STUDY

Requested by the AGRI committee

The Bioeconomy in the Agriculture of the Future

Its Role in Promoting Farms' Economic Sustainability

Policy Department for Regional Development, Agriculture and Fisheries
Directorate-General for Cohesion, Agriculture and Social Policies (CASP)
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Abstract

This study was prepared by the Policy Department at the request of the Committee on Agriculture and Rural Development (AGRI). It examines the bioeconomy's role in future EU agriculture, focusing on promoting farms' economic sustainability. The paper analyses policy frameworks, successful circular models, and trends in biomass valorisation to identify strategies for income diversification. Finally, it provides policy options to boost bioeconomy initiatives and strengthen value chains within the European farming sector.

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CONTENTS

LIST OF ABBREVIATIONS

AKIS	Agricultural Knowledge and Innovation Systems
BBI JU	Bio-Based Industries Joint Undertaking
CAP	Common Agricultural Policy
CBE	Circular Bio-Based Economy
CBE JU	Circular Bio-Based Europe Joint Undertaking
CE	Circular Economy
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
EC	European Commission
EIB	European Investment Bank
FSDN	Farm Sustainability Data Network
GE	Genetic Engineering
GHG	Greenhouse Gas
ILUC	Indirect Land Use Change
KBBE	Knowledge-Based Bioeconomy
NPBTs	New Plant Breeding Techniques
OGA	Other Gainful Activities
OECD	Organisation for Economic Co-operation and Development
SDGs	Sustainable Development Goals

LIST OF BOXES

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Background

Agriculture stands as a central pillar of the **European bioeconomy**, serving as the **primary source of biomass** and a **fundamental actor** in the transition towards a sustainable, circular, and climate-neutral economy by 2050. The sector is currently undergoing a paradigm shift, moving from a narrow focus on primary commodity production to a systemic role as a provider of multi-functional services and renewable resources. This transition to a **circular bioeconomy** (CBE) provides critical opportunities for income diversification and risk reduction for farmers by transforming agricultural residues and by-products into high-value bio-based products and renewable energy. Despite this potential, the development of the bioeconomy remains uneven across EU Member States due to fragmented policy frameworks, varying levels of technological readiness, and significant barriers to scaling innovations. The bioeconomy must move beyond isolated pilot projects toward robust, market-driven value chains that are deeply embedded in agricultural policy.

Aim of the Study

- Outline a strategic roadmap for the integration of circular bioeconomy models into future EU agricultural frameworks to enhance farm-level economic resilience;
- Identify the structural and institutional determinants required to scale successful bioeconomy initiatives from regional pilot cases to mainstream agricultural practice; and
- Define concrete policy pathways to strengthen the position of primary producers within bio-based value chains while resolving competition for land and resources.

Findings and Trends

The study identifies several **driving forces** shaping the agricultural bioeconomy. A key trend is the integration with the **circular economy**, which emphasizes the closing of nutrient loops and the reduction of waste. **Technological innovation**, including precision farming and advanced biotechnologies, is accelerating the transition, though it also creates a "digital and technological divide" between regions. Key findings include:

- **Income Diversification** – the relationship between bioeconomy engagement and farm income stability is complex and context-dependent. While diversification into other gainful activities (OGA) may reduce dependence on a single commodity market, the empirical analysis shows that farms with higher OGA shares tend to exhibit greater income variability rather than lower. Stable contractual arrangements and policy support are therefore important preconditions for making diversification economically viable.
- **The "Residues-First" Principle** – to avoid competition with food production, successful models prioritize the valorisation of underutilised by-products such as straw, manure, and processing waste.
- **Cascading Use** – prioritising material use (bioproducts) before energy recovery ensures maximum added value and resource efficiency.
- **Economic Performance** – farms with higher bioeconomy engagement tend to show lower agricultural income per hectare compared to less diversified farms. This reflects structural differences between farm types rather than a simple causal trade-off, and the drivers behind this association remain an open empirical question.
- **Policy Support as Income Stabiliser** – the empirical analysis shows that farms receiving higher subsidies per hectare exhibit measurably lower income variability, suggesting that

well-designed public support can partially offset the destabilising effects associated with bioeconomy diversification and high capital intensity.

Successful Models and Structural Drivers

The analysis of **successful initiatives** across the EU reveals several critical factors for scaling the bioeconomy:

- **Collective Structures** – cooperatives and producer groups are vital for aggregating biomass supply, sharing high investment risks, and ensuring farmers capture a fair share of the value added.
- **Regional Embeddedness** – "industrial symbiosis" at the local level, where the waste of one process becomes the raw material for another, reduces transport costs and strengthens rural economies.
- **Knowledge and Innovation** – access to technical and managerial skills through Agricultural Knowledge and Innovation Systems (AKIS) is a prerequisite for farmers to adopt complex bioeconomy solutions.
- **Market Signals** – long-term contractual frameworks and standardized quality parameters for biomass are essential to make bio-based investments "bankable" for private investors.

Regulatory and Market Barriers Limiting Development

Despite clear benefits, the adoption of bioeconomy models in mainstream agricultural practice faces several structural obstacles. One of the most significant is **regulatory uncertainty and administrative burden** associated with waste management and harmonised quality standards. In many cases, agricultural by-products are still classified as waste rather than secondary raw materials, complicating their further processing and trade. Legislative fragmentation hinders the development of value chains and discourages investors from committing to long-term projects. The study also highlights the risk of **biomass price** volatility.

Economic Impact Assessment Model

This study introduces a new incremental assessment model that quantifies the economic impacts of bioeconomy activities at the farm level. The model evaluates four dimensions: **costs and input savings**, **revenues and diversification**, **value added**, and **resilience**. Findings call for a differentiated and evidence-based approach to bioeconomy policy design, backed by a combination of public support tools.

Policy Options for the EU

To foster a scalable and inclusive bioeconomy, the study proposes several **policy pathways**, some of which are complementary:

- **Strategically Targeted Common Agricultural Policy (CAP) for Bioeconomy Scaling (Option A)**: The post-2027 CAP should integrate the bioeconomy as a horizontal priority. A key instrument should be the introduction of specific schemes that reward farmers for circular nutrient management and the production of renewable raw materials beyond traditional food production. Support must shift from isolated measures toward integrated risk-sharing models.
- **Value-Chain Contracts and Standards (Option B)**: To reduce market uncertainty, the broader use of written contractual frameworks is essential, including transparent pricing formulas and risk-sharing mechanisms. Simultaneously, establishing harmonized quality standards for agricultural residues and by-products (e.g., moisture content, purity) is a prerequisite for reducing transaction costs and enabling the industrial integration of bio-based value chains.

- **"Residues First" Principle to Manage Land Competition (Option C)**: Policy should prioritize the valorisation of by-products and waste streams over the cultivation of dedicated crops for energy or materials. This approach minimizes competition with food production and nature conservation.
- **Investment Packages and Financial Instruments (Option D)**: Given the high capital intensity of bioeconomy technologies (e.g., biorefineries, biogas plants), it is necessary to combine traditional grants with financial instruments such as guarantees and concessional loans, particularly in cooperation with the European Investment Bank (EIB).
- **Strengthening Capacities and Advisory Services via AKIS (Option E)**: AKIS must be reinforced so that advisors can function as innovation brokers. They should assist farmers with biomass flow planning, contract negotiations, carbon footprint certification, and digital monitoring.

1. BIOECONOMY IN THE EU: KEY TRENDS AND DRIVERS IN AGRICULTURE

KEY FINDINGS

EU agricultural bioeconomy is driven by the integration with the circular economy, focusing on closing nutrient loops and reducing waste through the valorisation of residues and by-products.

The cascading use of biomass and a "residues-first" approach help limit competition for land and strengthen resource efficiency across value chains.

Technological innovation and digitalisation (from precision farming to advanced biotechnologies) are key enablers, but they risk widening a digital and technological divide between farms and regions.

The shift towards an ecological vision links bioeconomy development with agroecology, soil and biodiversity protection and climate goals, requiring coherent integration into CAP instruments and AKIS support.

The bioeconomy, sometimes referred to as the **bio-based economy**, is defined by the European Commission (EC) as "*the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy*" (European Commission, 2012). It encompasses the economic use of biomass or biological processes. A fundamental characteristic of the bioeconomy is that it represents a process of societal transformation that is highly dynamic and structurally very complex (Aguilar et al., 2018). The bioeconomy integrates a wide range of sectors (Staffas et al., 2013) with markedly different perceptions from the perspective of various stakeholders. Bioeconomy sectors include agriculture, forestry, aquaculture, the food industry, energy, biofuels, the chemical industry and biotechnology (Woźniak et al., 2021). Within the European Union (EU), the development of the bioeconomy is guided by ad hoc strategies and specific legislative frameworks, such as for carbon farming, and is strategically financed, among others, through the Horizon Europe program (particularly Cluster 6) and – in the next EU budgetary period post-2027 – by the proposed European Competitiveness Fund[1], both of which focus on the application of bio-based solutions.

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[1] The European Commission has proposed the European Competitiveness Fund (ECF) as part of the proposals for the long-term EU budget for the period 2028-2034. The proposal is available at the following link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52025PC0555

1.1. Conceptual and Policy Framework of the Bioeconomy with a Focus on Agriculture

The origins of the bioeconomy in the EU date back to the mid-20th century, with an emphasis on the "Knowledge-Based Bioeconomy" (KBBE), which first appeared in EU documents in 2005 (European Commission, 2005; European Commission, 2007).

The EU defined five main objectives of the bioeconomy in its 2012 Bioeconomy Strategy, which remained valid in the revised 2018 strategy: ensuring food security, sustainable management of natural resources, reducing dependence on non-renewable resources, climate change mitigation and adaptation, and job creation while maintaining European competitiveness (European Commission, 2018). The **Bioeconomy Strategy of 2025** focuses on four main areas (European Commission, 2025): scaling innovation and investments, building new lead markets for bio-based materials and technologies, ensuring sustainable biomass supply across value chains, and harnessing global opportunities. The bioeconomy aims to achieve the widespread use of sustainable bio-based materials and products in the EU by 2040 and to make biosolutions competitive, while contributing to EU growth, employment and competitiveness, the transition to a more circular and decarbonised economy, and the achievement of Europe's climate neutrality by 2050. Its strategic priorities include better use of renewable biological resources from land and sea, providing alternatives to critical raw materials, supporting sustainable solutions to challenges such as climate change, resource scarcity, and biodiversity loss. The strategy also aims to promote industrial innovation and sustainable growth, reduce dependence on fossil fuels, strengthen the resilience of value chains, and improve food security. In addition, it highlights carbon farming certification rules and the European Soil Monitoring Law to provide credible additional income streams for primary producers.

In addition to the general strategic objectives of the European bioeconomy, agriculture represents one of its key sectors. The agricultural sector is understood as the main source of biomass and as a fundamental element linking bioeconomy strategies with practical land use and the production of biological resources. Without the active role of agriculture, it is not possible to fulfil the long-term objectives of bioeconomy development.

Agriculture (including crop production, livestock farming and related services) is defined as part of the primary bio-based production sector. In the EU, approximately two thirds of employment in the bioeconomy originates from agriculture (Ronzon et al., 2022). Agriculture represents the main sector for the development of the bioeconomy, as it is the industry with the largest volume of primary biomass production. The intensification of agricultural production through the use of fertilisers, irrigation, mechanisation, pesticides and technological innovations has led to significant growth in both crop and livestock productivity over recent decades. However, this approach faces environmental, socioeconomic and resource constraints that may undermine its long-term sustainability.

The agricultural bioeconomy focuses on the sustainable production of renewable biological resources and their efficient conversion into food, feed, bio-based products, and bioenergy (Toplicean & Datcu, 2024). An irreplaceable function of the agricultural bioeconomy is the use of renewable biological resources instead of fossil-based materials (Diakosavvas & Frezal, 2019). Agriculture is therefore positioned at the centre of the development of many downstream industrial sectors, such as the textile and pharmaceutical industries.

