BRILIAN

Circular Future for Rural Areas

Trade-offs and synergies of the bioeconomy sector

Deliverable 3.2 (v1)

WP3 Routes for the development of a sustainable bioeconomy

Circular Bio-based Europe Joint Undertaking

Bio-based Industries Consortium

Co-funded by the European Union

The project is supported by the Circular Bio-based Europe Joint Undertaking and its members under grant agreement № 101112436. Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CBE JU. Neither the European Union nor the CBE JU can be held responsible for them.

DOCUMENT TITLE:	**Trade-offs and synergies of the bioeconomy sector**
DUE DELIVERY DATE:	**May 31st, 2025**
NATURE:	**Report**
PROJECT TITLE:	Cooperative business models for bio-based chains in rural areas.
PROJECT ACRONYM:	**BRILIAN**
INSTRUMENT:	**Collaborative Project**
CALL IDENTIFIER:	HORIZON-JU-CBE-2022
TOPIC:	HORIZON-JU-CBE-2022-IA-02 Cooperative business models for sustainable mobilization and valorisation of agricultural residues, by-products, and waste in rural areas.
GRANT AGREEMENT:	**101112436**

Organisation name of lead contractor for this deliverable:

CIRCE

DELIVERABLE TYPE		
R	Document, report	**X**
DMP	Data Management Plan	
O	Other	

DISSEMINATION LEVEL		
PU	Public (fully open)	**X**
SEN	Sensitive, limited under the conditions of the Grant Agreement	

DISCLAIMER OF WARRANTIES

This project is supported by the Circular Bio-based Europe Joint Undertaking and its members under grant agreement Nº 101112436.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CBE JU. Neither the European Union nor the CBE JU can be held responsible for them.

VERSION RECORD			
Version	Name (Partner)	Description of changes	Date
V0	**CIRCE**	Table of Contents	March 21st, 2025
V0.a.	**CIRCE**	First version	May 8th, 2025
V0.b	**Reviewers (see below)**	Comments and suggestions from partners	May 16th, 2025
V0.c	**CIRCE**	Addition of requests (2nd draft)	May 23rd, 2025
V2	**CIRCE**	Final review by coordinator	May 29th ,2025
V3	**CIRCE**	Final version 1 for submission	June 2nd, 2025

VALIDATION		
Authors	**Contributors**	**Reviewers**
CIRCE – María Dolores Mainar & Irene Gonzalez	DTI – Clara Fernando Foncillas, Angelica Tamayo Tenorio NVMT – Marta Saccomano PATURPAT – Ana Carrasco	CIRCE – Maider Gómez DTI – Clara Fernando Foncillas, Angelica Tamayo Tenorio

EXECUTIVE SUMMARY

The BRILIAN project investigates the trade-offs and synergies of bioeconomy value chains in rural Europe, focusing on three pilot cases in Spain, Denmark, and Italy. These pilots exemplify how agricultural residues and by-products can be transformed into high-value bio-based products such as biodegradable packaging, vegan proteins, and sustainable agricultural inputs. The Spanish pilot valorizes potato starch for thermoplastic applications, the Danish pilot converts rapeseed cake into protein powders and adhesives, and the Italian pilot integrates non-conventional crops like cardoon and safflower into biorefinery systems. The report reveals that these initiatives generate substantial benefits, including job creation, rural revitalization, improved resource efficiency, and alignment with EU sustainability goals. Farmers benefit from diversified income streams and the adoption of regenerative practices, while agro-industries gain access to new markets and improve operational sustainability. Local communities experience increased employment and awareness of circular economic principles, and consumers are offered more sustainable product alternatives.

However, the report also identifies significant trade-offs that must be addressed to ensure long-term viability. These include environmental risks from intensive cultivation and chemical use, high capital and operational costs, regulatory uncertainty, and challenges related to social acceptance. For instance, the Spanish value chain faces issues related to infrastructure costs and odor pollution, while the Danish model must mitigate the environmental footprint of drying and protein extraction processes. In Italy, the transition to non-conventional crops and the operation of biorefineries introduce market and regulatory uncertainties that affect both farmers and industries. Despite these challenges, the analysis highlights numerous synergies that can be leveraged to enhance sustainability and resilience. These include shared infrastructure, cross-sector collaboration, and knowledge transfer between stakeholders. The integration of agricultural and industrial systems, particularly through biorefineries, shows how circularity can be operationalized at the regional level. Moreover, stakeholder engagement and cooperative models emerge as critical enablers of inclusive and effective bioeconomy development.

At the European level, the findings underscore the importance of strategic, cross-sector, and inclusive policy frameworks. Recommendations include promoting integrated land-use planning, prioritizing the cascading use of biomass and valorization of residues, enhancing policy coherence across agriculture, energy, and environmental sectors, and supporting public engagement and innovation through research and regional

bioeconomy clusters. In conclusion, the BRILIAN project demonstrates that a well-designed bioeconomy can contribute meaningfully to rural revitalization, climate action, and sustainable industry. However, realizing this potential requires addressing trade-offs transparently, scaling synergies strategically, and embedding sustainability at the core of policy and practice.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS

BRILIAN- Cooperative and Sustainable business models for bio-based chains in rural areas

CAGR – Compound Annual Growth Rate

CAP – Common Agricultural Policy

CBE-JU Circular Based Europe Joint Undertaking

EC – European Commission

ESG – Environmental, Social, and Governance

GA – General Assembly

GHG – Greenhouse Gas

HEU – Horizon Europe – the 9th framework Programme of the EC for research, technological development and innovation activities

PU – Public

INDEX OF FIGURES

INDEX OF TABLES

1 INTRODUCTION

This section compiles and analyzes data from previous tasks to provide a comprehensive background for the assessment of trade-offs and synergies in the bioeconomy sector. Additionally, the information serves as an input for identifying the availability and quality of bioeconomy-related data to quantify indicators proposed in previous tasks. For that purpose, "Bioeconomy Market Overview" (BRILIAN Project, Deliverable 2.3) provides an analysis of the market segment for each of BRILIAN's bio-based applications, aligned with “Barriers and Opportunities of bioeconomy” (BRILIAN Project, Deliverable 2.1) outcomes are analyzed and summarized.

The bioeconomy sector faces several barriers that hinder its development and expansion. Politically and legally, the sector is challenged by complex and often contradictory regulations, which complicate the implementation of bio-based practices. Additionally, there is a lack of clear and consistent legislative support, limiting the growth of sustainable business models. For instance, from the economic point of view, the high costs associated with side-streams and by-products, or waste treatment technologies and the substantial initial investments required for bioeconomy projects pose significant obstacles. While from the social point of view, consumers may be initially skeptical in accepting products derived from agricultural side streams, therefore affecting market demand and commercial viability. Furthermore, from the technological point of view, the transition from laboratory-scale innovations to industrial applications requires higher levels of technological readiness, which can be difficult to achieve. In fact, whereas some bio-based technologically mature materials – e.g. bioplastics -are characterized by a strong product diversification and versatility, in some cases further technological advanced may be required to enhance their applicability, as supported by the preliminary analysis of bio-based product marked conducted within BRILIAN Task 2.3. Additionally, from the environmental perspective, strict regulations and policy bottlenecks further limit the practices and processes within the bioeconomy.

Despite these barriers, there are notable opportunities for growth and innovation in the bioeconomy sector. Advances in biotechnology enable efficient processing of agricultural by-products and the development of high-value products. This technological progress opens the door to creating innovative solutions that meet the increasing demand for sustainable products. Consumer awareness and interest in sustainability are growing, providing a favorable market for bio-based products. European initiatives aimed at promoting the bioeconomy also create a supportive environment for development, offering potential for breakthroughs in the sector.

To capitalize on these opportunities and overcome the barriers, several recommendations are proposed such as:

- Enhancing technological integration across stakeholders is crucial to facilitate smoother transitions from development to commercial stages.
- Promoting the adoption of advanced technologies can optimize processes and improve efficiency.
- Strengthening policy frameworks to provide clearer and more supportive regulations is essential for the growth of bio-based industries.
- Implementing incentives encouraging investment and development in the bioeconomy can further support this sector.
- Expanding market outreach through strategic marketing emphasizes the environmental benefits of bio-based products can enhance consumer acceptance.
- Increasing efforts in education and awareness to inform consumers about the advantages of bio-based products is vital.

Overall, the bioeconomy sector presents a complex landscape filled with challenges and opportunities. Strategic interventions focusing on technological innovation, policy support, and market development are critical for overcoming barriers and capitalizing on the opportunities presented by bioeconomy. This approach can significantly contribute to ensuring the growth and sustainability of bio-based cooperative business models in rural areas. In this sense, the implementation of bioeconomy practices has significant implications for rural regions, affecting resource utilization, land use, water and soil quality, biodiversity, and infrastructure. While bioeconomy offers numerous benefits, it also presents trade-offs that need careful evaluation to avoid unintended negative consequences.

Assessing these trade-offs and synergies is crucial for ensuring that bioeconomy actions contribute positively to environmental sustainability and rural development. Additionally, synergies can enhance positive outcomes such as improved livelihoods, job creation, and community resilience. Effective communication and policy implications are essential for addressing these trade-offs and synergies.

Deliverable 2.3 provides an analysis of the market segment for each of BRILIAN's bio-based applications, aligned with Deliverable 2.1 outcomes (BRILIAN Project, Deliverable 2.1). The report highlights that growing environmental attention, sustainability awareness, and consumer consciousness strongly contribute to the rise of the bio-based products market. However, the lower maturity of some novel technologies, volatile availability of feedstocks, and regulatory gaps may restrict the applicability of bio-based products and increase production costs, ultimately slowing down market development. The report emphasizes the importance of developing novel technological solutions and replicable technologies to expand profitable manufacturing in the bioeconomy sector. The market snapshot includes the new bioproducts to be developed within BRILIAN project such as bioplastics, biolubricants, bioherbicides, biostimulants, animal feed, edible mushroom substrates, bio-based cosmetics ingredients, vegan proteins, and bio-based adhesives. Each product category is analyzed in terms of market value, compound annual growth rate (CAGR), drivers, gaps, and restrictive factors. The report concludes that while environmental attention and sustainability awareness drive the bio-based market, technological advancements are necessary to enhance product applicability and reduce costs.

Complementary to the previous information, Task 3.2 aims to assess the trade-offs and synergies associated with the bioeconomy, focusing on its environmental sustainability and circularity within the EU economy. By analyzing the interactions between bioeconomy activities and rural communities, the task seeks to prevent and minimize negative impacts and enhance the positive contributions of bioeconomy. This assessment will provide valuable insights for stakeholders to implement bioeconomy actions responsibly and effectively.

2 OVERVIEW OF BIOECONOMY

Bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products, and bioenergy. It aims to reduce dependency on fossil resources, mitigate climate change, and promote sustainable development. Furthermore, bioeconomy requires the integration of various sectors, including agriculture, forestry, fisheries, food, and biotechnology, to create a sustainable and circular economy.

In this sense, bioeconomy leverages advances in biotechnology, digital technologies, and circular economy principles to produce food, materials, and energy while addressing global challenges such as climate change, resource depletion, and food security. Technological advancements are driving innovation, enabling the creation of sustainable solutions across sectors. Examples include bioplastics, biofuels, and bio-based materials that reduce reliance on fossil fuels and minimize environmental impact.

Within BRILIAN project three pilot cases are being developed which involves 10 value chains (2 in Spain, 2 in Denmark and 6 in Italy), through the implementation of 3 demonstrative Pilot cases, where the byproducts obtained from the agroindustry are valorised. The objective of this work is to understand the interactions between stakeholders and the byproducts processes in terms of trade-offs, positive benefits and synergies for each pilot case.

3 ASSESSMENT FRAMEWORK

3.1 Identification and evaluation of trade-offs, positive impacts and synergies

The methodology followed for the present assessment involves systematically identifying the trade-offs and positive benefits associated with the BRILIAN pilots. It includes clustering process stages and the associated stakeholders, as well as the identification of differences when evaluating pilot cases per type of stakeholder and pilot. In addition, the framework aims to balance competing interests and optimize overall sustainability by analyzing how bioeconomy activities intersect with other sectors [1].The procedure for the identification and evaluation of the trade-offs, positive impacts and synergies has been addressed by systematically identifying the trade-offs, including the differences when evaluating the pilot cases (per type of stakeholder and pilot). In other studies, the Kano Model has been applied aligned with the bioeconomy's focus on sustainable value chains and stakeholder engagement [2]. The Kano Model is a valuable framework for assessing customer preferences and prioritizing features, products, or services. When applied to bio-based value chains, it can guide decision-making by helping stakeholders understand which trade-offs will most effectively satisfy user and market demands.

More in detail, the Kano Model [3] is a strategic tool developed by Noriaki Kano that classifies customer needs into five categories—Must-be, One-dimensional, Attractive, Indifferent, and Reverse attributes—to help organizations prioritize features and assess trade-offs. In the context of bio-based value chains, which span from biomass sourcing to the delivery of bio-products, the model can be instrumental in aligning product development with stakeholder expectations, including those of consumers, producers, regulators, and investors. Must-be attributes are baseline expectations, such as biodegradability in eco-products; their absence causes dissatisfaction, but their presence is often taken for granted. One-dimensional attributes, like cost-competitiveness or production efficiency, directly influence stakeholder satisfaction. Attractive attributes, such as carbon-negative processes, are not expected but can significantly delight stakeholders and create market differentiation. Indifferent attributes, those that neither enhance nor diminish satisfaction, should be deprioritized to conserve resources. Reverse attributes, like the presence of synthetic additives, may alienate some users and should be approached with caution.

