview in written form by typing your answers directly into a document and your answers will of course be treated confidentially.

In the AgriLoop project, Ecozept/FCAC is responsible for the market studies. If you have in-depth questions about the technologies, we are happy to clarify these in consultation with the project partners after the interview.

Is the procedure clear to you? Do you have any questions? Then I will directly start with the first question.

Inform: Some of the data you provide will be published anonymously

I. Questionnaire 1 for arable farmers/ horticulture businesses/ plant production / food processors (= suppliers of residual streams)

Block "Introduction and ice breaker":

16. To begin with, please briefly describe your company and your position within the company.
17. Which type of residue stream (apple, tomato, grape, potatoes, or brewer's grains) do you deal with in your company?

Block "current structures"

1. How do you currently valorise your agricultural by-products/residues of apple-/tomato-/grape-/potato processing/brewer's grains (see Table 1)? (Q6) (additional question)

2. What is the financial compensation you receive for providing your agricultural by-products for valorisation? Additionally, who handles and finances the transportation of these by-products? (***important**: **ask exactly for which unit the price applies, e.g., per ton wet material, per ton dry material, per cubic meter**, etc.*)? (Q29)

3. How integral are agricultural by-products to your current value chains? What would be the impact if these by-products were redirected to alternative valorisation pathways (economically, environmentally, eg.)?

4. A. In the previous round of expert interviews, we were told that satisfaction with the current valorisation of agricultural residues is largely low due to low profitability. Do you agree with this?

   B. Would the valorisation of your agricultural by-product apple-/tomato-/grape-/potato processing/brewer's grains in alternative pathways like PHA production to to mulch films or horticultural pots or extracted / microbial protein be a preferable alternative for you and lead to more satisfaction?
   If yes, under what conditions?

5. Which other (new, alternative) pathways have you heard of? (Q8) (not only the residues we focus on)

Block "strengths and challenges"

1. In the previous round of interviews, the experts often spoke of positive effects through valorisation. (environmental benefits, cost savings associated from reduced by-product management)
   Do you confirm this and in which domains?

   Would the valorisation of residues to PHA or protein for feed and food bring more benefits than the current standards?

2. In the previous round of interviews, the experts identified the following as the main challenges for the valorisation of agricultural by products:
   1. Transportation & Logistics

2. Processing difficulties
3. Limited seasonal availability of feedstock
4. Legislation

Do you agree with that?
Could you elaborate on each one based on your experience?

3. How could challenges in transportation & logistics, processing, seasonal availability of feedstock and legislation be overcome? (Q36) Please address one challenge at a time.

Block "expectations"

1. What would an ideal valorisation solution for **your** by-products of apple-/tomato-/grape-/potato processing /brewer's grains look like (see Table 1)? Could you explain, why? (Q8.2) ***(Internal remark: give examples like conversion in plant proteins, produce mulch-films for application on own farm, etc.)***

   Would you consider the valorisation of residues to PHA as an ideal valorisation process?

2. Experts stated that financial support, an adapted framework, and a functioning network are crucial for an ideal valorization process of by-products (apple-/tomato-/grape-/potato processing /brewer's grains see Table 1)? (Q8.5) E.g.

   Do you agree with this?

   Can you specify which financial support (level of supply chain, activity) you find most useful?

3. What are your expectations regarding the valorisation of by-products from apple-/tomato-/grape-/potato processing /brewer's grains in terms of effort and Output (Benefits from result)? (Q8.6)

   Do you agree that the valorisation to PHA or proteins gains more output compared to the current valorisation?

4. When thinking about residue-based PHA-applications for agriculture. Which products would meet for your practical needs the best? (mulch films, twines, clips, pots) (Q16.1) (do not ask to food processors)

5. Under which circumstances would you be willing to pay a higher price for PHA from agricultural residues than for conventional materials? (Q31) (do not ask to food processors)

Block „Outlook and perspectives"

6. Do you observe any new solutions in the area of valorisation of by-products from apple-/tomato-/grape-/potato processing /brewer's grains in your professional environment? (Q8.6)

7. In your opinion, where is the development going regarding the use of the by-products from apple-/tomato-/grape-/potato processing /brewer's grains? (Q8.7)
   For example outlet the most developed, production e.g.