1.2. Current Trends and Driving Forces of the Agricultural Bioeconomy

The current development of the agricultural bioeconomy in the EU is shaped by the convergence of several interrelated trends that are fundamentally transforming the role of agriculture in economic, environmental and societal contexts. Agriculture is no longer perceived solely as a sector of primary food production, but increasingly as an actor in a broader transformation towards a sustainable, low-carbon and resource-efficient economy. This transformation is driven by the **deepening integration of agriculture with the principles of the circular economy, rapid technological and innovative developments enabling more efficient use of biological resources, and a shift towards an ecological vision** in which the environmental functions of agriculture are regarded as an integral part of its economic role.

These trends therefore represent significant transformative potential; however, their impacts vary across the EU and are strongly influenced by the institutional and policy framework, including support for research and innovation, regional bioeconomy strategies, and the design of the CAP. Taken together, these driving forces create new opportunities as well as challenges for agricultural enterprises, value chains and policymakers.

1.2.1. Integration with the Circular Economy

The EU Bioeconomy Strategy of 2018 emphasises that sustainability and circularity form the core of the European bioeconomy (European Commission, 2018). The integration of the bioeconomy with the **circular economy** (CE) is a central and strategic objective of the Strategic Framework for a Competitive and Sustainable EU Bioeconomy from 2025 (European Commission, 2025). The circular economy complements the bioeconomy, as it seeks to maximise resource efficiency, minimise waste and preserve the value of products and materials for as long as possible.

Since the mid-2010s, the concept of the **circular bioeconomy** (CBE) has increasingly appeared in the academic literature, reflecting efforts to integrate these two concepts into a coherent framework for sustainable development (Stegmann et al., 2020). CBE has been present in both academic literature and EU policy documents since 2015 (Ubando et al., 2020). The 2018 Bioeconomy Strategy explicitly states that "*The European bioeconomy needs to have sustainability and circularity at its heart*" (European Commission, 2018). The updated 2025 strategy adds: "*It develops practical solutions that support economic prosperity, and strong rural and coastal communities, while helping industry shift to more circular production models. It contributes to the EU's strategic autonomy by reducing reliance on imported fossil-based products and can contribute significantly to climate and environmental goals such as resource efficiency, greenhouse gas emissions reduction, water resilience, zero pollution and biodiversity*."

Agriculture is one of the sectors of the CE, as it enables the closing of biological cycles through the efficient use of biomass, nutrients and by-products. In agricultural practice, this is reflected in:

i. an emphasis on the efficient use of biomass, including by-products and waste; and
ii. the development of local value chains.

An emphasis on the efficient use of biomass, including by-products and waste

The CBE focuses on the sustainable, resource-efficient **valorisation of biomass** and seeks to minimise both resource inputs into the system and waste outputs from it. This represents a fundamental pillar of the CBE and is closely linked to the development of integrated biorefineries with an emphasis on the material use of biomass. Progress towards the CBE strengthens the use of locally available resources (D'Adamo et al., 2019a). Agriculture is an actor in this context, as it supplies biomass, while the CBE encompasses both production and the utilisation of residues and waste (European Commission, 2012; European Commission, 2018).

Waste and residue valorisation is an indispensable activity within the CBE (Salvador et al., 2021). The principle of cascading use of biomass (see Box 1) is embedded in several European strategic documents. It emphasises the prioritised use of biomass with the highest possible added value, first for food and feed production, subsequently to produce materials and raw materials, and only as a last option for energy purposes (Diakosavvas & Frezal, 2019).

Biorefineries are regarded as indispensable transformational systems enabling the ecological transition of the economy. Their objective is to optimise technological processes so that multiple commercially usable primary and secondary products can be generated from a single feedstock base. Biorefineries thus not only increase the efficiency of biomass processing but also contribute to replacing fossil-based chemicals and materials with sustainable alternatives (Ubando et al., 2020).

The development of local value chains

The development of bioeconomy sectors brings new **opportunities for innovation and job creation in both rural and industrial regions** (Morone & D'Amato, 2019). Local economies benefit from the use of local resources, waste and residual materials (D'Adamo et al., 2019b), while the CBE concept emphasises comprehensive and place-based approaches aimed at closing material and energy flows (Ubando et al., 2020). The development of the CBE supports regional or national self-sufficiency and partial autarky, thereby reducing dependence on external resources and inputs (Salvador et al., 2021). An important element of the transition to the CBE is the linking of actors into integrated value chains and regional clusters, which enable more efficient resource use and strengthen local economies (Stegmann et al., 2020).

Research indicates that the implementation of CBE principles is associated with the creation of innovative value chains and local clusters that facilitate cooperation among different actors and increase resource-use efficiency. For example, the development of synergistic linkages between agriculture, the processing industry and services is crucial for the successful implementation of the CBE in a regional context (Bianchi et al., 2024).

Box 1: The Biomass Use Hierarchy and Cascading Principle

The cascading use of biomass is a strategic pillar of the CBE that prioritizes biological resources for their highest added value. This hierarchy establishes that biomass should be used first for food and feed production to ensure food security, followed by the production of high-value materials and chemicals, and only as a last option for energy purposes. Integrating this hierarchy into policy design is essential to manage the risk of Indirect Land Use Change (ILUC), where the expansion of biomass production onto new land can lead to biodiversity loss and undermine environmental goals. To achieve this, policy frameworks must adopt a residues first principle by prioritizing the use of by-products and waste streams over primary biomass production, thereby minimizing competition for land and ensuring the social legitimacy of the bioeconomy.

1.2.2. Technological and Innovation Dimension

The development of the bioeconomy is inherently linked to **technological innovation**. In Europe, two competing visions of the bioeconomy have emerged. One emphasises a technocentric pathway (often referred to as the Knowledge-Based Bioeconomy, KBBE), which promotes research and development and innovation (Levidow et al., 2013), while the other places greater emphasis on social and environmental aspects (Papadopoulou et al., 2022). These visions reflect two trajectories: biotechnology and genetics, and digitalisation.

Genetic engineering (GE) is identified as one of the main drivers of the bioeconomy (Zilberman et al., 2013). New plant breeding techniques (NPBTs), particularly gene-editing methods (CRISPR), have the potential to enhance biomass production (Wesseler et al., 2017) and to increase crop resilience to diseases and environmental stresses, such as drought and heat (Eriksson et al., 2019). The objective of sustainable and productive agriculture is the development of smart farming, which uses information and communication technologies for the efficient management of agricultural processes (MacPherson et al., 2022).

The digitalisation and bipolarisation of agriculture represent a convergent pathway supporting efficiency, sustainability and innovation within the bioeconomy. The introduction of digital and production innovations increases resource-use efficiency and supports sustainable management. A key role is played by precision agriculture (Mukhamedova et al., 2022), digitalisation, and new technologies for processing biomass and agricultural residues, which enable cascading and circular use of biological resources. These technological changes are accompanied by organisational and systemic innovations, in particular the linking of actors into integrated value chains and regional clusters. This strengthens the transfer of innovations into practice, increases the added value of production, and contributes to the resilience of agriculture and the broader bioeconomy.

1.2.3. Shift Towards an Ecological Vision

In recent years, the vision of the bioeconomy has shifted, from an originally techno-economic approach focused primarily on **biotechnological progress and increasing competitiveness** (Birch et al., 2010), towards a normative approach (Pfau et al., 2014; Papadopoulou et al., 2022) that emphasises broader environmental and societal objectives:

- It highlights sustainability and circularity, moving away from the fossil-fuel-based "throughput economy" model towards a sustainable circular flow based on renewable resources (Gawel et al., 2019).
- The bioeconomy is viewed as part of a broader socio-ecological transformation that is not limited to technical innovation but also addresses social issues such as social cohesion, equity and stakeholder engagement (D'Amato et al., 2022).

The ecological vision focuses on territorially and regionally concentrated circular and integrated systems (Bugge et al., 2016) that support rural development. This new orientation emphasises the transition to a sustainable CE based on renewable resources, thereby increasingly linking the bioeconomy with the principles of sustainable development (Gawel et al., 2019; Dieken et al., 2021). Sustainability is a fundamental pillar of the bioeconomy (European Commission, 2018). Its aim is to reduce environmental risks and minimise the ecological impacts of current production and consumption systems, thereby contributing to the long-term balanced development of society. The agricultural bioeconomy serves as a tool for ecological intensification. It seeks to increase agricultural yields and productivity while reducing environmental pressures and minimising negative impacts on the environment (Caron et al., 2014; Pretty, 2018).

The transition to a sustainable and circular, renewable-resource-based agricultural economy includes:

i. agroecology, crop diversification and ecosystem services;
ii. the integration of carbon-neutral processes into production; and
iii. the promotion of sustainable resource management (water, soil and biodiversity).

Agroecology, crop diversification and ecosystem services

Agroecology is one of the most important approaches aimed at integrating biodiversity-rich ecosystems into primary production (European Commission, 2018). Agroecological farming strengthens ecological functions and produces diverse biomass to achieve economic, social and environmental objectives at the territorial level (Wohlfahrt et al., 2019).

The objective is to harness the benefits provided by the environment (e.g. biodiversity, hedgerows, specific crop rotation cycles), as noted by Grouiez et al. (2023). **Crop diversification** is considered a key agroecological solution supporting the development of the bioeconomy (Faucon et al., 2023). It includes both temporal diversifications, such as crop rotation systems involving more than three species, and spatial diversification, including intercropping, cover crops and agroforestry (Tamburini et al., 2020). Crop diversification enhances the functional diversity of agroecosystems, improves ecological stability and reduces the need for chemical inputs (Cong et al., 2015).

The bioeconomy seeks to restore and conserve natural resources, placing emphasis on the sustainable use of **ecosystem services** and the promotion of biodiversity (Diakosavvas & Frezal, 2019). This is reflected in the application of regenerative practices that contribute to the restoration of natural ecosystem functions.

Integration of carbon-neutral processes into production

Agriculture represents one of the most significant drivers of global environmental change, while at the same time being among the sectors most affected by these changes. Among environmental impacts, the increase in **greenhouse gas (GHG) emissions** has emerged as the most pressing global environmental challenge. Agriculture contributes to GHG emissions primarily through methanogenesis in livestock production, emissions of nitrous oxide from soils treated with nitrogen fertilisers (Solazzo et al., 2016), and the decomposition of organic matter. The increase in the carbon footprint is also partly a consequence of intensive international trade. The bioeconomy is understood as a strategic tool for climate change mitigation, as it contributes to the reduction of GHG emissions, carbon sequestration and reduced dependence on fossil resources using renewable biological resources, innovative technologies and sustainable production systems (European Commission, 2018; Diakosavvas & Frezal, 2019; Stegmann et al., 2020). The transition strategy comprises **two main approaches**: reducing emissions through efficient resource use, and active carbon sequestration leading towards carbon neutrality.

Support for sustainable resource management (water, soil and biodiversity)

Sustainable management of natural capital forms the foundation of bioeconomy development, which seeks to use biological resources efficiently while at the same time protecting the natural systems on which it depends (McCormick & Kautto, 2013; Woźniak et al., 2021). Agriculture is one of the main users of water resources, and efficient water management is essential for the long-term sustainability of production as well as for ecosystem protection. Maintaining soil quality is crucial for the bioeconomy. The objective is to prevent soil degradation and to maintain soil as a fertile and renewable source of biomass (European Commission, 2018; Diakosavvas & Frezal, 2019). However, rising demand for biomass leads to intensive management practices that can deplete soils (Juerges & Hansjürgens, 2018). European strategies therefore support conservation agriculture and research into practices that enhance soil fertility and productivity while safeguarding natural processes (European Commission, 2018; 2025).

The protection of biodiversity and ecosystem services is an integral component of the bioeconomy framework (Wohlfahrt et al., 2019). Unregulated expansion of agricultural land could seriously threaten species diversity (Heimann, 2019); consequently, the bioeconomy vision promotes an approach that combines production with ecosystem protection and views nature both as a resource and as a partner (Levidow et al., 2013).

1.3. Policy Implications of the Transition Towards a Sustainable and Circular Agricultural Bioeconomy in the EU

The transition towards a sustainable bioeconomy entails several significant policy implications for the agricultural sector and requires careful coordination. The agricultural bioeconomy represents a fragmented policy field that functions more as a conceptual umbrella under which existing, often conflicting, sectoral policies are brought together (Vogelpohl & Töller, 2021). Policy must ensure coherent governance across multiple sectors. It is crucial that policymakers act as enablers, promoters and facilitators (Papadopoulou et al., 2022).