By classifying features this way, developers and decision-makers in bio-based value chains can better manage trade-offs, focusing on what truly matters to their markets. Prioritizing Must-be and One-dimensional attributes ensures market acceptance and operational efficiency, while investing in attractive features can build loyalty and reputation. Meanwhile, minimizing reverse and indifferent features avoids unnecessary risk and waste. The model supports informed decision-making that balances innovation, cost, and impact, aligning with broader sustainability and economic goals. Overall, the Kano Model enhances value chain strategies by linking technical and economic decisions with customer satisfaction dynamics.

For the present study, a matrix has been developed where value chain processes have been included in columns and possible stakeholders involved in each process in rows. This analysis has been conducted collecting key data to identify trade-offs, positive impacts and synergies separately, this exercise has been done for each of pilot (Spanish, Danish and Italian). The matrix has been designed to cluster data, considering the different processes tackled by each pilot but including the same stakeholders involved in the processes. One the one hand, processes involved in each value chain are included in the Annex A for each pilot case considering the different value chains evaluated within the project. On the other hand, the stakeholders mentioned before needed to be identified. This part of the methodology is included in section 2.1.1. It also includes the identification of synergies between bioeconomy activities and rural communities to enhance positive outcomes, such as improved livelihoods, job creation, and community resilience.

3.1.1 Stakeholder's definition and identification

Identifying and defining stakeholders involved in the bioeconomy sector is essential for understanding their roles, interests, and impacts on bioeconomy activities. Effective stakeholder engagement is crucial for developing regional bioeconomy strategies and ensuring the successful implementation of bioeconomy initiatives [4]

Stakeholders play a crucial role in the value chain of a bioeconomy process, each contributing to the development, implementation, and success of bio-based initiatives.

The key stakeholders involved and identified are:

Feedstock Providers: These are the primary producers, such as farmers and cooperatives, who supply the raw materials needed for bio-based production. Their role is essential in ensuring a consistent and sustainable supply of feedstock, which forms the foundation of the bio-based value chain.

Agro-Industries: Agro-industries are responsible for processing the raw materials provided by feedstock providers into intermediate or final bio-based products. They play a critical role in adding value to the raw materials through various processing techniques, ensuring the production of high-quality bio-based products.

Biorefineries/bio-based industries: industrial players that convert biomass to energy and other products (such as chemicals). The International Energy Agency Bioenergy Task 42 defined biorefining as "the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat) [5]. Biorefineries can provide multiple chemicals by fractioning an initial raw material (biomass) into multiple intermediates that can be further converted into value-added products, each refining phase can be considered part of a "cascading process". The use of biomass as feedstock can provide a benefit by reducing the impacts on the environment, for instance by lowering pollutants emissions and reduction in the emissions of hazard products.

Research and technology organizations: RTOs can be intended as entities that conduct research and analysis to generate data and inform policy decisions as well as to contribute to the development of novel technological solutions. The group includes research centers, academia, spin-offs, technological institutes and universities, but also industrial realities with commitment to R&D activities oriented towards innovation.

Local Community: The local community is integral to the bioeconomy value chain as they are directly impacted by the activities and outcomes of bio-based initiatives. Engaging the local community ensures that the benefits of the bioeconomy are shared, and their support and participation can enhance the sustainability and acceptance of bio-based practices.

Policy Makers: Policy makers are responsible for creating and implementing regulations and policies that support the development of the bioeconomy. Their role includes providing incentives, establishing standards, and ensuring a favorable regulatory environment that encourages investment and innovation in bio-based industries.

Consumers: Consumers drive the demand for bio-based products. Their preferences and purchasing decisions influence market dynamics and can accelerate the adoption of sustainable products. Educating consumers about the benefits of bio-based products is crucial for increasing market acceptance and demand.

General Public: General public, including non-consumers, plays a role in shaping societal attitudes towards bioeconomy. Public awareness and support can lead to broader acceptance and integration of bio-based practices into everyday life, fostering a culture of sustainability.

By engaging these stakeholders effectively, bioeconomy can contribute to boost sustainability, innovation, and economic growth, ensuring that the benefits are widely distributed and supported across different sectors of society.

The stakeholders identified—feedstock providers, agro-industries, local community, policy makers, consumers, and general public—cover the most relevant stakeholders involved in the bioeconomy sectors addressed by BRILIAN. These stakeholders cover the entire spectrum of the value chain, from production to consumption. The matrix helps in understanding the complex interactions and dependencies within the bioeconomy, ensuring that the development of bio-based initiatives is balanced and sustainable.

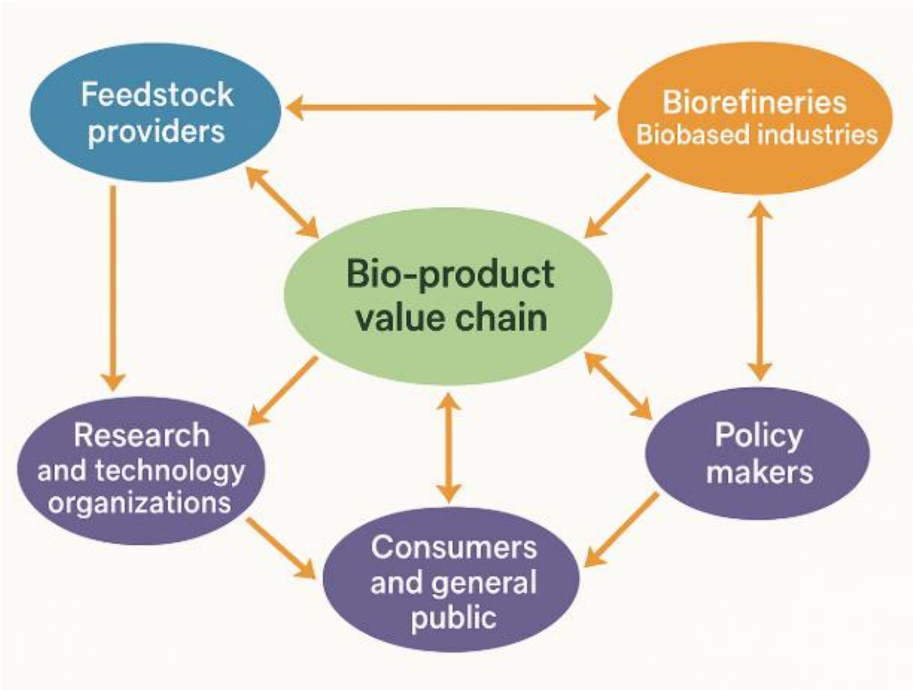


Figure 1 Diagram with stakeholders' interactions within a bio-product value chain

3.1.2 Assessment results by pilot case

Results of the assessment are obtained and shown in the following sections, the tables resulting from the analysis are included per result (positive impacts, negative impacts and synergies by pilot).

3.1.2.1 Spanish pilot case

Figure 2 Process phases considered in the Spanish pilot case

Table 1. Positive & negative impacts for the Spanish pilot case

Target group	Process phase	Key benefits	Negative impacts
Feedstock providers	[1] Potato cultivation	• Sustainable practices like mulching (adoption of sustainable farming techniques benefits the environment, promoting long-term agricultural viability for local farmers). • Securing supply (there is fluctuation in the market for the straw needed for mulching, they will not be affected because they have a guaranteed price).	
	[4] Thermoplastic starch packaging/ mulching		• Price competition (there are companies that demand this product for non-food application and can compete on price).
Agro-industries	[3] Starch extraction	• New market opportunities (creates additional revenue streams through the sale of extracted starch). • Resource utilization (efficient use of raw materials reduces waste and maximizes the value extracted from each potato).	• Impact of the plant infrastructure (the use of chemicals in starch extraction can lead to environmental pollution if not properly managed).

Target group	Process phase	Key benefits	Negative impacts
		• Economic growth (provides employment opportunities and stimulates the local economy through job creation and local spending, moreover the profit from the sale of starch is reinvested in their own cooperative of farmers). • Improvement of the expertise of the employees (staff will be working on new technology). • Reduction of water consumption (before it was sent to a water treatment plant, now this water is cleaned and potentially could be recirculated if the quality parameters are fulfilled, reducing water consumption) and in any case can be disposed lowering the price of the treatment. • Increasing awareness of the importance of byproduct revalorisation among employees.	• Resource intensity (the extraction process can be resource-intensive, which impacts on the overall sustainability of the value chain). • Need for more efficient equipment (that may render current equipment obsolete).High costs (for technology and equipment). • If the industry keeps growing, plant would need capacity increase. • Starch storage (if larger quantities of starch are managed, storage would need management, potential health impact on staff handling it would need to be considered).
	[4] Thermoplastic starch packaging/mulching	• Economic growth (provides employment opportunities and stimulates the local economy through job creation and local spending, moreover the profit from the sale of starch is reinvested in their own cooperative of farmers). • Improvement of the expertise of the employees (staff will be working on a new bio-product).	• Possible supply problems (companies interested in this product compete for raw materials with other companies).
Local community	[1] Potato cultivation	• Excess straw can be used for livestock farming.	
	[3] Starch extraction	• Economic growth (provides employment opportunities and stimulates the local economy through job creation and local spending).	• Environmental and odour impact (starch is stored outside, if it gets moldy it may smell and have a visual impact).

Target group	Process phase	Key benefits	Negative impacts
		• Increasing awareness of the importance of product revalorisation in society.	• Starch storage (if larger quantities of starch are managed, storage would need management and adaptation to the growing volumes to manage).
	[4] Thermoplastic starch packaging/mulching	• Economic growth (provides employment opportunities and stimulates the local economy through job creation and local spending).	
Policy makers	[3] Starch extraction	• Contribute to promoting bio-based objectives for the community.	• Social impact (local opposition can make difficult to promote similar activities in other regions). • Regulatory changes (value chain address challenges if the existing regulatory framework changes and no longer allows this kind of process or includes requirements that are difficult to reach by the agro-industry). • Uncertainty in regulations (regulations can change in the short and medium term which can difficult potential investments).
	[4] Thermoplastic starch packaging/mulching	• Sustainability (develops eco-friendly packaging solutions, reducing environmental impact and aligning with sustainability goals). • Regulatory compliance (meets increasing regulatory requirements for sustainable packaging, supporting compliance and market acceptance).	
Other feedstock providers	[2] Processing of the potato	• Waste reduction (rejected potatoes can be used for animal feed from the starch extraction plant).	
	[4] Thermoplastic starch packaging/mulching		• New products compete with traditional packaging (obligation to replace synthetic products with bio-based products). • Characteristics (new products may not achieve the same characteristics as traditional ones).

Target group	Process phase	Key benefits	Negative impacts
			• Biodegradability issues (if not properly managed, biodegradable packaging can still contribute to pollution, especially in environments not conducive to biodegradation). • Price competition (there are companies that demand this product for non-food application and can compete on price, causing prices to increase). • New products certification (there might not be a specific certification for these products which reduces its competitivity against traditional alternatives in the market, the user must know that this new product is better than the traditional ones).
Other agro-industries	[3] Starch extraction	• Contribute to boost replication among other agro-industries (best case example of an agro-industry that has valorised a byproduct).	• Difficulty to replicate (there are not many success stories with this byproduct/product to replicate). • Local acceptance (it is difficult to gather information on the local acceptance of these new products). • Technology providers (there are no technology providers at national level, it must come from outside the country which can contribute to increase implementation and operating costs).
	[4] Thermoplastic starch packaging/mulching	• Contribute to boost replication among other agro-industries (best case example of an agro-industry that has valorised a byproduct).	
Consumers and general public	[3] Starch extraction	• Increasing awareness of the importance of byproduct revalorisation among civil society. • Development of a new bio-based product offered on the market (converts a by-product from raw potato processing into valuable products, increasing the economic value of agricultural products).	

Target group	Process phase	Key benefits	Negative impacts
	[4] Thermoplastic starch packaging/mulching	• Sustainability (develops eco-friendly packaging solutions, reducing environmental impact and aligning with sustainability goals).	• Customer mistrust regarding the applications and characteristics of the new product. • In some cases, a poor knowledge in terms of biodegradable products can lead to incorrect disposal, therefore alignment with international standards which regulates biodegradability certifications and provides indications on disposal conditions to achieve full biodegradation (for example biodegradable in soil is addressed in ISO 17556 or under composting conditions UNI EN ISO 14855:2013) • Price competition (there are companies that demand this product for non-food application and can compete on price).

Table 2. Synergies for the Spanish pilot case

Target groups involved	Description of the synergy
Feedstock providers - agro-industries	Intermediate storage to facilitate the distribution of products in Europe. If the cooperatives (feedstock providers) have storage facilities instead of accumulating them in the agro-industries, it will free up storage for agro-industries.
Agro-industries - local community	Collaboration with consumer associations. The market for new products may not be as familiar with the consumption of such products, by organising tests of these new products, they may reach a larger market.
Agro-industries - local community	Training: having agreements with training centres and agro-industries. In this case, agro-industries will have staff prepared to operate this type of equipment which promotes local employment.
Agro-industries - Other agro-industries	Search for collaborations with other projects addressing the same or similar bio-product and technologies in other locations.
Agro-industries - Consumers and general public	Raise awareness regarding the initiative and encourage synergies: contact groups (working groups, focus groups, deployment groups, covenant of mayors) to report on results and to create ways to replicate the model.