•

II. Questionnaire 2 for traders, processors, converters of the end-product PHA

Block "Introduction and ice breaker":

Before starting with the first question I want to clarify one thing: When talking about PHA end-products we are speaking about mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling. I will not mention all of them below. However, if you have specific information on any of these products for the relevant questions, please feel free to provide it.

16. To begin with, please briefly describe your company and your position within the company.
17. Which type of residue stream (apple, tomato, grape, potatoes or brewer's grains) do you deal with in your company? OR Which material/ end products (mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from PHA) do you manufacture in you company?

Block 1: Market opportunities

18. In previous interviews, experts assessed significant market potential for PHA end-products like mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling compared to conventional materials? Do you agree with their assessment? (Q9) Why or why not?

19. Regarding the market potential of mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags of PHA, experts identified biodegradability, price, legislation and logistics as determining factors. Do you agree with all of those factors? (Q10), e.g.:

If yes, what is the most determining factor? And **why**?

20. Experts stated that mulch films are the best application of PHA in agriculture, followed by PHA clips, blends, twines, and seedling bags. Do you agree with this? Why or why not? (Q13)

21. How do you perceive the competitiveness of PHA derived from agricultural by-products in the market compared to conventional products (applications from petrochemicals)? (Q11)

6.1. Do you know any examples of specific agricultural applications where PHA products outperform conventional alternatives? (Q4)6

22. Which other applications of PHA are attractive in terms of functionality? (Q14)

23. For which agricultural applications is PHA not suitable? And **Why**? Which properties are missing? (Q15)

Block 2: Stakeholders' expectations

24. What functional requirements must PHA meet to be effectively used in various agricultural applications (e.g., mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags)? Please consider: (Q27)
    a. Material Properties: What specific characteristics (e.g., strength, flexibility, thickness) are necessary across these applications?
    b. Service Life: What is the expected lifespan for these products in practical use?
    c. Usage: How should these products perform based on typical consumer use?

25. What specific features must PHA possess for practical usability in agricultural applications like mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2)? (Q27)
    a. Key features appreciated by consumers:
    b. Key features appreciated by industries:
    c. Ability to print on the material; example: Printability is key.

26. In how far is contamination of the material/end-application an issue? (Q31)
    a. Mycotoxins
    b. Microplastic
    c. Pesticides

27. In producing composite products, experts in the previous round suggested that PHA should be partially supplemented by other materials like cellulose to compost faster. Do you agree with this? Why or why not? (Q28)

28. How do you assess price development of PHA applications for agriculture, in this case for mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2)?

    On which factors does the price development depend? (Q30)

Block 3: Limits and barriers

29. Do you agree that scalability, price, production, durability, seasonal availability of feedstock, and regional distribution are the primary challenges for the market potential of PHA? (Q36.1)

30. How could these challenges be overcome? (Q38)

31. How do you assess the scalability of PHA production? And how would you scale up? (Q39)

32. How fast could scalability of PHA applications from agricultural residues like mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags take place in your opinion? (Q40)

III. *Questionnaire 3 for arable farmers/ horticulture businesses as users of the end-product PHA applications (mulch films etc. according to Table 2)*

Block "Introduction and ice breaker":

Just one comment before we start with the first question: According to our literature review, apple, tomato, grape, potato or brewer's grains residues have a high potential in terms of volume and practical possibilities. We are therefore particularly interested in them and mention them in our questions.

17. To begin with, please briefly describe your company and your position within the company.

18. Which products made of plastic (mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags) do you use in your farm/ business?