Bioeconomy objectives cannot be achieved solely through research and innovation programmes (such as Horizon Europe or the Circular Bio-based Europe Joint Undertaking, CBE JU) but must be **systematically integrated into the CAP Strategic Plans, eco-schemes, rural development interventions and Agricultural Knowledge and Innovation Systems (AKIS) advisory services**.

Policy must actively **address competition for biomass and land** by establishing a clear hierarchy of biomass uses in line with the cascading use principle, to ensure that the development of bioenergy or bio-based materials does not displace food production or generate additional environmental pressures. This requires coordination between agricultural, energy, climate and industrial policies, which is often insufficient. A key challenge is competition for land between food, feed, fibre and energy crop production (Hertel et al., 2013; Wohlfahrt et al., 2019).

A critical implication is the need for a **stable and predictable regulatory framework** for bioeconomy enabling technologies. The regulation of agricultural biotechnologies represents an example in this sense. GE, including CRISPR (Woźniak et al., 2021; Zhang et al., 2022), is regarded as a transformative technology with the potential to improve quality and reduce chemical inputs. Persistent political conflicts in Europe regarding the regulation of genetically modified organisms and new breeding techniques, together with the absence of a clear regulatory framework, hinder their practical application.

The EU must also strengthen policy implementation capacity, particularly through AKIS, demonstration projects, and regional clusters, because a key barrier to further bioeconomy development is often not the lack of technology but the limited capacity for its practical deployment within the heterogeneous agricultural environment of the EU.

Policy also has broader implications for the economic structure of agriculture and rural areas (see Chapter 6), as it shifts support from mere income stabilisation towards the active development of entrepreneurial capacities. The emphasis on employment and entrepreneurship implies that public interventions should target higher value-added activities that create local jobs and foster the emergence of new bio-based enterprises (Papadopoulou et al., 2022). Efforts to reduce farmers' dependence on volatile international commodity prices require EU policies to systematically support income diversification through participation in bioeconomy value chains, including by-product processing, bioenergy production and regional biorefineries (Heimann, 2019). This underscores the need to prioritise investment instruments over CAP area-based farm payments, particularly public grants and preferential loans, which strengthen the capital base of farms and cooperatives and enable collective investments in technologies and infrastructure (Grouiez et al., 2023).

2. REGULATORY FRAMEWORKS FOR THE DEVELOPMENT OF THE BIOECONOMY IN THE EU AGRICULTURAL SECTOR

KEY FINDINGS

The EU regulatory framework has transitioned from an initial focus on biotechnology toward a holistic model that integrates environmental sustainability, circularity, and economic competitiveness.

The current 2025 Bioeconomy Strategy prioritizes scaling up industrial innovations and ensuring a resource-efficient biomass supply to enhance the EU's strategic autonomy and climate neutrality goals.

The bioeconomy has become a cross-cutting policy priority that systematically links the CAP with broader frameworks like the European Green Deal and the Circular Economy Action Plan.

New legislative tools, such as carbon farming certification and soil monitoring laws, are being introduced to provide farmers with credible additional income streams and reduce regulatory fragmentation.

The EU is regarded as a trendsetter in the field of the bioeconomy and plays a key role in its strategic development, albeit with considerable disparities among Member States. The development of the bioeconomy in the EU is closely linked to the introduction of the KBBE concept in 2005 (European Commission, 2005). The objective of the KBBE was to move beyond the earlier narrow focus on biotechnology (Yaremova, 2020) and to transform knowledge from the natural sciences into new, sustainable, eco-efficient and competitive products (Potocnik, 2005). Over time, the conceptualisation of the bioeconomy in the EU has shifted from a primary emphasis on economic output towards a more holistic understanding that encompasses industrial restructuring, sustainable resource use, and socio-economic and rural development (Priefer et al., 2017; Bell et al., 2018).

2.1. Initial Bioeconomy Frameworks and the Challenge of Coordination (2009–2012)

In this early period, the concept of the bioeconomy was still in its **formative stages**, which was reflected in diverse interpretations across national strategies (Staffas et al., 2013). The first strategic documents of the Organisation for Economic Co-operation and Development OECD (2009) and the European Commission (2012) already emphasised the need for improved policy coordination and the involvement of a broad range of stakeholders in policy design. The **first EU Bioeconomy Strategy** was published by the European Commission in February 2012 under the title "Innovating for Sustainable Growth: A Bioeconomy for Europe" (European Commission, 2012b). This strategy defined the bioeconomy as "*production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy*" (European Commission, 2012b).

The 2012 strategy was structured around **three pillars**: increasing investment in research, innovation and skills; strengthening markets and competitiveness; and enhancing policy coordination and stakeholder engagement. Agriculture was defined as the primary input sector of the bioeconomy and was not perceived merely as a producer of raw materials, but as a technologically oriented and innovative sector. The strategy emphasised the need for sustainable intensification, efficient resource use and the adoption of modern technologies, including biotechnology and precision agriculture. It supported the valorisation of agricultural by-products, the development of circular practices, and the strengthening of rural economies through new value chains.

2.2. Shift towards Sustainability and Transformation (2018–2025)

The updated **EU Bioeconomy Strategy of 2018**, entitled *"A Sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment"* (European Commission, 2018), broadened its objectives to reflect wider global trends, such as the Paris Agreement and the Sustainable Development Goals (SDGs). The 2018 strategy defined five objectives (European Commission, 2018):

1. Ensuring food and nutrition security.
2. Sustainable management of natural resources.
3. Reducing dependence on non-renewable, unsustainable resources.
4. Climate change mitigation and adaptation.
5. Strengthening European competitiveness and job creation.

The updated EU strategy frames the bioeconomy as a strategy contributing to the 2030 Agenda/SDGs and the Paris Agreement, and in implementation documents link it more explicitly to a "green and just transition" (European Commission, 2018; European Commission, 2022).

The new **EU Bioeconomy Strategy 2025**, adopted on 27 November 2025, establishes a strategic framework for a competitive and sustainable bioeconomy that combines the scaling up of innovation, the development of new markets for bio-based materials, the sustainable and circular use of biomass, and the strengthening of the EU's strategic autonomy.

In March 2026, the Council of the EU formally endorsed the new EU Bioeconomy Strategy, confirming the bioeconomy as a central pillar of the Union's competitiveness, resilience and strategic autonomy. The Council stressed the need to accelerate the transition from laboratory-scale innovation to industrial deployment, simplify regulatory procedures and create a more predictable demand for sustainable bio-based materials. It also highlighted the importance of identifying and supporting high-potential lead markets beyond those listed in the strategy and called on Member States to ensure a sustainable and resource-efficient biomass supply, prioritising the use of by-products, residues and other secondary biomass sources.

2.3. The bioeconomy as a cross-cutting policy priority

The development of the bioeconomy in the EU is the result of a gradually expanding and deepening policy framework which, since 2010, has encompassed not only dedicated bioeconomy strategies but also a wide range of cross-cutting and sectoral policies. The bioeconomy has thus not evolved as an isolated agenda, but rather as an integrative element linking policies on sustainability, climate, the CE, agriculture, forestry, fisheries, industry, research and regional development. Table 1 summarises **selected strategies and initiatives relevant to the bioeconomy** and illustrates how policy priorities have shifted over time. Attention is devoted to agriculture and other biomass-supplying sectors.

Table 1: Selected Strategies Relevant to the Bioeconomy since 2009

Strategies relevant to the bioeconomy	
Bioeconomy	Innovating for sustainable growth: a bioeconomy for Europe (2012) A Sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment (2018) Strategic Framework for a Competitive and Sustainable EU Bioeconomy (2025)1
Sustainability	Seventh Environmental Action Programme (2014) Paris Agreement (2015) UN 2030 Agenda for Sustainable Development (2015) Sendai Framework for Disaster Risk Reduction 2015–2030 European Green Deal (2019) EU Biodiversity Strategy for 2030 (2020) Circular Economy Action Plan (2020) Farm to Fork Strategy (2020) EU Sustainable Finance Taxonomy (2020) EU Climate Law (2021) Fit for 55 Package (2021) EU Soil Strategy for 2030 (2021) EU Adaptation Strategy (2021) Zero Pollution Action Plan (2021) 8th Environment Action Programme (2022) Circular Economy Act (due for adoption in 2026)
Biomass-supplying sectors	
Agriculture	CAP Strategic Plans (2023–2027) EU Carbon Removals Certification Framework - CRCF (2024) Soil Monitoring Law (2025)
Forestry	A new EU forest strategy: for forests and the forest-based sector (2013) Multiannual implementation plan of the new EU forest strategy (2015) EU Forest Strategy for 2030 (2021) Nature Restoration Law (2024)
Fisheries, aquaculture and algae	Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030 (2021) Updating EU Algae Initiative (2021–2025) EU Action Plan: Protecting and restoring marine ecosystems for sustainable and resilient fisheries (2023) Energy Transition of the EU Fisheries and Aquaculture sector (2023) EU Ocean Pact (2026) EU strategy on fisheries external action (2025/2026)
Waste	Circular Economy Action Plan frameworks (2014–2020) The Role of Waste-to-Energy in the Circular Economy (2017) Packaging and Packaging Waste Regulation - PPWR (2024) Revised Waste Framework Directive (2025)
Biomass-using sectors	
Food security & nutrition	An EU policy framework to assist developing countries in addressing food security challenges (2010) Increasing the impact of EU development policy: an agenda for change (2011) The EU approach to resilience: learning from food security crises (2012)

	Enhancing maternal and child nutrition in external assistance: an EU policy framework (2013) Farm to Fork Strategy (2020)
Bioenergy/ Biofuels	An energy policy for Europe (2007) A European strategic energy technology plan (SET-plan) – Towards a low-carbon future (2007) Limiting global climate change to 2 degrees Celsius – The way ahead for 2020 and beyond (2007) Energy 2020 – A strategy for competitive, sustainable and secure energy (2010) Energy roadmap 2020 (2011) A policy framework for climate and energy in the period from 2020 to 2030 (2014) Accelerating Europe's transition to a low-carbon economy (2016) The role of waste-to-energy in the circular economy (2017) Renewable Energy Directive II & III (RED II/RED III) (2021–2023)
Bio-based industries	A lead market initiative for Europe (2007) Common strategy for key enabling technologies in the EU (2009) A stronger European industry for growth and economic recovery (2012) For a European industrial renaissance (2014) Strategic Framework for a Competitive and Sustainable EU Bioeconomy (2025)
Cross-cutting policies relevant to the bioeconomy	
Energy and climate change	Paris Agreement (2015) Energy Union Strategy (2015) 2030 Climate Target Plan (2020) Energy System Integration Strategy (2020) EU Climate Law (2021) Fit for 55 Package (2021) EU Adaptation Strategy (2021) Renewable Energy Directive II (2018) and III (2023)
Circular economy	Towards a circular economy: a zero-waste programme for Europe (2014) Closing the loop – An EU action plan for the circular economy (2015) Plastic Bags Directive (2015) Future strategy on plastics use, reuse and recycling (2016) The role of waste-to-energy in the circular economy (2017) Plastics Strategy (2018) Circular Economy Action Plan – New CEAP (2020) Sustainable Products Initiative (2022) EU Strategy for Sustainable and Circular Textiles (2022) Bio-based, biodegradable and compostable plastics framework (2022) Packaging and Packaging Waste Regulation – PPWR (2024)
Biodiversity	Our life insurance, our natural capital: an EU biodiversity strategy to 2020 (2011) EU Biodiversity Strategy to 2020 (2011) EU Biodiversity Strategy for 2030 (2020) EU Pollinators Initiative (2018, updated 2023) EU Soil Strategy for 2030 (2021) Zero Pollution Action Plan (2021) Nature Restoration Law (2024)
Regional policies	Regional policy contributing to smart growth in Europe 2020 (2010) Smart Specialisation Strategy 2021–2027 New European Innovation Agenda (2022)

Research and innovation	Overarching EU frameworks for research and innovation: Europe 2020 flagship initiative – Innovation union (2010) European Research Area – ERA (2020) EU framework programmes for research funding: Horizon 2020 (2014–2020) Horizon Europe (2021–2027) – Mission Soil, Mission Oceans, Cluster 6 Thematic initiatives focused on the bioeconomy: European Biotechnology and Biomanufacturing Initiative (2024–25) Bio-based Industries Joint Undertaking (BBI JU, 2014–2020) + Circular Bio-based Europe JU
Resource Efficiency	EU Roadmap to a Resource Efficient Europe (2011) European Green Deal (2019) EU Industrial Strategy (2020, updated 2021) Raw Materials Strategy (2020) Sustainable Finance Taxonomy (2020) Chemicals Strategy for Sustainability (2020)

Source: EEA (2018), based on Ronzon et al. (2017), own elaboration

The overview of selected strategies (Table 1) clearly shows that the bioeconomy has gradually become established in the EU as a cross-cutting policy priority that links sectoral policies with sustainability, climate and competitiveness objectives, while agriculture within this framework increasingly assumes a prominent role not only as a source of biomass, but also as an actor of systemic transformation towards a circular and bio-based economy.