3.1.2.2 Danish pilot case

Figure 3 Process phases considered in the Danish pilot case

Table 3. Positive & negative impacts for the Danish pilot case

Target group	Process phase	Key benefits	Negative impacts
Feedstock providers	[1] Rapeseed cultivation	• Sustainable practices (adoption of sustainable farming techniques benefits the environment, promoting long-term agricultural viability for local farmers). • Securing supply.	• Dependency on crop, monocropping risks, and potential soil degradation.
	[7] Protein powder production	• Increased demand of rapeseed cake, contributing to more market stability for the farmers.	• Price competition (there are companies that demand this product for non-food application and can compete on price).
	[8] Adhesives production		• Price competition (there are companies that demand this product for non-food application and can compete on price, non-food can such as adhesives can be more price competitive).

Target group	Process phase	Key benefits	Negative impacts
Agro-industries	[2] Transport to the storage	• Contributing to secure the suppply and optimize logistics considering environmental performance (intermediate storage facilities). • Job creation. • Monitoring environmental and social performance.	
	[3] Storage of the rapeseed		
	[4] Drying		• Environmental impact associated to drying (emission and energy. consumption if not based on renewable energies).
	[5] Processing of the rapeseed	• Job creation. • Monitoring environmental and social performance: CO2 avoidance, energy savings.	• Impact of the plant infrastructure (the use of chemicals in protein production to environmental. pollution if not properly managed)
	[6] Rapeseed oil extraction		• Resource intensity (the production process can be resource-intensive, which impacts on overall sustainability). • High costs (for technology and equipment). • If the industry keeps growing, plant would need capacity increase. • Rapeseed waste storage (if larger quantities are managed, storage would need management, potential health impact on staff handling it would need to be considered).
	[7] Protein powder production	• New market opportunities (creates additional revenue streams through the sale of extracted vegan protein). • Resource utilization (efficient use of raw materials reduces waste and maximizes the value extracted from the rapeseed). • Economic growth (provides employment opportunities and stimulates the local economy through job creation and local	• Possible supply problems (companies interested in this product compete. for raw materials with other companies) • High costs (for technology and equipment). • Need for a large investment and subsequent financial insecurity in case the business does not succeed.

Target group	Process phase	Key benefits	Negative impacts
		spending, moreover the profit from the sale of the vegan protein is reinvested in their own cooperative of farmers). • Improvement on the expertise of the employees (staff will be working on a new technology). • Increasing awareness of the importance of product revalorisation among the employees.	• Need for novel Food application if the final product specifications do not fit within the products already approved.
	[8] Adhesives production	• New market opportunities (creates additional revenue streams through the sale of adhesive). • Resource utilization (efficient use of raw materials reduces waste and maximizes the value extracted from the adhesive). • Economic growth (provides employment opportunities and stimulates the local economy through job creation and local spending, moreover the profit from the sale of the adhesive is reinvested in their own cooperative of farmers). • Improvement on the expertise of the employees (staff will be working on a new technology). • Increasing awareness of the importance of product revalorisation among the employees.	• Possible supply problems (companies interested in this product compete. for raw materials with other companies).
Local community	[1] Rapeseed cultivation	• Excess rapeseed cake can be used for livestock feeding	• Potential environmental impact from intensive cultivation.

Target group	Process phase	Key benefits	Negative impacts
	[5] Processing of the rapeseed	• Economic growth (provides employment opportunities and stimulates the local economy through job creation and local spending). • Increasing awareness of the importance of product revalorisation in society.	
	[6] Rapeseed oil extraction		• Environmental and odour impact (the waste is stored outside, if it gets mouldy it may smell and have a visual impact). • Waste storage (if larger quantities of waste are managed, storage would need management).
	[7] Protein powder production	• Economic growth (provides employment opportunities and stimulates the local economy through job creation and local spending).	• Competition with other small companies if a large company establishes.
	[8] Adhesives production		
Policy makers	[5] Processing of the rapeseed	• Contribute to promoting bio-based objectives for the community	
	[6] Rapeseed oil extraction		• Social impact (local opposition can make difficult to promote similar activities). • Regulatory changes (value chain may have complications for its implementation if there are some regulatory changes). • Uncertainty in regulations (regulations can change in the short and medium term, it can difficult possible investments).
	[7] Protein powder production	• Sustainability (develops eco-friendly solutions, reducing environmental impact and aligning with sustainability goals). • Regulatory compliance (meets increasing regulatory requirements for sustainable products, aiding compliance and market acceptance).	
	[8] Adhesives production		

Target group	Process phase	Key benefits	Negative impacts
Other feedstock providers	[5] Processing of the rapeseed	• Waste reduction	
	[6] Rapeseed oil extraction		
	[7] Protein powder production	• Opportunities to collaborate (shared infrastructure for other feedstock providers that also work with protein extraction for example).	• New products compete with traditional one (animal protein) and characteristics (new products may not achieve the same characteristics as traditional ones. • Price competition as there are other sources of protein and vegan protein in the market. • New products certification is also an issue for vegan protein obtained from rapeseed cake as a side stream of the traditional process.
	[8] Adhesives production		• Price competition as there are other sources of protein and vegan protein in the market. • Obtaining new product certification could be difficult for vegan protein obtained from rapeseed cake as a side stream of the traditional process.
Other agro-industries	[5] Processing of the rapeseed	• Contribute to boost replication among other agro-industries (it is a case example of an agro-industry that has valorised a product).	
	[6] Rapeseed oil extraction		

Target group	Process phase	Key benefits	Negative impacts
	[7] Protein powder production	• Contribute to boost replication among other agro-industries (it is a case example of an agro-industry that has valorised a product).	• Difficulty to replicate (there are not many success stories with this product to replicate). • Local acceptance (it is difficult to gather information on the local acceptance of these new products). • Technology providers (there are no technology providers at national level, it has to come from outside the country, it increases implementation and operating costs). • The protein powder may replace products from competing agro-industries.
	[8] Adhesives production		• Difficulty to replicate (there are not many success stories with this product to replicate). • Local acceptance (it is difficult to gather information on the local acceptance of these new products). • Technology providers (there are no technology providers at national level, it has to come from outside the country, it increases implementation and operating costs).
Consumers and general public	[5] Processing of the rapeseed	• Increasing awareness of the importance of product revalorisation in society. • Development of a new bio-based product offered on the market (converts a residue from rapeseed production into valuable products, increasing the economic value of agricultural products).	
	[6] Rapeseed oil extraction		

Target group	Process phase	Key benefits	Negative impacts
	[7] Protein powder production	• Sustainability (develops eco-friendly solutions, reducing environmental impact and aligning with sustainability goals).	• Customer mistrust of the applications and characteristics of the new product. • Price competition as there are other sources of protein and vegan protein in the market.
	[8] Adhesives production		

Table 4. Synergies for the Danish pilot case

Target groups involved	Description of the synergy
Feedstock providers - agro-industries	Intermediate storage to facilitate the distribution of products in Europe. If the cooperatives (feedstock providers) have centres of storage instead of accumulating them in the agro-industries, it will free up storage for agro-industries.
Feedstock providers - other feedstock providers	Collaboration with other feedstock providers for sustainable practices
Policy makers - feedstock providers	Policy alignment with feedstock providers for land management
Agro-industries - local community	Collaboration with consumer associations. The market for new products may not be as familiar with the consumption of such products, by organising tests of these new products, they may reach a larger market.
Agro-industries - local community	Training: having agreements with training centres and agro-industries. In this case, agro-industries will have staff prepared to operate this type of equipment, promotes local employment.
Agro-industries - Other agro-industries	Search for collaborations with other projects with the same or similar bio-product and technologies in other locations.
Agro-industries - Other agro-industries	Shared drying facilities with other agro-industries
Agro-industries - Consumers and general public	Raise awareness of the initiative and encourage synergies: contact groups (working groups, focus groups, deployment groups, covenant of mayors) to report on results and to create ways to replicate the model.

3.1.2.3 Italian pilot case

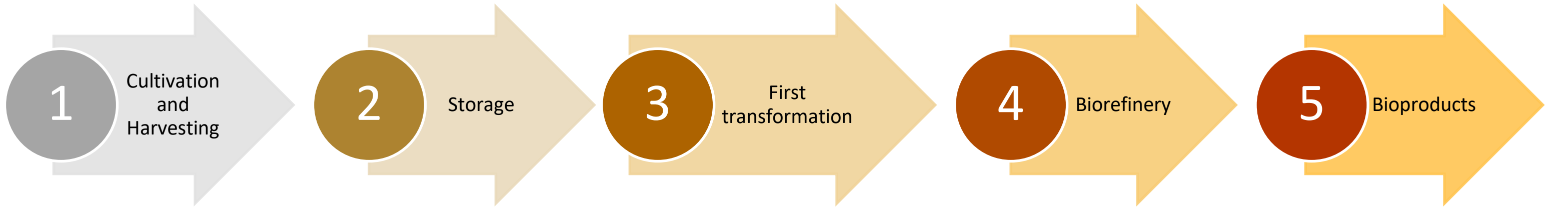


Figure 4 Process phases considered in the Italian pilot case

Table 5. Positive & negative impacts for the Italian pilot case

Target group	Process phase	Key benefits	Negative impacts
Feedstock providers (farmers and cooperatives)	[1] Cultivation and Harvesting	• Adoption of low impact agricultural practices through the cultivation of low-inputs oil crops (such as sunflower, safflower, and cardoon) supporting the recovery of abandoned and unproductive lands and the obtaining the agro-feedstocks that the biorefineries will convert into added-value products, and specifically: oil seeds; vegetable oils, oil cake and lignocellulosic biomass. • Adoption of cooperative models contributes to cost savings for farmers, deriving from saving the costs related to soil improvers, fertilizers, plant protection products and land labour, Additional potential revenues from the direct sale of processed feedstock and intermediate products. • Adoption of new agricultural agreements rewarding positive externalities and ecosystem services. • Improvement on the expertise for the cultivation of unconventional crops (e.g. cardoon, safflower).	• Need to modify the conventional farms agricultural plan to add the selected crops in rotation with conventional cultivated crops. • Potentially high prices for the increased use and adoption of bio-based products for agricultural operations. • Needs for investments to upgrade equipment.

Target group	Process phase	Key benefits	Negative impacts
		• Farmers training for sustainable and integrated agriculture (reduced input/low tillage) cropping systems, valorization of marginal territories. • Improve connection with primary producers and biorefineries (pushing territories development).	
	[2] Storage	• Farmers can improve their income through the storage of harvested biomass. • Cooperative efforts to share storage facilities and equipment to reduce costs and labor for primary producers	• Potential for investments to upgrade facilities.
	[3] First transformation	• Cooperative efforts to share transformation equipment to reduce costs and labor for primary producers	• Potential needs for investments to upgrade equipment for the processing of new feedstock through novel processes.
	[4] Biorefinery	• Improve connection with primary producers and biorefineries (pushing territories development).	• Possible increase of competition for feedstock availability.
	[5] Bioproducts	• Soil-2-Soil approach: Circular use of the final bio-based products for farms (i.e. biodegradable in soil mulch film, bio-based herbicide, bio-based lubricants, biostimulants etc.) obtained valorizing the agro-feedstocks through biorefinery processes.	• The need for awareness and acceptance towards novel and not well-known bio-based products/processed feedstocks may hinder market. • Competitiveness of bio-based products.
Agro-industries/ Agroservice companies	[2] Storage	• The agroindustries can improve their income through the storage of harvested biomass. • Sharing storage facilities and equipment to reduce costs for agro-industries.	• Potential needs for investments to upgrade facilities.

Target group	Process phase	Key benefits	Negative impacts
	[3] First transformation	• Improve connection with local farmers, transformers and biorefineries (pushing territories development). • New market opportunities: creation of additional revenues through the processing of non conventional agro-feedstocks (e.g. cardoon and safflower seeds and oil, oilcake and lignocellulosic biomass of cardoon). • Improvement on the expertise of the employees (e.g by working on new agro-feedstocks and innovative technologies).	• Impact on the agro-industry operational planning and need to ugrade for new agro-feedstocks treatment processes, equipment and facilities.
	[4] Biorefinery	• Improve connection with agro-feedstock transformers and biorefineries (pushing territories development).	• Possible increase of competition for feedstock availability.
	[5] Bioproducts	• Circular use of bio-based products (i.e. bio-based lubricants, mushroom cultivation bales) obtained by valorizing the processed and semi-processed agro-feedstocks.	• Bottlenecks linked to raw materials availability and price. • The need for awareness and acceptance towards novel and not well-known Bio-based products/processed feedstocks may hinder market competitiveness of bio-based products.
Biorefineries	[1] Cultivation and Harvesting	• Valorization of unexploited feedstocks through the engagement of farmers/cooperative for the cultivation of low-input oil crops. • Valorising marginal territories with precious sources of raw materials. • Improve connection with primary producers and biorefineries (novel business opportunities).	
	[2] Storage	• Improve connection with agro-industries and biorefineries (novel business opportunities).	