Block 1: Market opportunities

19. To what extent are bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags (Table 2) from agri-residues a better solution than products from petrochemicals for you? (Q1)

20. What additional practical advantages do you see in using bio-based and biodegradable from agri-residues mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags? (We are talking about the practical use) (Q2)

21. What practical disadvantages have you encountered with bio-based and biodegradable applications? (Q3)

22. Which other bio-based and bio-degradable applications from agri-residues are attractive to you in terms of practical functionality (like, e.g., mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags; see Table 2)? (Q13)

23. For which agricultural applications are bio-based and biodegradable material from agri-residues not suitable for you? And why? Which functions could not be fulfilled compared to conventional materials? (Q14)

Block 2: Stakeholders' expectations

24. What functional properties must bio-based and biodegradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags meet for practical use in your operations? (Q23 ff) (Consider aspects such as durability, environmental resistance, additional functionality, practical considerations, user experience, and technical requirements related to appearance)
    Which one determines the usage the most? And **why**?

25. How important is the issue of contamination generated by the material? (Q30)

26. Would you be willing to pay a higher price for bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues than for conventional materials? (Q27)

    If yes, how much (%)

Block 3: Limits and barriers

27. Do you agree that price, legislation, availability of by-products and development are the biggest barriers for the market potential of PHA-applications from agri-residues? (Q34) Why and why not?

28. How could these barriers be overcome? (Q36)

Block 4: Outlook and perspectives

29. Do you agree that new bio-based and biodegradable solutions derived form agri-residues (e.g., mulch films, plant pots, seed bands) should be low-cost and easy to use? In detail, experts mentioned mulch films, plant pots and seed bands as most suitable solutions. Can you agree with them? (Q8.6)

30. In your opinion, where is the development going with regard to the application of bio-based and bio-degradable mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, grow/seedling bags from agri-residues? (Q8.7)

IV. *Questionnaire 4 for feed traders and processors of the end-product extracted and microbial proteins & food producers*

Block "Introduction and ice breaker":

23. To begin with, please briefly describe your company and your position within the company.
24. Which type of residue stream (apple, tomato, grape, potatoes or brewer's grains) do you deal with in your company? OR Which material/ end products (mulch films, horticultural pots, twines, growth protectors, greenhouses, nets, growth/seedling bags from PHA) do you manufacture or trade in you company?

Block 1: Market opportunities

1. How do you assess the market potential for extracted/microbial proteins for feed / food? (Q26) In the first round of interviews, experts rated the market potential for extracted/microbial protein as very high. Anlimal feed has more potential than human food. Do you agree with these results? And why?

2. In which markets can these proteins be applied? (Q21)

3. To what specific functionalities or characteristics do you prioritize when evaluating extracted/microbial proteins as alternatives to conventional products? (feed and food) (Q18)

4. Which functions could extracted/ microbial proteins not fulfil compared to conventional proteins for feed / food? (Q19)

5. What functionalities or properties do you consider essential when incorporating extracted/microbial proteins into feed/food products? (Q20)

6. What do you consider to be the best practical use of extracted/ microbial proteins in terms of feed / food regarding their functionality (e.g., feed for aquaculture)? (Q22)

7. Which other applications (besides feedstuff and food) of these proteins are attractive to you in terms of practical functionality (e.g., improved growth rates, feed efficiency)? (Q23)
8. Which applications are inappropriate for the use of extracted/ microbial proteins? (Q20)

Block 2: Stakeholders' expectations

9. What quality and functional requirements must these proteins meet for practical use in your operations (e.g., amino acid profile, digestibility, palatability, contamination levels minimum quantities of certain ingredients, sensory)? (Q33)
10. How do you assess the qualities of extracted/microbial proteins compared to conventional proteins for feed / food? (Q33)
11. Which expectations regarding the qualities of agri-residues as feedstock for processing of extracted/ microbial proteins do you have? (Q342.1)

Block 3: Limits and barriers

12. How does the geographical distribution of agricultural residues (Table 1) influence the production of extracted/microbial proteins? (Q41)

13. How could this logistical challenge be overcome? (Q42)
14. In the first round of interviews, the experts identified:
    i. Price

ii. Legislation
iii. Scalability
iv. Geography & logistics
v. Consumer acceptance and comparability

as the main barriers for the market potential of extracted/microbial proteins. Do you argee with that? (Q47)

15. How do you assess the costs of conventional proteins compared to extracted/ microbial proteins? (Q43)

16. When looking at the factors on which the price of extracted/ microbial proteins depends on, experts in the previous round named price of the coproducts, the costs of processing, e.g. purification, the price of microbial broth and the production volume. Can you prioritise the factors? (Q43)