3. THE ROLE OF THE BIOECONOMY IN THE EU AGRICULTURAL SECTOR: SUCCESSFUL MODELS, NEW VALUE CHAINS AND FACTORS INFLUENCING THEIR UPTAKE

KEY FINDINGS

Successful bioeconomy models transform farms from passive raw material suppliers into active, high-value-added actors by prioritizing local biomass processing, which keeps economic benefits within the region.

Effective initiatives rely on regional systems where the by-products of one process become inputs for another, reducing transport costs and strengthening local circular economies.

Cooperatives and producer groups are vital for overcoming high investment barriers; they allow smaller farms to aggregate biomass supply, share technological risks, and strengthen their bargaining position.

A fundamental factor for success is the application of the cascading principle, which prioritizes high-value applications (food and materials) before energy recovery, maximizing the total value added from primary resources.

Realizing bioeconomy potential requires social innovation and advisory services (AKIS) to bridge the gap between pilot projects and commercial reality through the sharing of practical expertise and "innovation brokers".

The bioeconomy creates new value chains and supports innovation primarily through the utilisation of residues and waste. One relevant example of good practice in the field of the bioeconomy is the **COOPID project**, implemented under the Horizon 2020 programme. The project focuses on strengthening bioeconomy business models in the European primary sector through effective knowledge transfer and innovative forms of dissemination. A key element of the project is the linkage of existing successful bioeconomy practices with practitioners, particularly farmers and other primary producers, through specialised bioeconomy clusters.

An important role within the project is played by so-called **COOPID ambassadors**, i.e. experts active in the agri-food sector with a strong interest in the development of the bioeconomy. These actors systematically draw on experience from the most successful bioeconomy initiatives in the EU and transfer this knowledge into their professional environments. At the same time, they serve as a multipliers by disseminating the acquired knowledge through their professional networks and contributing to its practical application. Its main tools include the presentation of successful case studies, the organisation of thematic workshops and targeted awareness-raising activities. In this way, COOPID supports not only increased awareness of the bioeconomy but, above all, the actual implementation of innovative solutions in primary production, thereby contributing to the long-term sustainability and competitiveness of the sector (COOPID, 2026).

The COOPID project has identified **success stories** across EU Member States, demonstrating how farmers can use modern techniques to build profitable and environmentally sustainable businesses. These real-world examples (see next paragraph 3.1) serve to mobilise European producers and support the overcoming of barriers to the adoption of circular business models.

3.1. Successful Models and New Value Chains

Spain

Oleícola El Tejar established in 1967 is a Spanish **second-tier cooperative** whose strategy is based on the comprehensive **valorisation of by-products from the olive sector**, with a particular focus on alperujo[2]. What was originally considered waste is transformed into a wide range of products through a biorefinery approach, including pomace oil, animal feed, activated carbon, organic fertilisers and pellets for bioenergy production. The scale and scope of this model are evident from the fact that the cooperative employs approximately 300 staff and processes 2 million tons of olive pomace annually, collected from 240 olive oil mills (Oleícola El Tejar, 2026). The cooperative is among the technological leaders in environmentally friendly solutions. One example is the HYGROSCOPIC CYCLE technology, which significantly reduces both water consumption and CO_2 emissions. Oleícola El Tejar processes approximately 31% of Spain's alperujo production and is the largest player in this sector worldwide (COOPID, 2026b).

France

The French bioeconomy ecosystem Grand Est represents a comprehensive and innovative model based on the **utilisation of biomass from cereals, sugar beet and wood**. The **regional ecosystem** is supported by a massive agricultural footprint encompassing 3 million hectares of land, complemented by 2 million hectares of forest production (Région Grand Est, 2026). Its core is the Pomacle–Bazancourt

agri-industrial complex, which processes around 4 million tonnes of biomass annually and employs approximately 1 200 people. The ecosystem produces a wide range of outputs, including sugar, wheat-based food and technical products, ethanol, bio-CO_2 and wood-based HPCI pellets. It is built on efficient resource use, water recycling, by-product valorisation and industrial symbiosis between companies and research institutions. The region's productivity is of national significance, contributing to 25% of France's sugar production, 20% of its rapeseed, and 10% of its wheat, while also being the leading hemp-producing region in Europe (Région Grand Est, 2026). The region supports bioeconomy development through the Grand Est Strategy 2019–2022, which, with annual investments of EUR 35 million, aimed to strengthen biofuels, biorefineries, sustainable agriculture, bio-based materials in construction and sustainable food systems. The ecosystem thus represents a strong and functional model linking economic growth with environmental ambitions (COOPID, 2026c).

Italy

Caviro is the largest Italian wine cooperative, producing wine exported to more than 70 countries. Established in 1966, Caviro is structured as a **cooperative** and an organization of primary producers that employs 567 people. The organization operates specifically within the wine sector and is recognized as one of the success cases of the bioeconomy in Italy (Caviro Group, 2026). A key characteristic of Caviro is its circular business model, based on the **valorisation of all grape waste** so that nothing is discarded and everything generates added value. Caviro transforms agricultural and agri-food by-products and waste (such as grape pomace and lees) into high-value components, including alcohol, tartaric acid, and various extracts for the pharmaceutical, cosmetic and food

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[2] Alperujo is a by-product of modern olive oil production that plays a crucial role in the circular bioeconomy of Southern European countries. It is a dense, dark paste produced during oil extraction using modern two-phase centrifuges. This material combines the solid components of olives (skins, pulp, pit fragments) with vegetation water, making it rich in organic matter but also challenging to process. In the past, alperujo was considered a problematic waste due to its high content of phytotoxic polyphenols, which prevented its direct use as fertilizer.

industries. In addition, waste is used to produce bioenergy, such as bioethanol, biomethane and electricity, enabling energy self-sufficiency and the return of nutrients (fertilisers) to the soil, thereby closing the cycle. Caviro is also pursuing further development, for example through the introduction of facilities for CO_2 capture from the biorefinery process, which can be utilised in the food and beverage sector (COOPID, 2026d).

Greece

Pindos is a fully integrated enterprise focused on the production, processing and distribution of poultry food products, systematically applying the principles of the circular economy and sustainable business practices. Established in 1958, the Agricultural Poultry Cooperative Pindos operates as a cooperatively owned organization in Greece, employing 1 200 individuals (Pindos, 2026). The **cooperative** is comprised of 600 members and co-operating producers who together achieve a weekly production volume of approximately 850 000 chickens and 1 million eggs (Pindos, 2026). Key features include the **valorisation of by-products and the use of waste (e.g. dead poultry and manure) to produce bioenergy (electricity and heat) and organic fertilisers (compost)**. Pindos uses slaughterhouse by-products (such as feathers and animal fats) for pet and fish feed. Through the combustion of waste, it produces bioenergy that is partly used internally in processing, while chicken manure is collected and converted into a high-quality organic fertiliser, AGROSYN. Pindos also has plans for further development, including the establishment of new meat-processing and cooked-product units, the expansion of poultry waste processing capacity, and the construction of a new slaughterhouse and biogas plant (COOPID, 2026e).

Bulgaria

The Bulgarian bioeconomy success story ZP Victor Asenov represents a privately owned **farm** established in 2018, specialising in the sustainable year-round production of vegetables in greenhouses. The Victor Asenov Farm falls under the crops sector and is operated as a personally owned enterprise. In terms of personnel, it has 11 permanent employees (COOPID, 2026f). Its model is based on the **use of renewable energy from pellets made from sunflower residues, the recycling of drainage and rainwater, and the circulation of biological waste**, which is transferred for compost and biofertiliser production. The farm's success is supported by the proactive adoption of new technologies, efficient resource management, cooperation with external companies, and financial support that has enabled investment implementation. The owner plans further expansion, including the implementation of blockchain technology for plant growth monitoring, the construction of a new strawberry greenhouse, and the establishment of an in-house line for recycling vegetable bio-waste (COOPID, 2026f).

Poland

A Polish example of a successful bioeconomy model is Biogal, a **farm** established in 2010 that focuses on **biogas production**. Biogal, which is privately owned, employs a total of 35 workers (COOPID, 2026g). The main objective of Biogal is to address environmental problems associated with manure management and by-products from livestock production by converting them into renewable energy and organic fertilisers. The company operates based on anaerobic digestion and processes approximately 100 000 tonnes of biomass annually, **using pig manure and food waste**. Biogal's outputs include electricity (sold to the grid), heat (used for internal purposes and supplied to local schools and households), and an organic fertiliser (digestate) marketed under the brand Naturgal. This approach contributes to the reduction of CO_2 emissions and the development of local energy infrastructure, while simultaneously strengthening farmers' incomes (COOPID, 2026g).

Austria

An Austrian example of success in the bioeconomy is the **cooperative** Pelletierungsgenossenschaft eGen, founded in 2015 in south-eastern Styria. eGen has 4 employees. The organization is formally structured as an organisation of primary producers/cooperative and is categorized within the Cereal and Forage sector. Its main objective is the valorisation of regional, previously underutilised agricultural biomass and residual materials. The cooperative **transforms residues such as straw, landscape maintenance materials, skins and pomace from the wine industry into value-added products**, thereby strengthening nutrient and carbon cycles. Its main products include high-quality bedding pellets, which have proven suitable for poultry and horses due to their high absorbency and low dust content, as well as fibre-rich feed pellets. The cooperative processes approximately 2 000 tonnes of raw materials annually and, in addition to direct pellet sales, also generates income through contract pellet production for farmers, enabling them to efficiently utilise their own residues. One example is the Buschenschank Weiss **farm**, which, through cooperation with the cooperative, **uses hay from grasslands in protected areas (where management plans prohibit ploughing) to produce pig feed**, thereby supporting animal welfare and helping to preserve valuable meadow habitats. Production uses pelletising equipment with a capacity of 5 tonnes per hour (currently operating at 1.5–2 tonnes per hour) and pressure hydrothermal processing technology, with plans to expand by adding a production line for biofuel pellets (COOPID, 2026h).

Ireland

Founded in 1965, Carbery Group is one of the key employers in the Ballineen and Enniskean area of County Cork. The **company** processes milk from approximately 1 200 Irish farmers, with an annual capacity of 596 million litres of milk. Its core business model is based on the cascading use of dairy raw materials through biorefining, producing cheese, whey and flavouring ingredients. The Ballineen plant is the largest cheese production facility in Ireland and produces one quarter of the country's total cheese output. The company **utilises residual lactose streams for conversion into bioethanol** (approximately 12 million litres per year), which is used in the biofuels, chemicals and alcohol markets, while the remaining ethanol is subsequently processed into biogas for on-site energy use. Through this circular process, characterised by cascading biomass use and nutrient cycling, a nutrient-rich organic fertiliser is produced as a final co-product. Carbery is also engaged in the Farm Zero C initiative, which aims to establish the world's first climate-neutral dairy farm (COOPID, 2026i).