Target group	Process phase	Key benefits	Negative impacts
	[4] Biorefinery	• Valorization of unexploited bio-based feedstock through the development and optimization of novel industrial processes. • Enhancement of existinginfrastructures; • Increase the resilience of feedstock provision for industries (price; feedstock availability; sustainability)	• Possible increase of competition for feedstock availability as raw materials. • In some cases, further technological advances may be required to enhance the applicability of novel processes.
	[5] Bioproducts	• Meet market demand for the development of sustainable process and products conceived as solutions (products designed to close the carbon cycle and ensure that no persistent substances accumulate in compost, treated. water, sludge, and soil, overcoming the problem of pollution).	• The need for awareness and acceptance towards novel and not well-known products may hinder market competitiveness of bio-based products. • In some cases, further technological advanced may be required to enhance the applicability of bio-based products. The effectiveness and service life of less technologically mature products/applications may vary or show lower performances compared to conventional products.
Local community and general public	[1] Cultivation and Harvesting	• Indirect impact on the general public for increased awareness towards sustainability. • New training and job opportunities.	
	[4] Biorefinery		• The need for awareness and acceptance towards bio-based industries and biorefinery processes may hinder competitiveness of the sector as a consequence of skeptical social perception and acceptance.
	[5] Bioproducts	• Availability of novel products, conceived as solutions, designed to meet application requirements and sustainability criteria.	• The need for awareness and acceptance towards novel and not well-known bio-based products/solutions may hinder

Target group	Process phase	Key benefits	Negative impacts
		• Improved social awareness towards sustainability.	market competitiveness of bio-based products linked to skeptical social perception and acceptance.
Policy makers	[1] Cultivation and Harvesting	• EU (e.g. CAP) and local (e.g Piano sviluppo rurale PSR) regulation boosting and improvements, direct feedback from farmers community.	
	[4] Biorefinery	• EU regulation boosting and improvement in relation to raw materials, feedback from biorefineries and bio-based industries.	
	[5] Bioproducts	• EU regulation boosting and improvements, e.g. in relation to new products.	• In certain cases, products certification requirements may slow down their adoption.
Research and technology organisations (RTO)	[4] Biorefinery	• Boosting applied R&D activities and increased incentives. • Creation of new technological knowledge.	
Producers/ supplier of products for agriculture	[1] Cultivation and Harvesting	• Increased revenues of innovative bio-based products.	• Potential price fluctuations/increase may affect revenues in relation to sales volumes.
	[5] Bioproducts	• Creation of new revenues opportunities from the circular use of the final products for agriculture.	• The need for awareness and acceptance towards novel and not well-known bio-based products may hinder market competitiveness of new bio-based products for agriculture, linked to skeptical product perception and acceptance.

Table 6. Synergies for the Italian pilot case

Target groups involved	Description of the synergy
Feedstock providers-agro-industries	Intermediate storage to facilitate the processing of primary producers and agro-industries; adoption of shared facilities and equipment for storage/agricultural operations; cooperative efforts for gathering the stages for feedstock processing into diverse biorefinery processes (e.g. storage, oil extraction and refining, pretreatment of biomass and intermediates destined to different biorefinery purposes); participation to cooperative and innovation projects.
Local communities -Farmers	Improving the acceptance of local communities in the adoption of novel crops, raw materials and feedstocks. Potential for boosting employment, creating new opportunities for specialized jobs and trainings.
Agro-industries - biorefinery- farmers	Improve connection with local farmers, transformers and biorefineries (pushing territories development). Potential for boosting employment, creating new opportunities for specialized jobs and trainings.
Biorefinery - local community	Novel bio-based products answer the needs of consumers for growing environmental attention, sustainability awareness High potential for boosting employment, creating new opportunities for specialized jobs. Improved social acceptance of bio-based raw materials, processes and products as drivers to support technological processes towards the adoption of sustainable practices.
Biorefinery-agroindustry-farmers-supplier of products for agriculture	Increased revenues from new market opportunities deriving from the availability of novel products conceived as solutions designed to meet application requirements and sustainability criteria.
Agro-industries - Biorefineries- Farmers-Policy makers	EU regulation boosting and improvement in relation to raw materials, and bio-based products. Improved connections and feedback within the involved groups
Farmers-Agroindustry-Biorefinery-RTO	Boosting applied R&D activities and increased incentives for the creation of technological knowledge and trainings opportunities
Biorefinery-farmers-agroindustry-local community	Potential for boosting new opportunities for specialized trainings. Improved social acceptance of bio-based raw materials and products as drivers to support technological processes towards the adoption of sustainable practices.
farmers-biorefinery-local community	Resources optimisation (environmental as well as financial) as a result of the adoption of cooperative models, technological development, and increased environmental awareness.

3.1.3 Comparative Analysis Results

This section provides a comparative analysis of three bio-based value chains:

- The **potato-starch value chain in Spain**, where starch is valorized as a by-product.
- The **rapeseed value chain in Denmark**, where rapeseed cake is used to produce vegan protein and adhesives.
- The **Italian value chains** involving cardoon, safflower, and sunflower, cultivated on marginal lands.

The comparative analysis is grounded in the outcomes derived from the pilot cases, providing a concrete, real-world basis but in addition to this case-specific perspective, the analysis incorporates a sector approach, allowing for a more comprehensive understanding of patterns, challenges, and opportunities that are common across municipalities within the same economic or environmental sector. This dual methodology enhances the robustness of the findings by capturing both local specificities and broader sector trends.

The analysis focuses on identifying **unique positive impacts**, **trade-offs**, and **synergies** in each case, based on stakeholder matrices and sustainability outcomes.

3.1.3.1 Positive Impacts

The matrix of positive impacts derived from the development of bio-based value chains in Europe reveals significant benefits across multiple stakeholder groups. These impacts are categorized below by value chain and stakeholder type:

Spanish Potato-Starch Value Chain:

Feedstock Providers (Farmers):

Farmers benefit from the adoption of sustainable agricultural practices such as mulching, crop rotation, and precision irrigation. These practices not only improve soil health and reduce input costs but also contribute to climate resilience and biodiversity conservation [6]. Moreover, income stability is enhanced through guaranteed pricing mechanisms and long-term contracts, which reduce market volatility and provide financial predictability.

Agro-industries:

Industries processing potato starch gain from new revenue streams through the valorization of by-products (e.g., potato peels for bioenergy or animal feed). Additionally, resource efficiency is improved via closed-loop systems that reduce water and energy use [7]. Investments in employee training also can lead to enhanced workforce skills, supporting innovation and operational excellence.

Policy Makers:

This value chain aligns with EU bioeconomy strategies, promoting regulatory compliance and contributing to climate and sustainability goals. It supports the European Green Deal by reducing environmental footprints and fostering rural development.

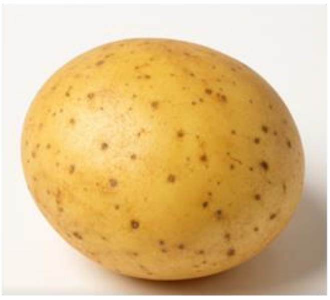
Consumers and Other Stakeholders:

There is a growing awareness of circular economy principles, as consumers gain access to sustainable, locally sourced products. Educational campaigns and eco-labeling further reinforce responsible consumption patterns.

The figure below summarizes the main concepts:

Feedstock Providers
Adoption of sustainable agricultural practices (mulching, crop rotation, precision irrigation)
Income stability is enhanced through guaranteed pricing or long-term contracts

Agro-industries
New revenue streams from valorization of by-products (biomaterials or animal feed)
Improved resource efficiency via closed-loop systems



Policy makers
Align the value chain with EU bioeconomy strategies.
Promote regulatory compliance and sustainability goals

Consumers and other stakeholders
Growing awareness of circular economy principles
Increased access to sustainable, locally-sourced products
Educational campaigns reinforce responsible consumption trend

Figure 5 Summary of the main concepts for the stakeholders involved in the BRILIAN Spanish value chains

Danish Rapeseed Value Chain

Feedstock Providers:

Farmers benefit from the valorization of rapeseed cake, a by-product of oil extraction, which is used as high-protein livestock feed or for protein extraction in food and feed applications. This enhances the economic value of the crop and supports nutrient recycling.

Agro-industries:

Industries benefit from optimized logistics through shared infrastructure and digital tracking systems, reducing costs and emissions. Environmental and social performance monitoring tools help companies meet ESG (Environmental, Social, and Governance) standards, while also improving transparency and stakeholder trust.

Local Communities:

The development of this value chain leads to job creation, particularly in rural areas, and fosters community engagement through co-ownership models and local partnerships. Increased awareness of product revalorization supports a culture of innovation and sustainability.

Policy Makers:

Support for eco-innovation and sustainability targets is strengthened through public-private partnerships and funding mechanisms. This aligns with Denmark’s national bioeconomy strategy [8] and EU directives on renewable resources [9].

Other Stakeholders:

There is a growing trend in the development of new bio-based products, such as bioplastics and bio-lubricants, which enhances the replication potential of successful models across regions and sectors.

Figure 6 Summary of the main concepts for the stakeholders involved in the BRILIAN Danish value chains

Italian Value Chains (oilcrops as feedstock for biorefineries)

Farmers/Cooperatives:

Farmers benefit from the adoption of sustainable and integrated agricultural practices, that allow the recovery of unproductive lands to obtain value added agro-feedstock, improving the connections with transformers and biorefineries. Low input crops also contribute to ensuring cost savings for farmers, deriving from the reduced use of soil improvers, fertilizers, plant protection products and land labour. Income is further stabilized through improved storage infrastructure and access to niche markets for non-conventional crops (like dry oilcrops) as well as through potential sales of processed feedstock/bio-based products. Novel opportunities for training and improved connections with stakeholders, pushing territories development.

Agro-industries:

These actors gain new market opportunities through the processing of diverse feedstocks and stronger ties with local farmers, biorefineries and research, fostering resilient supply chains and economic development. Novel opportunities for training and improved connections with stakeholders, pushing territories development.

Biorefineries:

Biorefineries unlock new business models by valorizing previously unexploited biomass (e.g., agricultural feedstock from unconventional crops and the respective side streams). They contribute to carbon neutrality and technological processes development through the production of bio-based feedstock and products and enhance feedstock resilience by diversifying input sources, resulting in the deployment of novel solutions for relevant market sectors (e.g. bio-based biodegradable materials for agriculture and a range of diverse application fields).

Local Communities and general public:

Tailored training programs regarding bio-based technologies and agriculture contribute to push territorial development, raise social and environmental awareness and create a skilled workforce, leading to indirect public benefits such as reduced unemployment and increased social cohesion.

Policy Makers:

A close interaction of policymakers and regulation bodies with value chain stakeholders (bio-based industries, primary producers and agro-industry) that can inform improvements to the Common Agricultural Policy (CAP), ensuring that subsidies and regulations are aligned with sustainability goals and in relation to regulations for novel feedstock and raw materials as well as for the introduction of novel products in the market.

Research and Technology Organizations (RTOs):

RTOs benefit from opportunities to apply research and development in real-world settings, fostering knowledge creation and technology transfer.

Suppliers of products for agriculture:

Suppliers of product for agriculture benefit from the availability of new products with high quality, more accessible prices as a consequence of technology development and of the improved knowledge and social acceptance and see increased revenues from the demand for innovative bio-based solutions for agriculture, reinforcing the industrial ecosystems.

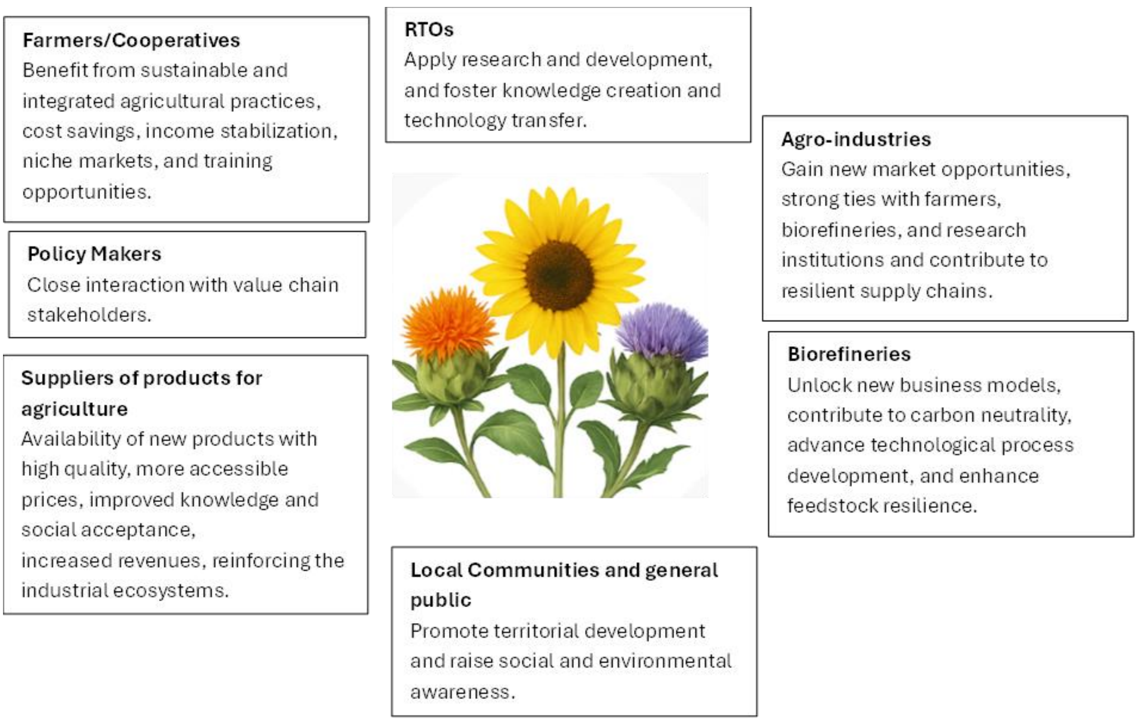


Figure 7 Summary of the main concepts for the stakeholders involved in the BRILIAN Italian value chains

The comparison among the pilot case allowed to extract the following commonalities: (1) the valorization of agricultural residues or by-products; (2) the enhancement of economic stability for farmers through improved market access or pricing mechanisms; and (3) the integration of environmental goals aligned with EU sustainability policies and the Green Deal.