17. Would you be willing to pay a higher price for extracted/ microbial proteins from agricultural residues? (Q45)
18. How do you assess the future development of prices for extracted/ microbial proteins? (Q45)
19. How do you assess the legislation regarding approval of extracted/ microbial proteins as feed or food (e.g., preferential treatment of extracted/ microbial as feed, impediment of extracted/ microbial as feed, etc.)? (Q46)
20. How do you assess the scalability of extracted/ microbial proteins from agricultural residues? (Q48)
21. What does the scalability depend on? (Q49)
22. How does scalability limit today's market success of extracted/ microbial proteins? (Q50)

V. *Questionnaire 5 for potential users of the end-product extracted/ microbial proteins (=livestock farmers and aquaculture, protein producers)*

Block "Introduction and ice breaker":

19. To begin with, please briefly describe your company and your position within the company.
20. Which types of extracted/ microbial proteins do you use in your farm/ business?

Block 1: Market opportunities

21. Which proteins do you currently use for your purpose? (Q15)
22. To which extent could extracted/ microbial proteins fulfill the same purpose? (Q16)
23. What do you consider to be the best use of extracted/ microbial proteins regarding their functionality? (Q18)
24. Which other applications (besides feedstuff) of extracted/ microbial proteins are attractive to you in terms of functionality? (Q19)
25. Which applications are inappropriate for use of extracted/ microbial proteins? (Q20)
26. How do you assess the market potential of extracted/ microbial proteins (Q22)?

Block 2: Stakeholders' expectations

27. Which expectation to extracted/ microbial proteins do you have regarding quality, e.g.:
    If not mentioned provide some examples:
    - regarding microbial risks
    - contamination
    - toxicity
    - anti-nutritional factors
    - nutritional qualities
    - amino acid profile
    - digestibility
    - feed conversion ratio
    - minimum quantities of certain ingredients, etc. (Q31)

And why?

28. How do you assess these qualities compared to conventional proteins? (Q32)
29. Under which circumstances would you be willing to pay a higher price for extracted/ microbial proteins than for conventional feedstock? (Q33)

Block 3: Limits and barriers

30. Which factors limit the market potential of extracted/microbial proteins, e.g.:
    - availability of extracted/microbial proteins as feedstuff
    - legislation
    - consumer acceptance
    - price
    - processing technology
    - infrastructural issues
    - logistics
    - allocation of feedstock
    - competition
    - scalability, etc.? (Q45)
31. How do you assess the costs of conventional proteins compared to extracted/ microbial proteins? (Q41)

32. When looking at the factors on which the price of extracted/ microbial proteins depends on, experts in the previous round named price of the coproducts, the costs of processing, e.g. purification, the price of microbial broth and the production volume. Can you prioritise the factors? (Q43)

33. How do you assess the future development of prices for extracted/ microbial proteins? (Q43)

34. How do you assess the legislation regarding approval of extracted/ microbial proteins as feed (e.g., preferential treatment of extracted/ microbial as feed, impediment of extracted/ microbial as feed, etc.)? (Q44)

Block 4: „Outlook and perspectives"

35. Do you observe any new interesting solutions for the use of extracted/ microbial proteins in your personal surrounding? (Q22.1)
36. In your opinion, where is the development going with regard to the use of extracted/ microbial proteins? (Q22.2).

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Last page for all of the interview guidelines above

We are already approaching the end of our interview. I only have some last organizational questions for you.

4. Are there aspects about the topic of the interview that are relevant for you but that we did not consider in our interview? Could you specify them please?

5. Do you know further experts about the topic of the interview who would be interested to participate in the survey?

6. Are you interested in receiving a summary of the results of this study? This document will of course not disclose any confidential information. If yes, I would need your e-mail address, please: __________________________

The interview is now over. We thank you for your participation.

Postscript of the interview
Anything particularly noticeable during the interviews? E.g. Interruption, tense discussion atmosphere? Did the interviewee give relevant information after the official end of the interview? If so, please note it in the postscript section