Denmark

Møllerup Brands is a family-owned **company** founded in 2015 that focuses on the hemp sector and represents an innovative business model based on the maximum valorisation of the entire raw material. In terms of personnel capacity and organizational scale, it is a small enterprise with 4 employees (COOPID, 2026j). The raw material cultivation strategy is based on a hybrid model, where only a portion of the hemp is grown on the company's own land, while the bulk volume of the harvest comes from externally collaborating farms. The core of the business is the **fractionation of the whole hemp harvest into seeds, leaves and stems, thereby applying a cascading approach to raw material processing**. Hemp seeds and leaves are used to produce high-value products for human consumption, such as hulled seeds, flour, oil and skincare products. The remaining hemp stems are subsequently valorised into bio-based materials, specifically furniture boards and insulation panels for the construction sector. The company introduces crops with high yields and environmental benefits and is actively involved in the development of new technologies. It also plans to shift from retail towards supplying raw materials to the food industry, such as industrial bakeries, and to increase production volumes for industrial applications (COOPID, 2026j).

Finland

The **cooperative** Valio established in 1905 is one of the largest dairy producers and the largest milk processor in Finland. It supports employment for around 25 000 people on dairy farms and directly employs approximately 4 200 professionals (Valio, 2026). Valio is owned by approximately 3 200 dairy farms, and its primary objective is to process raw milk and return profits to farmers through the cooperative structure, thereby supporting their livelihoods. As part of its sustainability strategy, Valio has committed to reducing the carbon footprint of its entire dairy value chain to zero by 2035. A key initiative to achieve this target is the joint venture Suomen Lantakaasu Oy, which, together with the company St1, aims to produce 1 TWh of biomethane by 2030. This **biomethane, produced from livestock manure**, is used as a biofuel primarily in logistics for milk collection and product distribution trucks, as well as in private biogas vehicles. In addition, Valio distributes approximately EUR 50 million annually to its farmer-owners through a sustainability programme for voluntary measures that go beyond legal requirements in animal welfare and carbon footprint reduction (COOPID, 2026k).

3.2. Factors of Successful Initiatives

Successful bioeconomy examples exhibit a set of interrelated factors that together enable an effective and long-term sustainable transformation of production systems. These factors are not limited to technological solutions but also encompass organisational, institutional, regional and social dimensions of development. Their combination supports the maximum utilisation of biological resources, strengthens the resilience of local economies and facilitates the transfer of innovation into practice.

3.2.1. Full and Cascading Use of Biomass

The expansion of the bioeconomy must not lead to the displacement of food production or create additional environmental pressures (erosion, biodiversity loss, increased emissions). European strategies therefore repeatedly emphasise the need for a **hierarchy of biomass use**. A fundamental pillar of all initiatives is the maximisation of the value of primary raw materials:

- by-products and waste are not perceived as a burden, but as inputs for further production;
- a cascading approach is applied (food → chemicals/extracts → energy → fertilisers);
- multi-source income streams are created, reducing risks.

Successful projects therefore make use of **"secondary" or residual biomass** (manure, slurry, residues, grass from landscape management, marginal land). Strategic documents emphasise that the bioeconomy must respect the primary food function of agriculture.

Successful initiatives approach the bioeconomy as an integrated system rather than as an isolated technology:

- closing nutrient, carbon, water and energy flows;
- returning residues back to the soil in the form of fertilisers (digestate, compost);
- linking food, energy and material production (e.g. biogas + heat + electricity).

3.2.2. Circular and Systems Thinking

Another unifying factor of the successful initiatives presented above is the application of **circular and systems thinking**, which goes beyond individual technological solutions and is reflected in the overall configuration of value chains. These examples demonstrate that the bioeconomy is not based solely on substituting fossil resources with biological ones, but primarily on a new understanding of material, energy and nutrient flows within the entire system, from primary production through processing to the reintegration of residues back into circulation.

In the cases presented, the circular approach is manifested particularly through the consistent **valorisation of by-products and waste**, which in linear models are considered a burden. Successful projects systematically transform production residues into new inputs for energy, agriculture, the food industry or the chemical sector.

Systems thinking is further evident in the **linking of individual actors and sectors**. The examples show that the success of bioeconomy models depends on effective industrial symbiosis, where the output of one process serves as the input for another. These linkages involve not only companies, but also research institutions, public authorities and regional development strategies. The bioeconomy is thus understood as a territorially embedded system rather than an isolated technological innovation.

An important aspect of the systems approach is the **integration of energy, material and nutrient flows**. Bioenergy production (biogas, bioethanol, pellets) is in most cases closely linked to the return of nutrients to the soil in the form of digestate or organic fertilisers, thereby closing carbon and nutrient cycles. This approach contributes to increased self-sufficiency of enterprises, reduced dependence on external inputs and enhanced environmental resilience of agricultural systems.

Circular and systems thinking are also reflected in a long-term strategic perspective. Successful initiatives do not optimise only a single link in the value chain, but strive for an overall improvement in system performance, including social and regional impacts. This is particularly evident in cooperative structures, where the economic benefits of circular models remain within the region and support the stability of rural areas.

3.2.3. Knowledge Levels and Access to Technologies

A lack of technical know-how and limited access to modern technologies represent one of the most significant barriers to bioeconomy development in European agricultural enterprises. Another success factor is therefore a high level of **knowledge and effective access to technologies**, which enable bioeconomy principles to be translated into practically implementable and economically viable solutions. Technological innovation alone is not sufficient; what is decisive is the ability of actors to understand these technologies, adapt them to local conditions and operate them sustainably over the long term.

Successful initiatives are characterised by targeted knowledge transfer between research institutions, technology providers and primary producers. Projects such as COOPID play a crucial role in this process by facilitating access to proven practices and reducing information barriers that often prevent farmers from adopting innovative solutions. The **sharing of practical experience** through case studies, workshops and demonstration activities enables producers to better assess the risks and benefits of new technologies. An equally important aspect is the availability of investment capital and technical advisory services, which make it possible to implement capital-intensive technologies even at the level of small and medium-sized enterprises or farms. Many of the examples discussed rely on a combination of public support, cooperative financing and collaboration with the private sector, thereby reducing the risks associated with technological investments and accelerating their uptake.

The level of knowledge is not limited to technical skills but also includes managerial, economic and strategic competencies. Successful actors can identify new market opportunities for bio-based products, respond to demand and adapt their business models to changing conditions. Examples include enterprises that expand their portfolios to include high-value products (pharmaceutical, cosmetic or food ingredients) or introduce new digital tools for production monitoring and supply chain transparency.

3.2.4. A Strong Role of Cooperatives and Collective Structures

The strong role of **cooperatives and other collective structures** serves as an institutional mechanism enabling the implementation of bioeconomy models in the primary sector. Empirical evidence shows that it is precisely collective producer organisations that create the structural conditions necessary for the transition from linear production models to technologically demanding, circular and capital-intensive solutions. A contribution of cooperative structures lies in their **ability to internalise biomass processing stages** that are economically or technically inaccessible to individual producers. Through shared ownership of biorefinery facilities, energy technologies or logistics infrastructure, barriers to entry into higher segments of the value chain are overcome. Primary producers become active actors within the bioeconomy rather than merely suppliers of raw materials.

Collective structures also enable the **aggregation of biomass flows**, which is essential for the stable operation of bioeconomy technologies with high input volume requirements. This aspect is particularly critical for biorefineries and bioenergy facilities, where economic viability depends on the continuity of material flows. Another important function of cooperatives is the **coordination of investments and the management of technological risk**. The cooperative model distributes financial burdens among a larger number of actors and allows for the combination of own resources with public support and private capital. At the same time, it creates an institutional framework for the gradual adoption of innovation, whereby new technologies are first tested at the collective level and subsequently scaled up. This reduces uncertainty associated with technological development and accelerates the transition from pilot solutions to fully commercial applications.

A specific feature of cooperative bioeconomy models is the redistribution of generated value added back to primary producers. Profits derived from by-product processing, energy production or bio-based intermediates are not externalised but returned to cooperative members, thereby strengthening the economic stability of agricultural enterprises. This mechanism increases producers' motivation to actively participate in circular systems and to adopt changes in production practices.

Finally, cooperatives function as an institutional i**nterface between farmers, research institutions, industry and public authorities**. Owing to their organisational capacity, they can engage in research projects, influence regional bioeconomy strategies and facilitate the practical implementation of policy instruments. In this way, cooperative structures become not only economic entities but also actors in governing the bioeconomy transition at both regional and national levels.

3.2.5. Regional Embeddedness and Industrial Symbiosis

Regional embeddedness represents a fundamental spatial and organisational prerequisite for the functioning of bioeconomy systems. By its very nature, the bioeconomy is territorially bound, as biomass availability, logistics costs, environmental impacts and social linkages are strongly dependent on the local context. Successful models therefore do not emerge as isolated business projects, but rather as **regional systems linking primary production, processing, energy generation and research**. **Industrial symbiosis** enables the optimisation of material and energy flows within a region, whereby by-products of one actor serve as inputs for others. Spatial proximity among actors reduces transaction costs, limits the environmental burden of transport and increases the operational efficiency of bioeconomy technologies.

Regional embeddedness also supports **institutional coordination** between enterprises, research organisations and public authorities. Bioeconomy initiatives are thus better able to respond to local development strategies, make use of regional support instruments and engage in long-term planning. In this context, the bioeconomy functions as a tool of regional transformation rather than merely a sectoral innovation.

3.2.6. A Favourable Policy and Market Environment

A favourable policy and market environment constitutes a structural prerequisite for the feasibility of bioeconomy initiatives, particularly those that are capital-intensive, technologically complex and long-term oriented. Analysis of successful cases shows that bioeconomy projects tend to emerge and persist primarily in environments characterised by a combination of clear policy objectives, stable regulatory frameworks and effective market incentives.

From a policy perspective, the existence of explicit bioeconomy, climate and CE strategies is crucial, as these provide institutional anchoring and legitimacy for bio-based solutions. Regional and national strategies create a long-term direction that **reduces regulatory uncertainty and enables actors to plan investments with payback periods of 10–20 years**. This aspect is particularly critical for biorefineries, biogas plants and energy facilities, where short-term or unstable policies significantly increase investment risk.

Specific economic instruments also play an important role, including **investment subsidies, operational support schemes, preferential loans and tax incentives**. These instruments help to bridge the gap between conventional and bio-based technologies, especially in the early stages when new technologies have not yet achieved full cost competitiveness. Examples from the biogas, bioethanol and bioenergy sectors demonstrate that without targeted public support, most projects would not reach commercial viability. Equally important is the design of the market environment that enables the uptake of bio-based products. This includes both regulatory measures that create demand (e.g. mandatory biofuel blending, renewable energy targets) and voluntary market mechanisms such as sustainability certification, environmental labelling or corporate commitments to carbon footprint reduction. In the analysed cases, these instruments allow the environmental benefits of the bioeconomy to be monetised and translated into economic value.

Policy and market factors are also reflected **in access to infrastructure and networks**. The ability to connect to energy grids, the availability of logistics capacities, and the existence of regional processing centres significantly influence project economics. For example, in biogas and bioenergy initiatives, access to distribution networks and stable off-takers of heat or electricity are determinant of long-term viability. Another important aspect is regulatory flexibility and the administrative capacity of public authorities. Projects developed in environments with clear permitting procedures, consistent interpretation of environmental legislation and support from regional institutions exhibit faster implementation and lower transaction costs. Conversely, complex and poorly coordinated regulatory requirements can significantly delay or even prevent the realisation of technologically advanced projects.

3.2.7. Personal Motivation and Social Acceptance

Personal motivation of key actors and the degree of social acceptance represent behavioural and social determinants of the success of bioeconomy initiatives, significantly influencing their emergence, implementation and long-term stability. Bioeconomy projects are not solely the result of economic rationality; they often stem from individual leadership, value-based preferences and a willingness to bear the risks associated with innovation. At the level of individual enterprises and farms, personal motivation is frequently linked to **entrepreneurial vision, intergenerational responsibility and the pursuit of long-term sustainability of operations**. Many actors do not perceive the bioeconomy merely as a source of additional income, but rather as a strategy for stabilising their businesses under conditions of increasing environmental regulation, input price volatility and societal pressure for sustainability. Intrinsic motivation is particularly important in the early phases of projects, when economic benefits are not yet fully demonstrable.

The personal engagement of leaders often translates into their role as **innovation brokers**, who actively seek out new technologies, establish collaborations with research institutions and initiate collective projects. These actors serve as catalysts for change, and their success significantly influences other producers' willingness to adopt new models. In this sense, personal motivation is closely linked to processes of social learning and the diffusion of innovation within a region.