The main positive impacts preliminarily identified for primary producer are in fact associated with the adoption of low impact agricultural practices through the cultivation of low-input oil crops that allow the recovery of unproductive lands as in the italian case but also obtain value added agro-feedstock as raw materials for the biorefineries which in turn contributes to improving the connections with transformers and biorefineries, therefore pushing territories development. Additionally, low input crops also contribute to ensuring cost savings for farmers, deriving from the reduced use of soil improvers, fertilizers, plant protection products and, not least, land labour, and potential revenues from the sale of processed feedstock/products and increase the expertise for the cultivation of unconventional crops (e.g. cardoon, safflower) resulting in an overall technological growth and development for a better use of resources with cascade benefits over the community.

Technological innovation, logistical optimization, and closed-loop systems are pivotal in the Danish and Italian pilot cases of the cases, emphasizing operational efficiency and emissions reduction. In contrast, the Spanish pilot case places stronger emphasis on regenerative agricultural practices and product diversification. While all three engage local communities, the Italian pilot uniquely fosters co-ownership and rural job creation. Danish and Spanish pilots are narrower in feedstock specificity (potato and rapeseed), whereas the Italian case adopts a broader systems-level integration of non-conventional crops.

Policy interaction is evident in all cases, though one of them aligns explicitly with national bioeconomy strategies. ESG compliance and digital infrastructure appear prominently in the Italian case only.

Overall, the cases illustrate complementary pathways to sustainable, inclusive bioeconomic transitions, differentiated by sector focus, implementation scale, and value chain complexity.

3.1.3.2 Negative Impacts (Trade-offs)

Spanish potato-starch value chain

The Spanish potato-starch value chain, while offering numerous sustainability and economic benefits, also presents several **trade-offs** that affect various stakeholders. These challenges must be addressed to ensure the long-term viability and social acceptance of the bioeconomy model.

Feedstock Providers (Farmers):

- **Environmental Risks from Chemical Use:** Despite efforts to promote sustainable practices, many potato farms still rely on **synthetic fertilizers and pesticides**, which can lead to **soil degradation, water contamination, and biodiversity loss**. These risks are particularly acute in regions with intensive monoculture practices [10].

- **High Capital Investment:** Transitioning to sustainable farming methods and investing in infrastructure (e.g., storage, irrigation) requires **significant upfront capital**, which may be a barrier for small and medium-sized farms. Without adequate financial support, this could lead to **economic exclusion** of less-resourced farmers [11].

Agro-industries:

- **Infrastructure Costs and Pollution:** The construction and operation of starch processing and storage facilities involve **high capital costs**. Additionally, these facilities can generate **odour and visual pollution**, which may affect nearby communities and lead to **social resistance** if not properly managed.

Policy Makers:

- **Regulatory Uncertainty and Market Barriers:** The evolving nature of **EU bioeconomy regulations** and the lack of harmonized standards create **uncertainty for investors and producers**. This can slow down innovation and discourage participation in the value chain. Moreover, **market entry barriers**—such as complex certification processes—can limit the competitiveness of bio-based products.

Local Communities:

- **Nuisance and Limited Engagement:** Communities near processing plants may experience **odour and visual disturbances**, which can affect quality of life and lead to **opposition**. If the benefits of the value chain (e.g., jobs, infrastructure) are not equitably distributed, **social tensions** may arise.

Consumers and Other Stakeholders:

- **Market and Certification Challenges:** Consumers may face **higher prices** for bio-based products, and **confusion over sustainability claims** can reduce trust. The **complexity and cost of certification** for sustainable products also pose challenges for producers and retailers, potentially limiting product availability and uptake.

These trade-offs highlight the importance of **integrated policy frameworks**, **stakeholder engagement**, and **targeted financial support** to mitigate risks and ensure that the transition to a bio-based economy is both **inclusive and sustainable**.

Danish Rapeseed Value Chain

The Danish rapeseed value chain plays a key role in the bioeconomy, particularly in the production of biofuels and protein-rich by-products. However, its development also presents several **environmental, economic, and social trade-offs** that must be addressed to ensure sustainability and equity.

Feedstock Providers (Farmers):

- **Environmental Impact from Intensive Cultivation:** Rapeseed farming often involves **high nitrogen fertilizer use**, which contributes to **greenhouse gas emissions** and **eutrophication** of water bodies. This undermines the environmental goals of the bioeconomy and can lead to regulatory scrutiny.

- **Financial Insecurity and Technology Dependency:** Farmers face **price volatility** in rapeseed markets and increasing **dependence on advanced technologies** (e.g., precision agriculture, protein extraction systems). These technologies require capital and expertise, potentially marginalizing smaller or less-resourced farms.

Agro-industries:

- **Resource-Intensive Protein Production:** The extraction of protein from rapeseed cake is **energy- and water-intensive**, raising concerns about **life cycle**

sustainability. These processes can also increase operational costs and reduce the overall environmental benefit of the value chain.

- **Storage and Health Risks:** Improper storage of rapeseed by-products can lead to **mold growth and mycotoxin contamination**, posing **health risks** to livestock and humans. This necessitates strict quality control and waste management protocols, which must be included in the overall business case calculations.

Policy Makers:

- **Balancing Innovation with Environmental Oversight:** While supporting bio-based innovation, policymakers must also **regulate intensive farming practices** and **monitor environmental impacts**. This dual responsibility can be challenging, especially when economic and environmental goals conflict.

Local Communities:

- **Environmental and Health Concerns:** Communities near rapeseed processing facilities may be exposed to **air emissions, noise, or waste-related nuisances**. If not managed transparently, these issues can erode public trust and lead to **social resistance**.

Other Stakeholders:

- **Technology and Certification Barriers:** The complexity and cost of **certification schemes** for bio-based products can limit participation by smaller actors. A novel food approval might be needed, depending on the final properties of the protein powder. Additionally, **technology dependency** may create barriers to entry and reduce the inclusiveness of the value chain.

Italian Value Chains

The Italian Pilot bioeconomy initiatives—spanning the adoption of integrated and sustainable agriculture and the adoption of non-conventional oil crops, for biorefineries purposes to produce bio-based biodegradable products—offer promising sustainability outcomes. However, they also involve **trade-offs** that affect farmers, industries, biorefineries, communities, and policymakers. These must be carefully managed to ensure inclusive and resilient development.

Farmers and Cooperatives:

- **Crop Plan Adjustments and Investment Needs:** Farmers may be required to **modify traditional agricultural operations,** for instance including crop rotations or adopting unconventional crops, which may require equipment **capital investment** and **technical knowledge**.

- **Market Risk and Learning Curve:** The shift to new crops and agricultural practices involves a **steep learning curve** and **market uncertainty**, especially in the absence of guaranteed buyers or stable prices.

Agro-industries:

- **Equipment Upgrades and Feedstock Competition:** Processing diverse biomass types may demand **equipment upgrades or retrofitting**, which can be costly. Moreover, **competition for feedstock** between energy, and material uses can drive up prices and create **supply chain tensions**.

Biorefineries:

- **Feedstock Availability and Price Volatility:** Biorefineries are highly dependent on **consistent and affordable feedstock supply**. Seasonal variability, climate impacts, and market fluctuations can affect profitability.**High Operational Costs:** Operating biorefineries requires **significant investments in terms of technological development and skilled workforce** which can reduce efficiency if not optimized and requires parallel progresses in terms of regulatory, social and market development.

Local Communities and general public

- **Social Acceptance and trust issues:** The establishment of biorefineries or large-scale biomass cultivation may face **public opposition** (for instance if perceived alter traditional landscapes) if not supported by engagement initiatives to promote knowledge and social awareness. Additionally, **confusion over eco-labels and sustainability claims** can reduce consumer trust.

- **Uneven Benefit Distribution:** Without inclusive planning, the benefits of job creation and infrastructure development may not reach all community members, leading to **social tensions**.

Policy Makers

- **Certification and Policy Alignment Challenges:** Ensuring that bio-based products meet **sustainability certification standards** is complex and costly. Policymakers also face challenges in **aligning CAP (Common Agricultural Policy) reforms** with regional needs and drivers and diverse farming systems.

Suppliers for agriculture

- **Revenue Instability:** Suppliers of agricultural inputs, such as bio-based products for agriculture may experience **fluctuating demand** due to **price volatility** and **policy shifts**, affecting long-term planning and investment, hindering market competitiveness of new bio-based products for agriculture.

- **Confusion over eco-labels and sustainability claims** can reduce consumer trust and slow market adoption.

These trade-offs underscore the need for **targeted support mechanisms**, **inclusive governance**, and **transparent communication** to ensure that bioeconomy transition is both **sustainable and socially equitable**.

Comparing the three cases, it can be highlighted that in the Spanish case the persistent reliance on synthetic agrochemicals in monoculture-based potato farming can contributes to produce and impact on soil and water contamination if not performed properly. Additionally, it can also contribute to biodiversity loss, while the high capital intensity required for transitioning to sustainable agricultural practices creates barriers for smallholder farmers. Similarly, Danish rapeseed cultivation, despite its significance in biofuel production, is characterized by intensive nitrogen fertilizer use, leading to greenhouse gas emissions and eutrophication, thereby compromising environmental objectives. In both countries, agro-industrial operations are capital- and resource-intensive, with issues such as odour pollution, waste management, and mycotoxin contamination posing public health and social resistance risks. The Italian pilot, focused on sustainable agriculture and biorefinery integration, managing market volatility, and navigating the technological and infrastructural demands of processing diverse raw materials. Across all cases, regulatory uncertainty—particularly around EU bioeconomy policies and sustainability certification frameworks—creates disincentives for investment and innovation. Consumers across these contexts face affordability constraints due to price premiums on bio-based products and exhibit skepticism towards sustainability claims due in some cases to inconsistent labeling and certification schemes. Ultimately, these pilots highlight the imperative for harmonized regulatory support, inclusive stakeholder engagement, and targeted financial mechanisms to ensure that bioeconomy transitions are not only environmentally sound but also socially inclusive and economically resilient.

3.1.4 Synergies

The development of integrated bio-based value chains across Spain, Denmark, and Italy reveals a range of **synergistic effects** that enhance sustainability, economic resilience, and innovation. These synergies emerge from the **interconnection of stakeholders**, **shared infrastructure**, and **cross-sector collaboration**, and are essential for maximizing the benefits of the circular bioeconomy.

Cross-Sector Integration and Resource Efficiency

One of the most significant synergies is the **integration of agricultural and industrial sectors** through biorefineries. These facilities enable the **valorization of agricultural residues** (e.g., potato peels, rapeseed cake, pruning waste, oil crops side-streams) into high-value products such as bioplastics, and protein extracts. This not only reduces waste but also **closes nutrient and material loops**, contributing to a circular economy[12].

- For example, in Denmark, rapeseed cake—traditionally a low-value by-product—is now being used for **protein extraction**, which can contribute to create new revenue streams and reducing reliance on imported soy.
- In Italy, biorefineries are increasingly using **non-food biomass** and **agro-industrial residues**, enhancing feedstock flexibility and reducing pressure on land and food systems [13].

Shared Infrastructure and Logistics Optimization

Synergies also arise from **shared logistics and processing infrastructure**, particularly in regions with clustered agro-industrial activities. This reduces **transportation costs**, **carbon emissions**, and **duplication of investments**.

- In the Danish value chain, **co-location of processing facilities** and **shared storage systems** improve efficiency and reduce environmental impacts.
- In Spain, the integration of starch processing with local farming cooperatives enhances **supply chain coordination** and **reduces post-harvest losses**.

- In the Italian Pilot, resources optimization and the adoption of **cooperative models**, improves efficiency under a logic of social and environmental sustainability, and **optimal use of raw materials**.

Knowledge Transfer and Capacity Building

Bioeconomy contributes to boost **collaborative innovation** among farmers, industries, research institutions, and policymakers. This leads to **knowledge spillovers**, **skills development**, and **technological diffusion**.

- The Italian pilot thanks to the cooperation of biorefinery, RTOs (Research and Technology Organizations), farmers and agro-industry support training opportunities and raising awareness for the adoption of sustainable and integrated **agriculture** and **non-conventional crop management**, supporting the creation of skilled professional and cooperation opportunities for rural development.

- In Spain, agro-industries are investing in **employee upskilling** to manage new technologies and sustainability standards.

Policy Alignment and Market Development

Synergies are also relevant in the alignment of **regional development policies** with **EU bioeconomy strategies**, which helps unlock funding, reduce regulatory barriers, and stimulate market demand for bio-based products.

- The **Common Agricultural Policy (CAP)** reforms support sustainable practices and innovation, while **national bioeconomy strategies** in countries like Italy and Denmark promote integrated value chains.

- Public procurement and eco-labeling schemes are helping to **create markets** for sustainable products, reinforcing consumer trust and demand.

Social and Environmental Co-Benefits

Finally, these synergies generate **co-benefits** such as **rural revitalization**, **job creation**, and **climate mitigation**. By linking local biomass resources with industrial innovation, bioeconomy value chains contribute to **resilient local economies** and **reduced environmental footprints**.

- In all three countries, the development of bio-based industries in rural areas is helping to **counter depopulation** and **stimulate local entrepreneurship**.
- The use of agricultural residues contributes to finding the path towards **carbon-neutral production pathways.**

3.2 Enhance interactions at EU level

This section identifies synergies between bioeconomy activities and rural communities to enhance positive outcomes, such as improved livelihoods, job creation, and community resilience. This includes fostering collaboration between stakeholders and promoting sustainable practices that benefit both the bioeconomy and rural communities at EU level.

Identifying synergies between bioeconomy activities and rural communities

The bioeconomy has the potential to significantly enhance the livelihoods of rural communities across the EU by fostering job creation, improving community resilience, and promoting sustainable practices. To achieve these positive outcomes, it is crucial to identify and leverage synergies between bioeconomy activities and rural communities. This involves fostering collaboration among stakeholders and promoting sustainable practices that benefit both the bioeconomy and rural communities.

Improved livelihoods

Bioeconomy activities can provide rural communities with new economic opportunities by creating jobs in sectors such as agriculture, forestry, and bio-based industries. For instance, the cultivation of bio-based crops and the processing of bio-based materials can generate employment for local farmers and workers in rural areas. Additionally, bioeconomy initiatives can support the development of local businesses and cooperatives, enabling rural communities to diversify their income sources and reduce their dependence on traditional agricultural practices.

Job creation

The bioeconomy can drive job creation in rural areas by establishing new industries and expanding existing ones. For example, the production of bio-based products such as bioplastics, biofuels, and biochemicals requires skilled labor for cultivation, processing, and manufacturing [14]. By investing in bioeconomy activities, rural communities can benefit from increased employment opportunities and the development of a skilled workforce [15]. Moreover, bioeconomy initiatives can attract investments and funding from both public and private sectors, further boosting job creation in rural areas.

Community resilience

Enhancing community resilience is another key benefit of integrating bioeconomy activities with rural communities. By promoting sustainable practices, such as regenerative agriculture and circular economy principles, rural communities can improve their environmental sustainability and reduce their vulnerability to external shocks. For instance, the adoption of low-input crops and sustainable land management practices can help rural communities maintain soil health, conserve water resources, and mitigate the impacts of climate change [16]. Additionally, bioeconomy activities can strengthen social cohesion and community engagement by involving local stakeholders in decision-making processes and fostering collaboration among different sectors [17].

Fostering collaboration

To maximize the positive impacts of bioeconomy activities on rural communities, it is essential to foster collaboration among stakeholders. This includes engaging local farmers, businesses, policymakers, research institutions, and non-governmental organizations in the development and implementation of bioeconomy initiatives. Collaborative approaches, such as regional bioeconomy clusters and local action groups, can facilitate knowledge sharing, innovation, and the efficient use of resources. Furthermore, cross-sector partnerships can bring together diverse perspectives and expertise to address complex challenges and create synergies between bioeconomy activities and rural development.

Promoting sustainable practices

Promoting sustainable practices is crucial for ensuring that bioeconomy activities benefit both bioeconomy and rural communities. This involves adopting environmentally friendly technologies, reducing waste, and enhancing resource efficiency. For example, the use of bio-based solutions for environmental challenges, such as bioremediation and renewable energy production, can help rural communities achieve sustainability goals while supporting bioeconomy growth. Additionally, sustainable practices can enhance the social and economic well-being of rural communities by improving access to clean energy, reducing environmental pollution, and supporting biodiversity conservation.

3.2.1 Balance competing interests at EU level

Analyze how bioeconomy activities intersect with other sectors (e.g., food production, bioenergy, urbanization) and balancing competing interests and positive impacts is key to optimize overall sustainability. Bioeconomy activities intersect with various sectors such as food production, bioenergy, and urbanization, creating both opportunities and challenges. This involves evaluating the environmental, social, and economic impacts of bioeconomy activities and developing strategies to mitigate negative consequences.

Food production

The intersection of bioeconomy activities with food production is critical, as both sectors rely on the same biological resources. Bioeconomy initiatives, for instance related to the cultivation of bio-based crops, can enhance food security by improving agricultural productivity and sustainability [18]. To balance these interests, it is crucial to adopt integrated land-use planning and promote practices that enhance both food production and bio-based resource utilization. For example, agroforestry and intercropping can increase biodiversity and soil health while providing biomass for bioeconomy activities [19]

Bioenergy

Bioenergy is a significant component of the bioeconomy, contributing to greenhouse gas (GHG) reduction and energy security [20]. However, the production of bioenergy can compete with food production and lead to land-use changes that affect biodiversity and ecosystem services [21]. To balance these interests, it is essential to prioritize the use of waste and residues for bioenergy production and promote advanced biofuels that do not compete with food crops Additionally, integrating bioenergy production with other bioeconomy activities, such as biorefineries, can enhance resource efficiency and reduce environmental impacts [22].

Urbanization

Urbanization presents both challenges and opportunities for bioeconomy. On one hand, urban areas can provide markets for bio-based products and create demand for sustainable solutions [23]. On the other hand, urban expansion can lead to the loss of agricultural land and natural habitats [16]. To balance these interests, it is important to promote urban planning that incorporates green infrastructure and supports the development of bio-based industries [24]. For instance, urban agriculture and vertical farming can contribute to food security and resource efficiency in cities [25].

Evaluating environmental, social and economic impacts

To optimize sustainability, it is essential to evaluate the environmental, social, and economic impacts of bioeconomy activities. This involves assessing the life cycle impacts of bio-based products, including resource use, emissions, and waste generation. Social impacts, such as job creation, community resilience, and social equity, should also be considered. Economic impacts, including market opportunities, cost savings, and investment needs, are crucial for the viability of bioeconomy initiatives.

3.3 Recommendations for the EU Bioeconomy Sector development

To ensure that the European bioeconomy contributes to climate goals, rural development, and industrial innovation—while minimizing trade-offs—strategic, cross-sector, and inclusive approaches are essential. The following recommendations based on the current framework and integrating insights from recent EU policy analyses and sustainability science are included:

Integrated Land-Use Planning

Recommendation:
Promote land-use strategies that balance **food security**, **bio-based production**, and **ecosystem services** through spatial planning and agroecological zoning.

Rationale:
The expansion of biomass production has to be properly managed ito avoid risks related to **land-use conflicts**, while promoting soil and biodiversity protection. Integrated planning helps aligning land use with environmental thresholds and socio-economic needs. [26]

Sustainable Resource Management

Recommendation:
Promote the **cascading use of biomass** and the valorization of **by-products**, **waste and residues, while maintaining the sustainable use of** primary biomass for energy or materials.

Rationale:

The EU Renewable Energy Directive provides criteria for the sustainable use of biomass in energy, that should be used as a basis for the development of similar criteria also for bio-based materials use. While preserving the role of primary biomass, research and development should focus on providing **concrete and scalable alternative,** starting from waste and by-products, in a **circular economy perspective**.

Cross-Sector Collaboration

Recommendation:

Foster **interdisciplinary partnerships** between agriculture, industry, research, and civil society to co-develop solutions and share infrastructure.

Rationale:

Synergies between sectors enhance **resource efficiency**, **innovation**, and **market resilience**. Collaboration also helps address systemic challenges such as feedstock competition and technology gaps.

Policy Coherence and Governance Alignment

Recommendation:

Ensure that **EU and national policies** across agriculture, energy, environment, and industry are **mutually reinforcing** and aligned with bioeconomy goals.

Rationale:

Fragmented policies can lead to **contradictory incentives** (e.g., subsidies for both fossil fuels and bio-based products). Coherent governance is essential for scaling sustainable bioeconomy models [26]

Public Engagement and Social Inclusion

Recommendation:

Involve **local communities**, **farmers**, and **citizens** in bioeconomy planning and decision-making to ensure **social acceptance**, **equity**, and **transparency**.

Rationale:

Social resistance to land use changes, biorefineries, or new technologies can delay or cancel projects. Participatory governance builds trust and ensures that benefits are equitably distributed.

4. CASE STUDIES AND BEST PRACTICES AT EU LEVEL

In this section, different case studies and best practices are documented and analyzed to demonstrate successful integration of bioeconomy activities with rural development. Examples include regional strategies in Scotland, Southwest Netherlands, Saxony-Anhalt, and Veneto, which highlight distinctive approaches and strengths of each region. Lessons learned from these case studies can guide future bioeconomy initiatives and promote sustainable development.

Scotland

Scotland's regional strategy focuses on leveraging its natural resources and strong agricultural sector to promote bioeconomy activities [27]. The Scottish Government has implemented policies to support the development of bio-based industries, such as bioplastics and biofuels, while also promoting sustainable agricultural practices [28]. Key initiatives include the establishment of bio-refineries and the promotion of circular economy principles to enhance resource efficiency and reduce waste. Scotland's approach emphasizes collaboration between stakeholders, including farmers, businesses, and research institutions, to drive innovation and sustainable development [29]

South West Netherlands

The Southwest Netherlands region has adopted a comprehensive bioeconomy strategy that integrates agricultural, industrial, and environmental activities[30]. The region's approach focuses on the development of bio-based products and the promotion of sustainable farming practices. Key initiatives include the establishment of biorefineries, the use of agricultural residues for bioenergy production, and the promotion of sustainable land management practices. The Southwest Netherlands strategy emphasizes the importance of stakeholder engagement and collaboration to achieve sustainable development goals.

Saxony-Anhalt

Saxony-Anhalt's regional strategy leverages its strong industrial base and agricultural sector to promote bioeconomy activities. The region has implemented policies to support the development of bio-based industries, such as bioplastics, biofuels, and biochemicals. Key initiatives include the establishment of biorefineries, the promotion of circular economy principles, and the use of agricultural residues for bioenergy production. Saxony-Anhalt's approach emphasizes the importance of collaboration between stakeholders, including farmers, businesses, and research institutions, to drive innovation and sustainable development.

Veneto

Veneto's regional strategy focuses on leveraging its strong agricultural sector and industrial base to promote bioeconomy activities. The region has implemented policies to support the development of bio-based industries, such as bioplastics, biofuels, and biochemicals. Key initiatives include the establishment of biorefineries, the promotion of circular economy principles, and the use of agricultural residues for bioenergy production. Veneto's approach emphasizes the importance of stakeholder engagement and collaboration to achieve sustainable development goals.

4.1 Lessons Learned

The case studies from Scotland, South West Netherlands, Saxony-Anhalt, and Veneto highlight several key lessons that can guide future bioeconomy initiatives that can be applied to Brilian project:

Stakeholder Engagement: Engaging local farmers, businesses, policymakers, research institutions, and non-governmental organizations in the development and implementation of bioeconomy initiatives is crucial for success. Collaborative approaches, such as regional bioeconomy clusters and local action groups, can facilitate knowledge sharing, innovation, and the efficient use of resources.

Sustainable Practices: Promoting sustainable practices, such as regenerative agriculture and circular economy principles, is essential for ensuring that bioeconomy activities benefit both the bioeconomy and rural communities. This involves adopting environmentally friendly technologies, reducing waste, and enhancing resource efficiency.

Policy Support: Implementing supportive policies that promote bioeconomy activities and sustainable development is crucial for success. This includes providing incentives for bio-based industries, supporting research and innovation, and promoting sustainable land management practices.

Innovation and Research: Investing in research and innovation is essential for driving the development of bioeconomy activities. This includes supporting the establishment of biorefineries, promoting the development of bio-based products, and fostering collaboration between research institutions and businesses.

5. BENCHMARKING INDICATORS (AT PROJECT, PILOT AND EU LEVEL)

The following section depicts the results per Project, Sector and Pilot, regarding the Pillars and KPIs defined at month 24 of the project.

5.1 PROJECT RESULTS

Table 7 shows the results of the Pillars and KPIs project level, that serve as critical indicators of overall project performance and success. Pillars represent the key strategic areas or components of the project, while KPIs are quantifiable metrics used to measure progress and achievements.

Table 7. Results of Pillars and KPIs at Project level in Month 24.

Project					
Pillars	**Results before the project start (M0)**	**Results Project (M24)**	**KPIs**	**Results before the project start (M0)**	**Results project (M24)**
Legal and organisational	0%	34%	Regional development and economic cohesion	0%	35%
			Quality systems and certification	0%	33%
Economic	0%	31%	Financing/Investment	0%	25%
			Market conditions	0%	33%
			Economic viability	0%	35%
Social	1.17%	42%	Revitalisation of rural areas	3.33%	35%
			Human resource management strategies	2.5%	50%
			Social strategy for bio-based products	0%	35%
			Communication actions	0%	45%
			Dissemination actions	0%	45%
Environmental	0.83%	40.8%	Sustainability Strategy	0%	35%
			Energy use	0%	50%
			GHG emissions	0%	35%
			Water use	5%	35%

Project					
Pillars	Results before the project start (M0)	Results Project (M24)	KPIs	Results before the project start (M0)	Results project (M24)
			Circular economy	0%	50%
			Sustainable logistics	0%	40%
Technical	0%	55%	Productivity and efficiency	0%	50%
			Technical viability	0%	60%

The evolution of KPIs over the course of the project (from M0 to M24) shows significant overall progress across all categories, with some pillars advancing more than others. The Technical and Social pillars demonstrated the most substantial improvements, with technical viability increasing from 0% to 60% which is aligned with the work performed during this period to validate the different value chains and bio applications. In the environmental pillar, energy use and circular economy also stood out with a rise to 50%, showing robust environmental integration linked to the data collection process and initial phase of the analysis phase related to the life cycle assessment currently ongoing.