Social acceptance of bioeconomy initiatives depends on how local communities and other stakeholders perceive their benefits and risks. Projects that are able to communicate their environmental and socio-economic impacts transparently tend to achieve higher levels of acceptance and a lower likelihood of conflict. This is particularly important for technologies associated with waste processing or energy production, where concerns may arise regarding odour, transport or landscape impacts. An important mechanism for enhancing social acceptance is the involvement of local actors in the planning and implementation of projects. Cooperative models, community energy projects and regionally embedded enterprises create a sense of co-ownership and shared responsibility, thereby increasing the legitimacy of bioeconomy solutions. Social acceptance is further strengthened when the economic benefits of a project, such as employment, stable incomes or access to affordable energy, are visibly distributed within the region.

In the long term, personal motivation and social acceptance reinforce each other. Successful projects create a positive reference framework that reduces uncertainty for other actors and supports the replication of bioeconomy models.

Box 2: Structural Determinants of Scalable Bioeconomy Models

The transition from isolated pilot projects to scalable bioeconomy models is driven by a set of interconnected structural determinants that collectively enhance the economic and environmental performance of agricultural holdings. A fundamental pillar is the cascading use of biomass, which prioritizes high-value applications for food and materials before utilizing residues for bioenergy, thereby maximizing the value added from primary resources. The implementation of such models is facilitated by cooperative structures and collective organizations, which allow farmers to overcome capital-intensive investment barriers and aggregate biomass flows to reach industrial scales. Successful scaling further depends on deep value-chain integration and contractual stability, where long-term agreements and standardized quality parameters reduce market risks and increase the bankability of bio-based investments. These initiatives are typically characterized by strong regional embeddedness, leveraging industrial symbiosis and spatial proximity to optimize logistics and strengthen local economies. Ultimately, these factors must be underpinned by a supportive policy mix that effectively combines investment support with payments for sustainable practices, creating a stable regulatory environment that encourages long-term entrepreneurial engagement in circular bioeconomy pathways.

4. MODEL FOR ASSESSING THE ECONOMIC IMPACTS OF THE BIOECONOMY IN EU AGRICULTURE

KEY FINDINGS

There is currently no harmonized framework – either in the academic literature or in the analytical practices of European institutions – that can systematically evaluate the economic impacts of bioeconomy activities at the farm level in a way that is transparent, comparable, and consistently applicable across EU Member States.

The proposed model integrates farm-level microeconomic analysis, CBE principles, and policy needs, with the aim to provide a practical, replicable tool to assess the economic effects of bioeconomy activities under real farm conditions, comparing a reference system with one that includes specific bioeconomy activities.

The analysis shows that farms with structurally higher other gainful activity (OGA) shares – used as a proxy for bioeconomy engagement – report significantly lower agricultural income per hectare. This does not mean that diversification is harmful, but it does suggest that the economic case for bioeconomy engagement is more context-dependent than often assumed.

On cost efficiency, the data do not provide conclusive evidence in either direction.

Perhaps the most policy-relevant finding concerns income stability. Contrary to common expectations, farms with higher OGA shares exhibit greater income variability rather than lower. The one consistent stabilising mechanism identified in the analysis is public support, underlining the stabilising role of direct payments in contexts where bioeconomy diversification increases income volatility.

These findings are in some respects counterintuitive and call for a differentiated and evidence-based approach to bioeconomy policy design, rather than blanket promotion of diversification across all farm types. These considerations are particularly relevant for the design of the post-2027 CAP and the broader EU bioeconomy policy agenda.

Current approaches to assessing the bioeconomy rely either on aggregated statistics or on partial case studies focused on individual technologies or projects. These approaches capture the microeconomic reality of farms only to a limited extent, where decisions on engaging in bioeconomy activities are shaped by investment constraints, operating costs, risk, income volatility, and institutional incentives.

This chapter proposes a model designed to quantify the economic impacts of selected bioeconomy activities at the farm level. The model serves both as an analytical tool for this study and as a generally applicable framework for policymakers, analysts, and practitioners across EU Member States. It also establishes the analytical foundation for subsequent quantification of the bioeconomy's contribution to farm economic resilience and provides a structured basis for informed policy decision-making.

Annex A provides details on the methodology, how the model is structured and the results obtained.

4.1. Foundations and Logic of the Proposed Conceptual and Methodological Model

Neither the current literature nor the analytical practice of European institutions provides a unified model that systematically captures the economic impacts of bioeconomy activities at the individual farm level in a way that is comparable, transparent, and applicable across EU Member States. The proposed model therefore does not adapt an existing evaluation framework but **combines elements of farm-level microeconomic analysis, CBE principles, and practical policy assessment requirements**. Its aim is to create a functional and replicable tool for quantifying the economic mechanisms of the bioeconomy under real farming conditions. The model is based on the premise that, at the farm level, the bioeconomy does not operate as a standalone domain but as a set of decisions and activities that reshape cost structures, revenue streams, and risk exposure. Consequently, its economic contribution cannot be assessed solely through biomass output or technological performance, but through its impact on the farm's overall economic balance.

The model is designed as **incremental**, focusing on the difference between a reference farming system and a system in which a specific bioeconomy activity, or a combination of activities, is implemented. Unlike macroeconomic bioeconomy models based on aggregated inputs and outputs, this approach captures the farmer's decision dilemma: whether and under what conditions a bioeconomy solution improves economic performance and resilience. It also reflects the high heterogeneity of agricultural bioeconomy activities, which vary by production type, farm size, regional conditions, infrastructure availability, and institutional context. Rather than assuming a single "optimal" scenario, the model provides a flexible structure that allows individual activities to be assessed separately or in combination and adapted to the specific conditions of the farm under analysis.

The model is not intended to replace detailed farm-level analyses, investment studies, or techno-economic assessments, nor to serve as a tool for individual investment decisions. Instead, it acts as a bridge between farm-level realities and EU strategic policy evaluation. It delivers indicative yet analytically consistent estimates of economic impacts, capturing key mechanisms and their interlinkages, and supporting comparison of bioeconomy activities, identification of success factors, and formulation of targeted policy recommendations at both EU and Member State levels.

4.2. Structure and Elements of the Proposed Model

The model assesses the economic impacts of bioeconomy activities at the level of the farm, treating it as an integrated economic system where decisions, costs, and benefits converge, while accounting for differences in size, resources, and capacity across EU farms. It focuses strictly on direct economic effects, including changes in costs, revenues, investments, and policy incentives, while excluding broader macroeconomic, environmental, and social impacts unless they translate into measurable financial outcomes.

Impacts are evaluated using a reference scenario that assumes continuation of existing farm operations without bioeconomy activities, allowing results to be expressed as incremental differences attributable solely to the intervention. Finally, the model adopts a static, annual perspective, incorporating investment costs through annualized measures to ensure simplicity, comparability, and practical applicability, while leaving longer-term dynamic effects to supplementary analyses.

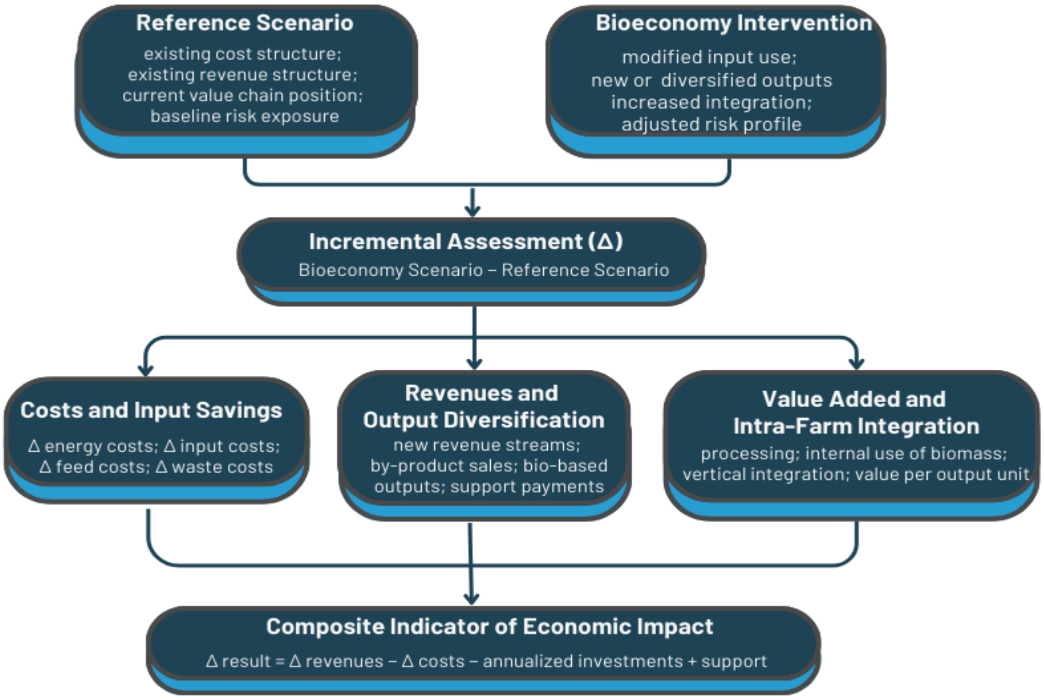
The model assumes that the economic effects of bioeconomy activities at farm level are multidimensional and operate through several interrelated mechanisms influencing performance, stability, and decision-making capacity. It identifies the following four economic dimensions common to different types of bioeconomy activities, although their relative importance varies depending on the farm's production structure, regional conditions, and institutional context:

- how bioeconomic activities affect a farm's cost structure (i.e. how bioeconomy is reflected in more efficient use of inputs and resources);
- how bioeconomic activities affect farm revenues by way of new or expanded income streams;

- how the bioeconomy enables a shift from selling raw primary products toward greater processing, integration, and internal use of biomass
- the impact of bioeconomic activities on farm economic stability and resilience.

The final output is a **composite indicator**[3] expressing the annual change in the farm's economic performance resulting from bioeconomic activities. It can be presented in absolute terms (e.g. EUR/farm/year), normalized per hectare, unit of output, or labour unit, disaggregated by economic dimension for interpretation. The composite indicator is not a standalone decision tool, but a synthetic summary of interconnected economic effects that must be interpreted in the context of farm structure and regional conditions. Figure 1 illustrates the **incremental framework for assessing the economic impacts of the bioeconomy at farm level**. The model compares a reference (conventional) scenario with a bioeconomy scenario and captures their differences across four interrelated economic dimensions: cost efficiency, revenue diversification, value creation, and economic stability.

Figure 1: Conceptual Framework of the Model for Assessing the Economic Impacts of Bioeconomy Activities at Farm Level



Source: Own

The model's main output is the net annual change in the farm's economic result, serving as a composite indicator of the economic contribution of bioeconomy activities.

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[3] A composite indicator aggregates multiple economic effects, such as costs, revenues, value added and stability, into a single summary metric.

4.3. Application of the Model: Econometric Evidence on the Economic Impacts of Bioeconomy Engagement

To fully understand the potential of the proposed evaluation framework for future users and policymakers, it is essential to demonstrate its application through **concrete examples**. As defined in the conceptual framework, an effective assessment of the bioeconomy requires a comprehensive analysis of four complementary components: **direct input cost savings, new revenue streams, increased value added, and the impact on overall cash-flow stability**.

While all four dimensions are addressed in the conceptual framework, the econometric analysis focuses on three empirically measurable dimensions available in the Farm Sustainability Data Network (FSDN) data:

- farm income per hectare as a proxy for revenue generation and value added,
- the cost ratio as a measure of operational cost efficiency and input savings,
- and the coefficient of variation of farm income as an indicator of cash-flow stability and income resilience.

By linking this incremental model with the results of our econometric analysis (see Annex A), it is possible to quantify the changes in costs, revenues, and risk levels associated with engagement in the bioeconomy across different typological groups of agricultural enterprises.

4.3.1. The share of other gainful activity (OGA) as a proxy of farm's bioeconomy engagement

To empirically test the relationships outlined in the conceptual framework, an econometric analysis was conducted using FSDN panel data covering the period 2018–2023. The unit of observation is a representative farm stratum – a cell defined by the intersection of Member State, region, type of farming (14 types of farming), and economic size. Bioeconomy engagement at the farm level is proxied by the share of OGA in total farm output, as recorded in the FSDN dataset under variable *SE700*. OGA captures non-agricultural or complementary economic activities carried out by the farm, representing the closest available approximation of bioeconomy-related diversification in farm data. The OGA share variable should be interpreted as a proxy for farm-level bioeconomy engagement rather than a comprehensive measure. In the FSDN framework, OGA includes only activities that utilise farm resources such as land, buildings or machinery. As a result, certain bioeconomy activities may not be fully captured, particularly those not directly linked to farm assets, such as some forms of bioenergy production (e.g. biogas plants operated outside the farm structure).

OGA directly related to an agricultural holding refer to any activities, other than typically agricultural ones, that are carried out using the farm's own resources. To be classified as OGA, an activity must meet four specific criteria: it must be non-agricultural, directly related to the holding, have a measurable economic impact, and, most importantly, it must utilize the farm's resources or means of production, such as land, buildings, machinery, labour, or raw materials (Cholewa and Smolik, 2021). Common examples of OGA include the on-farm processing of agricultural products (e.g., making cheese or juice), agritourism, contract work using farm equipment (e.g., snow clearing), and the production of renewable energy for the market. Crucially, off-farm work where the farmer is employed elsewhere without using farm assets is not considered OGA (Cholewa and Smolik, 2021).

In this analysis, the share of OGA in a farm's total output is utilized as the primary proxy for bioeconomy engagement. This choice is justified by the fact that OGA captures the essential elements of a circular bioeconomy, such as the valorization of residues, on-farm biomass processing, and the integration of renewable energy flows.

However, the use of this variable requires several important caveats:

- OGA is **not a perfect synonym for "bioeconomy."** It may include activities with limited bioeconomy relevance (e.g., simple room rentals) while potentially missing advanced bioeconomy initiatives, such as large-scale biogas plants, if they are operated under a separate legal entity outside the farm's accounting structure.
- The framework for collecting OGA data within FSDN is **still evolving**. There remain some ambiguities in the classification of certain economic operations across different EU Member States (Cholewa and Smolik, 2021).
- The presence of OGA is often a **structural characteristic** of specific farm types or regions rather than a simple lever for income stabilization. Our empirical evidence suggests that farms with higher OGA shares may actually experience greater income variability, likely because these activities are subject to their own demand cycles and investment phases.

Despite these limitations, **OGA remains the only systematically recorded and harmonized indicator** available at the farm level across the EU that allows for a quantitative assessment of how diversification into bio-based value chains impacts farm economic performance.

Our econometric analysis uses aggregated observations representing farm groups not individual farm-level data. With this level of aggregation, we cannot provide robust findings on differences by farm types, regions, or economic size classes from the econometric model.

The estimation strategy proceeded through several steps.[4] The model quantifies the effect of OGA share on all three stated economic dimensions, while controlling for farm structural characteristics, including farm size, labour input, capital intensity, and subsidy receipts, in order to isolate the partial effect of OGA engagement from other determinants of farm economic performance. Before focusing on the model results, it is instructive to examine the descriptive patterns in OGA share across the sample. Approximately 21% of farm strata report no OGA engagement at all, while 49% fall in the low category (0–5% OGA share), 24% in the medium category (5–20% OGA share), and 6% in the high category (above 20%).

A notable pattern emerges with respect to farm size. **Farms with high OGA engagement tend to operate on larger land areas than farms with no OGA engagement, averaging 119 hectares compared to 76 hectares.** Higher OGA engagement is associated with substantially lower agricultural income per hectare, falling from €2 626 among farms with no OGA engagement to €1 073 among high-OGA farms. Full details are in Annex A.

These raw patterns, however, do not control for other farm characteristics and cannot tell us whether OGA engagement itself drives the differences observed. The following sections present the results of the estimated econometric model, which isolates the effect of OGA share while holding farm size, labour intensity, capital intensity, and subsidy receipts constant.

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[4] It moved from a Fixed Effects model that produced imprecise estimates due to limited within-stratum variation in OGA share, through a Random Effects model rejected by the Hausman test (*p* = 0.000), to the final Mundlak-corrected Random Effects estimator, which resolves endogeneity while exploiting both within-stratum and between-stratum variation.

4.3.2. OGA Engagement and Farm Income per Hectare

When a farm temporarily increases its OGA share relative to its own historical average, say in a year when it expands agritourism or takes on additional processing activities, its income per hectare does not change in any statistically detectable way. However, this result should be interpreted with caution. OGA share tends to be remarkably stable within any given farm stratum from year to year, which means the data contain very little variation to identify a short-run effect, even if one exists. The absence of a detectable within-farm effect therefore reflects a data limitation as much as a substantive finding.

The picture is different when comparing **farms that have maintained persistently higher OGA shares** over the entire observation period against those that have not. After controlling for farm size, labour, capital, and subsidies, farm strata with **a 10-percentage point higher long-run average OGA share report approximately 18.7% lower income per hectare**. This structural gap is economically substantial. One interpretation is that farms engaging more deeply in OGA face a genuine trade-off: reallocation of capacity away from primary production reduces agricultural income per hectare, at least in the medium term. At the same time, this **does not necessarily mean that diversification causes income to fall**. Farms with historically higher OGA shares may simply be structurally different in ways the model only partially captures, operating in regions with lower agricultural potential, facing different market access conditions, or having production structures where high income per hectare from primary agriculture was never the primary objective. The negative association is robust, but what drives it remains an open empirical question.

Beyond the effect of OGA share itself, the income model reveals several structural patterns worth noting. Farm size exhibits a paradox familiar in agricultural economics: in years when a farm operates more land than usual, income per hectare tends to fall, consistent with short-run decreasing returns. Yet structurally larger farms achieve higher income per hectare, reflecting economies of scale that materialise only at the level of persistent farm organisation rather than year-to-year adjustments. A similar paradox emerges for capital intensity: higher depreciation per hectare reduces income in the short run, likely reflecting the cost burden of active investment years, while capital-intensive farms are structurally more profitable, suggesting that investment pays off over the long run. Subsidies consistently support farm income at both time horizons, with the structural effect being roughly three times larger than the short-run one. Labour intensity improves income within a farm in the short run but shows no significant structural difference across farms.

4.3.3. OGA Engagement and Cost Efficiency

The cost ratio model does not allow us to draw clear conclusions about the relationship between OGA engagement and cost efficiency. Farms with higher OGA shares do not appear to be systematically more or less cost-efficient than less diversified farms, but the estimates are too imprecise to say this with confidence. The data simply do not contain enough variation to detect a reliable effect in either direction, and it would be misleading to interpret this as proof that OGA engagement has no impact on farm cost structures. The honest conclusion is that we do not know.

The control variables reveal some interesting patterns. The clearest finding concerns labour. Farms that rely more heavily on their own labour tend to be more cost-efficient, both in individual years and as a structural characteristic. A 10% increase in labour input is associated with a reduction in the cost ratio of approximately 1 percentage point at the structural level. This makes intuitive sense as labour substitutes for purchased inputs such as hired services, energy, or external processing, reducing the share of costs in total output. **When a farm temporarily operates more land than usual, its operating costs tend to rise relative to output, suggesting that rapid expansion strains cost efficiency in the short run**. Across farms of different structural sizes, however, **no meaningful difference in cost**

efficiency is found, suggesting that larger farms do not systematically operate more cheaply relative to their output than smaller ones. Capital intensity works in the opposite direction to what one might expect from the income results. While capital-intensive farms tend to be more profitable in the long run, they also tend to carry higher cost ratios structurally, likely because machinery-heavy operations require more purchased inputs such as energy, spare parts, and maintenance to keep running.

4.3.4. OGA Engagement and Income Stability

Perhaps the most counterintuitive finding in the analysis concerns income stability. The common expectation is that diversification smooths farm income: if primary agricultural production has a bad year, income from other activities provides a buffer. The data do not support this intuition for the type of diversification captured by OGA share. **Farms with a higher long-run OGA share actually exhibit greater income variability.** A 10-percentage point increase in average OGA share is associated with income fluctuations that are roughly 2.5 percentage points wider, measured as a share of average farm income. This result does not necessarily mean that diversification destabilises farms. A more cautious reading is that farms with higher OGA shares tend to be structurally different in ways that make their overall income more variable, and that OGA revenues themselves may be subject to demand cycles, seasonal patterns, or investment phases that compound rather than offset the volatility of primary agricultural income. Either way, the data do not support the view that engaging in OGA provides a reliable income stabilisation effect.

Two other structural factors matter considerably for income stability. **Capital intensity is a significant driver of income variability**. Farms with higher fixed costs (depreciation) face larger income swings, because those costs remain constant even when revenues fall. A 10% increase in capital costs per hectare is associated with income variability that is roughly 0.71 percentage points higher. This is consistent with the operating leverage effect familiar from business economics, i.e. the higher the share of fixed costs, the more sensitive the bottom line is to revenue fluctuations.

Public support works in the opposite direction. Farms receiving higher subsidies per hectare exhibit significantly more stable incomes. **A 10% increase in subsidies per hectare is associated with income variability that is approximately 0.5 percentage points lower**. Direct payments provide a predictable income component that does not fluctuate with market conditions, effectively acting as a floor that dampens the impact of price and yield shocks on overall farm income. This finding lends empirical support to the stabilising role of agricultural policy and suggests that in contexts where bioeconomy-oriented diversification increases income volatility, well-designed policy support can partially offset this effect.

4.3.5. Summarization

The three models paint a nuanced picture of OGA engagement in EU agriculture. OGA share is best understood as a structural feature of certain farm types rather than a lever that farms can pull to improve their economic performance. Where it is present at scale, it is associated with lower agricultural income per hectare and greater income volatility, while its effect on cost efficiency remains unclear, given the precision of the available estimate. The factor that most reliably stabilises farm income in the data is not diversification into OGA but **predictable public support through direct payments**. **The economic case for bioeconomy-oriented diversification is therefore not universal**. It depends on the existing income structure of the farm, its capital intensity, and the policy environment in which it operates. **For farms where primary agricultural production is already highly productive, the opportunity costs of diversification are substantial. For farms operating in less productive contexts, OGA engagement may serve as a rational complementary strategy even if it does not improve income per hectare in absolute terms.**

5. STRENGTHENING THE BIOECONOMY IN THE EU AGRICULTURAL SECTOR

KEY FINDINGS

A successful transition to a scalable bioeconomy depends on a policy framework anchored in the residues-first principle and cascading use of biomass to resolve competition for land between food, energy, and materials.

Establishing long-term contractual frameworks and standardized quality parameters is essential to reduce market risks and make bio-based investments bankable for both farmers and private investors.

Cooperative and collective structures are vital for aggregating biomass flows, sharing high technological risks, and ensuring that primary producers capture a fair share of the value added.

Realizing the bioeconomy's potential requires a supportive policy mix that combines investment grants with payments for sustainable practices and risk-sharing financial instruments at the regional level.

The future development of the bioeconomy in the EU agricultural sector depends on the EU's ability to combine innovation, sustainable investment and effective policies with the active involvement of local actors. This chapter examines the instruments and mechanisms that can support the further development of the agricultural sector and enhance its competitiveness and sustainability in the long term.

5.1. Impact of Existing Policies and Support on the Bioeconomy in Agriculture

While the post-2027 CAP proposal does not define the bioeconomy as a standalone priority, several of its objectives and instruments (competitiveness, resilience, innovation and climate/environment actions) provide clear entry points to support bioeconomy-related diversification and circular value chains in agriculture. Whereas the early bioeconomy policy framework was criticised for the dominance of an "industrial perspective" and the insufficient representation of primary producers (Schmid et al., 2012), agricultural organisations have successfully called for the bioeconomy to become a modernisation policy addressing the structural problems of rural areas (Copa-Cogeca et al., 2018).

Consequently, current EU policies provide a stronger institutional and financial framework for the agricultural bioeconomy than in the past, particularly due to:

- a shift in support towards environmental functions,
- the development of innovation and knowledge networks, and
- the use of financial instruments for capital-intensive investments.

The main challenge remains the transition from pilot projects to scalable models that could make a substantial contribution to the economic sustainability of agricultural enterprises across the EU.