By contrast, the Economic and legal/organisational pillars saw more moderate advances. Financing/Investment and Economic viability only reached 25–35% since the work has focused on the technical side and the business model development and cost structure are just starting in this upcoming period with the outcomes of the booster service as input data. On average, most KPI categories moved from near-zero to 35–50%, reflecting a solid but incomplete trajectory toward full implementation.

For the upcoming period, efforts should prioritize organisational, financing/Investment and economic viability in line with the work foreseen to develop the business models.

5.2 SECTOR RESULTS

Table 8 shows the result of the degree of implementation of Pillars and KPIs at sector level.

Table 8. Results of Pillars and KPIs at Sector level.

Sector					
Pillars	**Results before the project start (M0)**	**Results Project (M24)**	**KPIs**	**Results before the project start (M0)**	**Results project (M24)**
Legal and organisational	**50%**	**60%**	**Regional development and economic cohesion**	**50%**	**60%**
			Quality systems and certification	**50%**	**60%**
Economic	**41.67%**	**53.3%**	**Financing/Investment**	**50%**	**60%**
			Market conditions	**50%**	**60%**
			Economic viability	**25%**	**40%**
Social	**35%**	**52.5%**	**Revitalisation of rural areas**	**25%**	**40%**
			Human resource management strategies	**62.5%**	**70%**
			Social strategy for bio-based products	**17.5%**	**35%**
Environmental	**50%**	**60%**	**Sustainability Strategy**	**50%**	**60%**

The sector perspective reveals consistent baseline performance, with most pillars starting between 25% and 62.5% at M0, contrasting with the territorial approach, which started mostly from 0%. The Social pillar, particularly Human resource management strategies, achieved the highest KPI at 70%, up from 62.5%, reflecting strong sector engagement in workforce planning and training.

Significant progress is also evident in the legal and organisational, economic, and environmental pillars, where all indicators improved by 10–15 percent, reaching 60% in most categories. Social strategy for bio-based products saw limited improvement (from 17.5% to 35%), suggesting these remain areas of concern. The average evolution across categories is around 12.5 percent, showing a steady but modest growth trend.

To reach 100% implementation, efforts should be allocated to address economic feasibility and social acceptance of bio-based products, while strengthening tailored exploration of financing tools and integrated sustainability strategies. These actions will help bridge existing gaps and consolidate sector transformation.

5.3 DANISH PILOT RESULTS

Table 9 shows the results of the degree of implementation of Pillars and KPIs at Danish Pilot level.

Table 9. Results of Pillars and KPIs at Danish Pilot level.

Danish Pilot					
Pillars	**Results before the project start (M0)**	**Results Project (M24)**	**KPIs**	**Results before the project start (M0)**	**Results project (M24)**
Legal and organisational	**75%**	**81.2%**	**Regional development and economic cohesion**	**50%**	**62.5%**
			Quality systems and certification	**100%**	**100 %**
Economic	**51.11%**	**56.1%**	**Financing/Investment**	**100%**	**100 %**
			Market conditions	**36.67%**	**48.3%**
			Economic viability	**16.67%**	**20%**
Social	**27.5%**	**36,4%**	**Revitalisation of rural areas**	**16.67%**	**25%**
			Human resource management strategies	**50%**	**66.6%**
			Social strategy for bio-based products	**5%**	**17,5%**
Environmental	**46.94%**	**58.1%**	**Sustainability Strategy**	**55%**	**62.5%**
			Energy use	**37.5%**	**75%**
			GHG emissions	**17.5%**	**17.5%**
			Water use	**75%**	**75%**
			Circular economy	**3.33%**	**45%**
			Environmental impact reduction	**36.67%**	**43.3%**
			Resource use	**100%**	**100%**
			Biodiversity preservation	**10%**	**10%**
			Sustainable logistics	**87.5%**	**95%**
Technical	**12.08%**	**34.2%**	**Productivity and efficiency monitoring**	**36.25%**	**67.5%**
			Productivity and efficiency	**0%**	**20%**
			Technical viability	**0%**	**15%**

The Danish pilot shows moderate to strong KPI improvements in several sectors, starting from relatively high baselines in some categories. The Environmental pillar presents the most remarkable growth, highlighting a strong focus on resource efficiency and environmental transition.

The technical pillar also saw solid progress, especially in productivity and efficiency monitoring, which rose around 30%, and overall technical KPIs increasing more than 15%. The social pillar experienced an average increase of 15 percent, with human resource management strategies reaching more than 60%.

In contrast, the economic viability KPI saw only a marginal rise from 16.67% to 20%, and GHG emissions stagnated at 17.5% a reduced improvement which is aligned with the workflow foreseen in the project that will develop the work related to the life cycle assessment and business development mainly in the upcoming period. On average, KPI evolution across pillars is around 15%, showing stable and gradual improvement.

The work planned in the next period will prioritize the obtaining of the information that will support the improvement of GHG emissions mitigation, economic feasibility, and technical scalability which remain under 20%. Reinforcing efforts in these sectors will be essential for consolidating the pilot's long-term sustainability and resilience.

5.4 SPANISH PILOT RESULTS

Table 10 shows the results of the degree of implementation of Pillars and KPIs at Danish Pilot level.

Table 10. Results of Pillars and KPIs at Spanish Pilot level.

Spanish Pilot					
Pillars	**Results before the project start (M0)**	**Results Project (M24)**	**KPIs**	**Results before the project start (M0)**	**Results project (M24)**
Legal and organisational	**56.25%**	**100%**	**Regional development and economic cohesion**	**50%**	**100%**
			Quality systems and certification	**62.5%**	**100%**
Economic	**63.89%**	**77.8%**	**Financing/Investment**	**75%**	**100%**
			Market conditions	**50%**	**53.3%**
			Economic viability	**66.7%**	**80%**
Social	**75.69%**	**100%**	**Revitalisation of rural areas**	**58.3%**	**100%**

Spanish Pilot					
Pillars	**Results before the project start (M0)**	**Results Project (M24)**	**KPIs**	**Results before the project start (M0)**	**Results project (M24)**
			Human resource management strategies	93.7%	100%
			Social strategy for bio-based products	75%	100%
Environmental	49.35%	75.8%	Sustainability Strategy	62.5%	70%
			Energy use	50%	62.5%
			GHG emissions	25%	55%
			Water use	50%	75%
			Circular economy	83.3%	83%
			Environmental impact reduction	23.33%	75%
			Resource use	75%	70%
			Biodiversity preservation	37.5%	75%
			Sustainable logistics	37.5%	65%
Technical	66.67%	91.7%	Productivity and efficiency monitoring	25%	75%
			Productivity and efficiency	75%	100%
			Technical viability	100%	100%

The Spanish pilot displays a strong and balanced evolution across all pillars, with multiple categories already achieving or nearing 100% implementation. This is aligned with the work performed during this period which enabled the validation of the main part of the value chain for the main bio-application in the Spanish demo, the bioplastic.

Environmental performance improved substantially which highlights a concerted effort in sustainability and ecosystem integration in line with the strategy of the economy and the effort to put in operation the extraction plant and test the bio-products developed.

The economic pillar had a moderate increase, especially in economic viability since the operation of the plant has already allowed to assess some figures and evaluate the cost and the investment required among other figures to determine the economic viability.

On average, KPI growth across all pillars is over 25 percent, indicating highly effective implementation. The upcoming work in the Spanish pilot should now focus on fine-tuning market conditions assessment and business model.

5.5 ITALIAN PILOT RESULTS

Table 11 shows the results of the degree of implementation of Pillars and KPIs at Italian pilot level.

Table 11. Results of Pillars and KPIs at Italian Pilot level.

Italian Pilot					
Pillars	**Results before the project start (M0)**	**Results Project (M24)**	**KPIs**	**Results before the project start (M0)**	**Results project (M24)**
Legal and organisational	68.75%	88.7%	Regional development and economic cohesion	50%	90%
			Quality systems and certification	87.5%	87.5%
Economic	58.33%	65.6%	Financing/Investment	100%	100%
			Market conditions	50%	65%
			Economic viability	25%	31.7%
Social	65.28%	72.3%	Revitalisation of rural areas	41.7%	55%
			Human resource management strategies	66.7%	83.3%
			Social strategy for bio-based products	87.5%	87.5%
Environmental	84.26%	90.56%	Sustainability Strategy	75%	85%
			Energy use	100%	100%
			GHG emissions	75%	85%
			Water use	75%	75%
			Circular economy	58.3%	70%
			Environmental impact reduction	100%	100%
			Resource use	100%	100%
			Biodiversity preservation	75%	100%
			Sustainable logistics	100%	100%
Technical	52.78%	66.9%	Productivity and efficiency monitoring	33.3%	66.7%

Italian Pilot					
Pillars	Results before the project start (M0)	Results Project (M24)	KPIs	Results before the project start (M0)	Results project (M24)
			Productivity and efficiency	75%	75%
			Technical viability	50%	50%

The Italian pilot demonstrates solid KPI improvements, particularly in the legal and organisational pillar and regional development associated to the efforts allocated to establish the agreements with the farmers which is also associated to the organisational module reflecting a strong stakeholder and territorial engagement. The environmental pillar was already advanced at baseline and now stands out in most categories, including GHG emissions, biodiversity preservation and sustained scores in energy use, resource use, and sustainable logistics.

The economic pillar showed moderate improvements in terms of economic viability and market conditions as work is still ongoing to collect all the information from the valirosation phase, and the booster service will be carried out during this upcoming period. Social aspects progressed modestly, increasing around 10% in general terms.

On the technical side, productivity and efficiency monitoring have increased significantly. The average KPI increase across all pillars is around 15–20 percent, indicating incremental but targeted progress.

For the next phase, efforts should concentrate efforts on improving the economic indicators, deepening social impact in rural revitalisation and advancing technical readiness. These will be key to ensure full deployment of the bio-based value chains targeted and boost itis replication potential by project completion.

6. CONCLUSIONS

The BRILIAN project's assessment of trade-offs and synergies- conducted through the analysis of the BRILIAN Pilot's case studies and the implementation of bio-based value chains in Spain, Denmark, and Italy - reveals a nuanced landscape of opportunities and challenges for the European bioeconomy. Through a stakeholder-centered approach, the study highlights how bioeconomy initiatives can drive rural development, environmental sustainability, and industrial innovation—while also presenting complex trade-offs that require careful governance.

Across all three pilot cases, **positive impacts** were evident in areas such as job creation, resource efficiency, and the valorization of agricultural residues. Farmers benefit from the implementation of innovative agricultural and regenerative practices and income diversification; agro-industries accessed new markets and improved operational sustainability; and local communities experienced increased employment and awareness of circular economy principles. These outcomes align with the EU's Green Deal and Circular Economy Action Plan, reinforcing the bioeconomy's role in achieving climate and sustainability goals.

However, the study also identified **significant trade-offs**. These include environmental risks from intensive cultivation and chemical use, high capital and operational costs, regulatory uncertainty, and social acceptance challenges. For example, the Spanish potato-starch chain faces issues related to infrastructure costs and odour pollution, while the Danish rapeseed chain must address the environmental footprint of drying and protein extraction. In Italy, the adoption to non-conventional crops and biorefinery operations introduces market and regulatory uncertainties that affect farmers and industries alike.

Importantly, the analysis uncovered **synergies** that can be leveraged to enhance sustainability and resilience. These include shared infrastructure, cross-sector collaboration, and knowledge transfer between stakeholders. The integration of agricultural and industrial systems, particularly through biorefineries, demonstrating how circularity can be operationalized at the regional level. Moreover, stakeholder engagement and cooperative models emerged as critical enablers of inclusive and effective bioeconomy development.

At the EU level, the findings underscore the need for **strategic, cross-sector, and inclusive policy frameworks**. Recommendations include:

- Promoting integrated land-use planning to balance food, feed, and biomass production.
- Prioritizing the cascading use of biomass and valorization of residues.
- Enhancing policy coherence across agriculture, energy, and environmental sectors.
- Supporting public engagement and social inclusion to build trust and acceptance.
- Fostering innovation through research, training, and regional bioeconomy clusters.

Concerning the achievements in terms of key performance indicators, across the project, all pilots showed clear KPI improvements, with many categories reaching 100%. The technical, social, and environmental pillars saw the strongest growth, particularly in areas like energy use, productivity and workforce strategies. Economic viability, market conditions, and GHG emissions remained among the least improved areas which is aligned with the work planned in the project as higher efforts will be allocated to the development of the business model and the life cycle performance during this upcoming period. While sectorial approaches started from higher baselines, their average improvements were more modest than project and pilot ones.

In conclusion, the BRILIAN project demonstrates that a well-designed bioeconomy can contribute meaningfully to rural revitalization, climate action, and sustainable industry. However, realizing this potential requires addressing trade-offs transparently, scaling synergies strategically, and embedding sustainability at the core of policy and practice. The lessons from the pilot cases offer valuable insights for replicating and scaling bioeconomy models across Europe.

7. REFERENCES

[1] W. Zeug, A. Bezama, and D. Thrän, “A framework for implementing holistic and integrated life cycle sustainability assessment of regional bioeconomy,” *International Journal of Life Cycle Assessment*, vol. 26, no. 10, pp. 1998–2023, Oct. 2021, doi: 10.1007/S11367-021-01983-1/METRICS.

[2] “(18) Strategic Significance: Leveraging the Kano Model in ESG-Driven Product Development and Beyond the Value Chain | LinkedIn.” Accessed: May 28, 2025. [Online]. Available: https://www.linkedin.com/pulse/strategic-significance-leveraging-kano-model-product-beyond-amoghli-poasf/

[3] “About the Kano Model - Kano Model - Kano Model.” Accessed: May 28, 2025. [Online]. Available: https://kanomodel.com/about-the-kano-model/

[4] “Enhancing stakeholder involvement in EU Bioeconomy Policy Final report”, doi: 10.2777/736837.

[5] S. Van Schoubroeck, M. Van Dael, S. Van Passel, and R. Malina, “A review of sustainability indicators for bio-based chemicals,” *Renewable and Sustainable Energy Reviews*, vol. 94, pp. 115–126, Oct. 2018, doi: 10.1016/J.RSER.2018.06.007.

[6] A. Devaux, J. P. Goffart, P. Kromann, J. Andrade-Piedra, V. Polar, and G. Hareau, “The Potato of the Future: Opportunities and Challenges in Sustainable Agri-food Systems,” *Potato Res*, vol. 64, no. 4, pp. 681–720, Dec. 2021, doi: 10.1007/S11540-021-09501-4/FIGURES/10.

[7] “Sustainability - National Potato Council.” Accessed: May 28, 2025. [Online]. Available: https://www.nationalpotatocouncil.org/benefits-of-potatoes/sustainability/

[8] “Det Nationale Bioøkonomipanel - Ministeriet for Fødevarer, Landbrug og Fiskeri.” Accessed: May 28, 2025. [Online]. Available: https://fvm.dk/arbejdsomraader/landbrug/aftale-om-groen-omstilling-af-dansk-landbrug/det-nationale-biooekonomipanel

[9] “Renewable Energy Directive.” Accessed: May 28, 2025. [Online]. Available: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en

[10] I. Chakraborty, P. N, S. S. Mal, U. C. Paul, M. H. Rahman, and N. Mazumder, “An Insight into the Gelatinization Properties Influencing the Modified Starches Used in Food Industry: A review,” *Food and Bioprocess Technology 2022 15:6*, vol. 15, no. 6, pp. 1195–1223, Feb. 2022, doi: 10.1007/S11947-022-02761-Z.

[11] D. Diakosavvas and C. Frezal, “Bio-economy and the sustainability of the agriculture and food system OPPORTUNITIES AND POLICY CHALLENGES,” 2019, doi: 10.1787/D0AD045D-EN.

[12] A. Kover, D. Kraljić, R. Marinaro, and E. R. Rene, “Processes for the valorization of food and agricultural wastes to value-added products: recent practices and perspectives,” *Systems Microbiology and Biomanufacturing 2021 2:1*, vol. 2, no. 1, pp. 50–66, Jul. 2021, doi: 10.1007/S43393-021-00042-Y.

[13] A. E. Atabani, V. K. Tyagi, G. Fongaro, H. Treichel, A. Pugazhendhi, and A. T. Hoang, “Integrated biorefineries, circular bio-economy, and valorization of organic waste streams with respect to bio-products,” *Biomass Convers Biorefin*, vol. 12, no. 3, p. 565, Mar. 2022, doi: 10.1007/S13399-021-02017-4/METRICS.

[14] G. Basch, “Rural climate action through bio-based initiatives”.

[15] N. Szarka *et al.*, “Stakeholder Engagement in the Co-Design of Regional Bioeconomy Strategies,” 2023, doi: 10.3390/su15086967.

[16] J. L. F. Virgolino and N. M. Holden, “Does the bioeconomy literature provide a balanced view of sustainability?,” *Sustain Sci*, vol. 20, no. 3, pp. 1075–1092, May 2025, doi: 10.1007/S11625-025-01642-6/FIGURES/5.

[17] “A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment | European Committee of the Regions.” Accessed: May 29, 2025. [Online]. Available: https://cor.europa.eu/en/our-work/opinions/cdr-6433-2018

[18] F. Schipfer *et al.*, “The circular bioeconomy: a driver for system integration,” *Energy Sustain Soc*, vol. 14, no. 1, pp. 1–19, Dec. 2024, doi: 10.1186/S13705-024-00461-4;TYPE=ARTICLE;KWRD=CIRCULAR.

[19] “Summary report on the social, economic and environmental impacts of the bioeconomy,” 2016.

[20] March, “Projected Impact and Growth of a Fully Unleashed Bioeconomy The Value of Food, Agriculture, and Manufacturing Biotechnology”.

[21] R. Diaz-Chavez, S. Mortensen, and A. Wikman, “Bioeconomy: tapping natural and human resources to achieve sustainability,” 2019.

[22] “Bioeconomy, biodiversity and soil quality - Willagri - Comprendre les enjeux de l’agriculture.” Accessed: May 29, 2025. [Online]. Available: https://www.willagri.com/2025/02/24/bioeconomy-biodiversity-and-soil-quality/?lang=en

[23] “Safeguarding the Bioeconomy Finding Strategies for Understanding, Evaluating, and Protecting the Bioeconomy while Sustaining Innovation and Growth | National Academies.” Accessed: May 29, 2025. [Online]. Available: https://www.nationalacademies.org/our-work/safeguarding-the-bioeconomy-finding-strategies-for-understanding-evaluating-and-protecting-the-bioeconomy-while-sustaining-innovation-and-growth

[24] C. A. Zuniga-Gonzalez, J. L. Quiroga-Canaviri, J. J. Brambila-Paz, S. G. Ceballos-Pérez, and M. M. Rojas-Rojas, “Formulation of an innovative model for the

bioeconomy," *PLoS One*, vol. 19, no. 11, p. e0309358, Nov. 2024, doi: 10.1371/JOURNAL.PONE.0309358.

[25] R. Meyer, "Bioeconomy Strategies: Contexts, Visions, Guiding Implementation Principles and Resulting Debates," *Sustainability 2017, Vol. 9, Page 1031*, vol. 9, no. 6, p. 1031, Jun. 2017, doi: 10.3390/SU9061031.

[26] B. Fleischmann, A. Mayer, C. Görg, and M. Pichler, "Negotiating biophysical limits in the European Union's bioeconomy: a critical analysis of two conflicts over regulating biomass use in EU policy," *Sustain Sci*, vol. 19, no. 6, pp. 1935–1948, Nov. 2024, doi: 10.1007/S11625-024-01543-0/TABLES/1.

[27] D. Charles *et al.*, "Case studies of regional bioeconomy strategies across Europe," 2016.

[28] "Case studies of regional bioeconomy strategies across Europe - EPRC." Accessed: May 29, 2025. [Online]. Available: https://eprc-strath.org/publication/case-studies-of-regional-bioeconomy-strategies-across-europe/

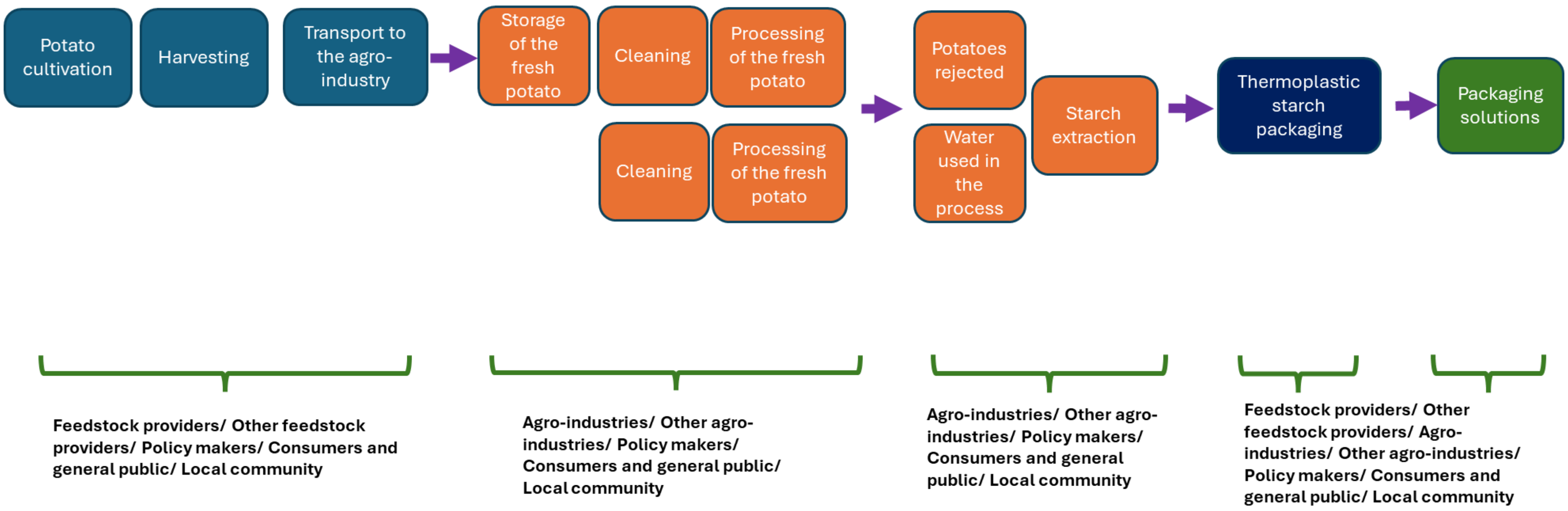
[29] "BioEconomy Regional Strategy Toolkit | FP7 | CORDIS | European Commission." Accessed: May 29, 2025. [Online]. Available: https://cordis.europa.eu/project/id/613671/reporting

[30] C. B. Păuna, D. Cosniță, and C. Leucuța, "Best practice guide on strategy development Bio-based strategies and roadmaps for enhanced rural and regional development in the EU," 2021.

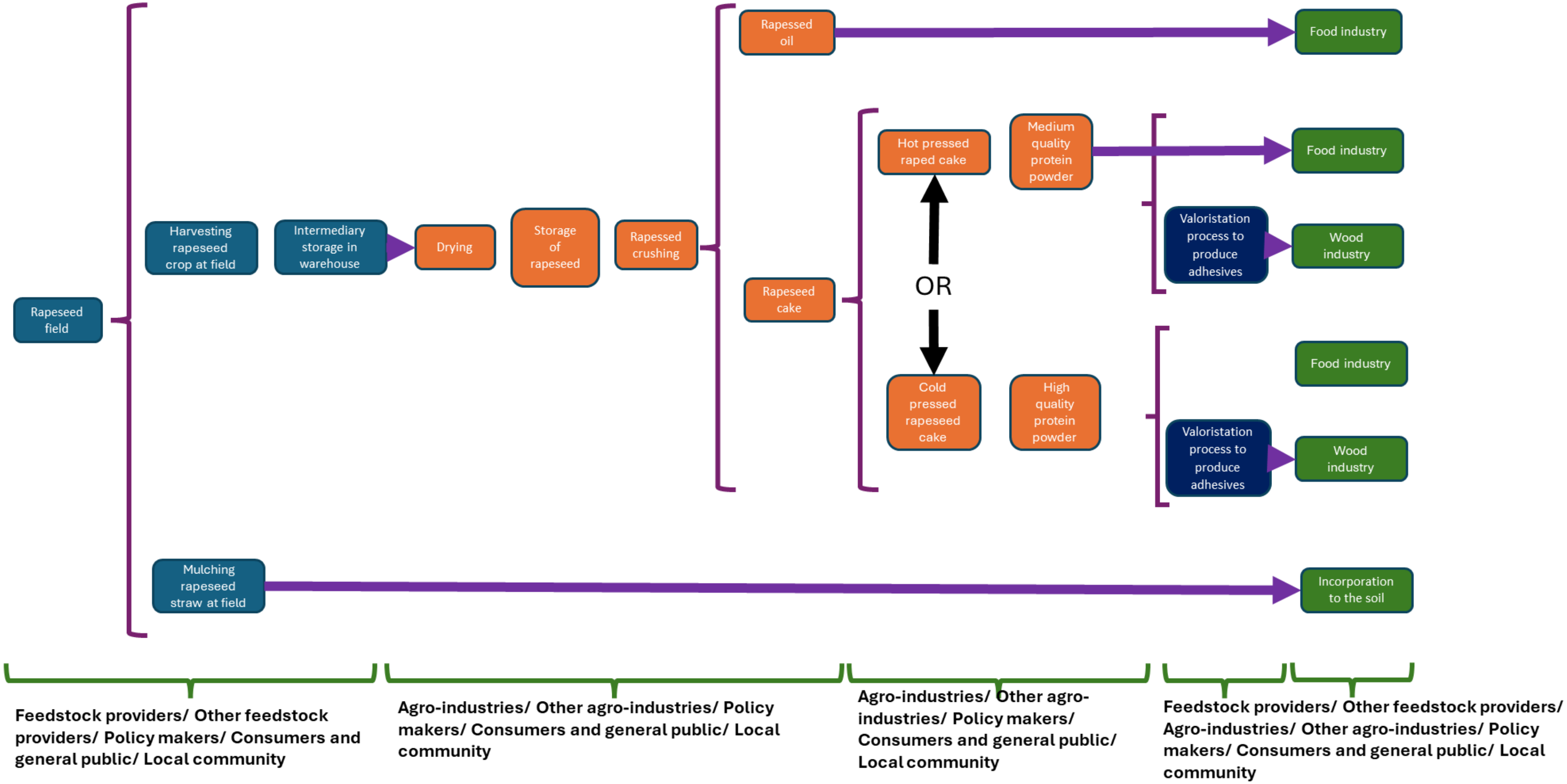
ANNEXES

ANNEX A Pilot case value chains

Spanish value chain diagram



Danish value chain diagram



Italian value chain diagram