5.1.1. From "commodity production" to "function provision"

The reformed CAP for the 2023–2027 period represents a significant structural shift in the way agricultural activity is supported. Whereas earlier support models were largely oriented towards production volumes and compliance with basic requirements, the current framework places increasing emphasis on the functions that agriculture provides to society, the areas of climate action, soil protection, biodiversity and resource efficiency. The main instrument of this shift is the use of **eco-schemes** (European Commission, 2026), which reward farmers for adopting practices that go beyond basic conditionality. These practices, such as increasing soil organic matter content, diversifying cropping systems, sustainable nutrient management, protection of landscape features or the reduction of inputs, are also fundamental building blocks of bioeconomy models.

The bioeconomy in agriculture is therefore not primarily based on maximising biomass production, but rather on the quality of biomass, the stability of material flows and the added environmental value generated. As a result, economic incentives are gradually being reoriented: farmers are no longer rewarded solely for how much they produce, but also for how they produce and for the additional functions their farming systems deliver. This approach increases the attractiveness of bioeconomy activities that combine food production with the generation of energy, materials or bio-based inputs, while simultaneously contributing to carbon sequestration, soil protection and biodiversity conservation.

At the same time, there is a growing emphasis on **circularity and on reducing the dependence of rural areas on non-renewable resources**. Projects and methodologies supported within the framework of the EU CAP Network, focusing on rural and CBE models, demonstrate that agriculture can function as a hub for local biomass, nutrient and energy cycles. This strengthens local economies, reduces reliance on external inputs and increases the resilience of agricultural enterprises to price volatility and geopolitical shocks (EU CAP Network, 2026).

Existing policies are creating a favourable institutional environment for the transition from a linear, commodity-oriented agricultural model to a multifunctional bioeconomy model, although this transition is still proceeding unevenly across regions and farm types.

5.1.2. A stronger “pipeline” from innovation to practice

One notable strength of EU bioeconomy policies is the existence of a relatively well-developed system that **supports innovation, pilot projects and knowledge networks**. Support and coordination mechanisms in agriculture play a crucial role, enabling farmers, rural enterprises and regional actors to better exploit new opportunities and respond to technological and market changes.

In this respect, the EU has particularly strengthened the functioning of **AKIS**, which connect advisory services, research, practice and innovation to accelerate the uptake of bioeconomy solutions in agriculture and rural entrepreneurship (Faulkner et al., 2024). The EC also emphasises the importance of targeted advisory services and lifelong learning to ensure that farmers have access to up-to-date knowledge (Faulkner et al., 2024). Instruments inspired by the Agricultural European Innovation Partnership (EIP-AGRI) approach (EU CAP Network, 2026b), including thematic projects, operational groups and knowledge-sharing networks, enable the testing of new bioeconomy solutions directly under real-world conditions. A significant role is also played by the Knowledge Centre for Bioeconomy within the Joint Research Centre, which monitors progress, provides scientific support for policymaking and contributes to the dissemination of validated knowledge into practice (Giuntoli et al., 2020).

These mechanisms have proven particularly effective in:

- mobilising local actors;
- identifying solutions based on regional biomass and residue resources;
- linking farmers with research institutions, advisory services and other segments of the value chain.

Furthermore, **public support** for agricultural R&D in the EU shows an increasing trend (Christensen et al., 2022). EU framework programmes, such as Horizon 2020 and its successor Horizon Europe, allocate substantial financial resources to bioeconomy-related research (particularly within Horizon Europe Cluster 6) and provide funding for the development of prototypes and AKIS activities (European Commission, 2021; Faulkner et al., 2024). **Public–private partnership programmes**, such as the BBI JU (Bio-based Industries Joint Undertaking) and its successor, the CBE JU (Circular Bio-based Europe Joint Undertaking), help to accelerate the development of bio-based industries (Stegmann et al., 2020; European Commission, 2021). Regional initiatives and networks, such as the BIOEAST macro-regional initiative (bringing together 11 Central and Eastern European countries), also promote cooperation and introduce a common strategic framework for research and innovation (Faulkner et al., 2024).

As a result of these partnerships and participation platforms, a wide range of innovative approaches has emerged, ranging from local processing of agricultural by-products to new models of cooperation between farms and the processing industry. However, a major limitation remains the scaling-up of these solutions. Many bioeconomy initiatives remain at the level of pilot projects or regionally confined demonstrations.

The main **barriers** include:

- the absence of standardised technological and organisational models;
- insufficient investment in downstream infrastructure;
- weak or unstable market conditions for bio-based products;
- limited capacity of farmers to bear the entrepreneurial risks associated with innovation.

Current policies therefore create a functional innovation "pipeline", but provide less support for the stages of commercialisation, replication and integration of bioeconomy solutions into mainstream agricultural practice.

5.1.3. The growing importance of financial instruments alongside grants

Another important trend is the gradual expansion of the role of **financial instruments alongside traditional grant-based support**. While grants remain crucial, particularly for the initial phases of projects and for smaller farms, bioeconomy investments often require high capital expenditure and involve long payback periods.

This applies to technologies such as:

- biogas and biomethane plants;
- facilities for processing by-products and residues;
- biorefineries and advanced biomass processing;
- precision and digital technologies for efficient resource management.

In these cases, guarantees, preferential loans and blended finance instruments are playing an increasingly important role, often in cooperation with the European Investment Bank (EIB). The EIB is a primary financier of the bioeconomy, supporting projects across the agricultural, fisheries, food, and forestry value chains to promote food security, climate resilience, and resource efficiency. In 2025 alone, the EIB Group provided €7.7 billion in financing for these sectors. Recently, the bank announced a €3 billion financing package specifically for farmers and the bioeconomy, which is expected to unlock nearly €8.4 billion in total long-term investment when matched by partner institutions.

Below are several specific examples of EIB actions and projects within the bioeconomy (European Investment Bank, 2026):

- The EIB supports CrowdFarming, a platform that connects consumers directly with farmers who grow products without pesticides, cutting emissions and boosting profits for small organic producers.
- The bank has financed the first pea protein plant in Sweden and supported a Spanish company's plant-based food innovations. In Germany, it funded a food biotech company using fermentation to develop sustainable alternatives to dairy and plant-based cheese.

5.2. Successful Strategies Suitable for Replication and Scaling

Successful strategies for developing the bioeconomy in agriculture share several common features: they are spatially embedded, integrated along value chains, based on circularity, and supported by a combination of policy instruments. These characteristics enhance their potential for replication and scaling across EU regions and make them highly relevant for future policy-making.

5.2.1. Circular Regional Bioeconomy

The **circular regional bioeconomy** is one of the most promising strategies for the development of the bioeconomy in agriculture, particularly in terms of replicability and long-term sustainability. This approach is based on the spatial concentration of actors and biomass flows, which enables the creation of local or regional value chains.

The core principle is the integration of farmers, municipalities, food and other processing industries, waste management systems and the energy sector into a functional whole. Agriculture does not operate in isolation, but as part of a broader socio-economic system in which biological resources are used repeatedly and efficiently. This approach is successful for several reasons. First, it significantly **reduces logistics costs** associated with the transport of bulky and often low-value biomass, which is a key limiting factor for bioeconomy projects. Shorter distances and stable local supply relationships also contribute to lower emissions and reduced environmental impacts.

Second, it enables the **stabilisation of biomass offtake** through long-term relationships between producers and processors. For farmers, this means greater security of demand and income, while processors gain reliable access to input raw materials. The regional approach also facilitates joint investments in infrastructure (e.g. biomass processing, energy facilities, logistics) that would be economically unattainable for individual farms.

From a policy perspective, this model is particularly attractive because it allows the combination of different funding sources (agricultural, regional, environmental and energy-related). The EU CAP Network repeatedly highlights the importance of raising awareness of available financing instruments and of their targeted coordination across the value chain. **The ability to "bundle" funding from multiple programmes is precisely what makes the circular regional bioeconomy highly replicable across different types of rural areas**.

5.2.2. Assessment and Monetisation of By-products and Residues

A second strategy with high potential for scaling is the systematic assessment and economic **valorisation of by-products and residues** generated in agriculture and related sectors. These include straw, slurry and manure, digestate, residues from food processing, post-harvest residues and cover crops. An advantage of this strategy is that it enables the development of the bioeconomy without increasing pressure on agricultural land. Instead of introducing new production areas, added value is created from existing material flows but are often undervalued or underutilised. This simultaneously reduces competition between food, feed, energy and material production.

Successful monetisation of residues, however, requires the fulfilment of several conditions. The first is **technical and organisational know-how** that ensures stable quality and consistent supply volumes. The second is the **existence** of contractual arrangements and quality standards that enable long-term offtake of residues by processors or energy facilities. Without such frameworks, projects often remain at the level of one-off pilots with limited potential for further development.

An important aspect is also a shift in farmers' perception of residues, from waste or secondary outputs to fully-fledged production inputs with economic value. This shift has significant implications for investment decisions, production management and cooperation within value chains.

5.2.3. Combining Payments for Practices, Investment Support and Market Signals

Practical experience shows that changes in farming practices alone, even when supported through eco-schemes and other operational payments are usually insufficient to stimulate the development of bioeconomy activities. The bioeconomy often requires new technologies, infrastructure and organisational changes, which entail significant investment costs and entrepreneurial risk.

The most successful models therefore **combine three types of instruments**:

- payments for sustainable practices (in particular eco-schemes), which compensate for additional costs and risks associated with changes in management;
- investment support (rural development and other funds), which enables the acquisition of technologies and infrastructure;
- market signals, such as long-term contracts, public procurement of bio-based products or quality standards, which create stable demand.

This "package" approach reduces uncertainty for farmers, increases the economic viability of projects and supports their long-term sustainability. From a replication perspective, it is crucial that this model can be relatively easily adapted to different regional conditions and production structures.

5.2.4. "Supply-chain First"

A fourth strategy that repeatedly proves successful is the so-called "**supply-chain first**" approach. It is based on the premise that bioeconomy projects should not start with the selection of technology at farm level, but rather with an analysis of the value chain and the market. The key question is therefore not "which technology can be installed on the farm", but "who will take the output, under what conditions and in what volumes". **This approach enables the design of projects that are economically viable from the outset and better integrated into existing market structures.**

From the farmers' perspective, this model offers major advantages: it reduces market risk, increases income predictability and facilitates access to finance. For financial institutions, the existence of a stable offtake is often a prerequisite for providing loans or other financial instruments, which significantly increases the likelihood of project implementation. It is precisely this capacity to reduce risk and enhance bankability that makes the "supply-chain first" approach highly replicable and suitable for wider deployment across the EU.

5.3. Responses to Key Policy Questions

The bioeconomy in agriculture is reaching a stage where the focus is no longer solely on individual technologies (biogas, bioplastics, "bio"-based inputs), but on reconciling food production with decarbonisation, circularity and the competitiveness of rural areas. As a result, the policy debate is shifting from the question of "how to support innovation" to "how to design a framework that enables scaling and broad farm participation". The following section summarises questions that will shape the future of the bioeconomy in the EU: which development pathways are realistic and desirable; how to manage competition for land between food, energy, materials and nature conservation; who is likely to engage in bioeconomy models; and how to design support in a way that strengthens both sustainability and income stability for farmers.

A value chain perspective is a crucial cross-cutting consideration in this context. Without functioning markets, contracts and quality standards, bioeconomy projects remain isolated and difficult to replicate.

5.3.1. Potential Development of the Bioeconomy in Future EU Agriculture

The future development of the bioeconomy in EU agriculture is framed by the Strategic Framework for a Competitive and Sustainable Bioeconomy, which emphasises ensuring a sustainable supply of biomass, the development of circular value chains and support for technological innovation. Within this policy framework, agriculture is understood as a key sector for both the production and cascading use of biomass, with particular emphasis on the efficient use of residues, digitalisation, sustainability monitoring and the linking of actors across sectors. The agricultural bioeconomy is thus systematically integrated into the EU's broader objectives in the areas of competitiveness, circular economy and strategic autonomy (European Commission, 2025).

The bioeconomy is increasingly oriented towards a competitive and sustainable model that is closely linked to the principles of circularity and to the ongoing industrial transformation of the EU. The European Commission's strategic framework for the bioeconomy no longer focuses solely on supporting individual sectors but is explicitly embedded within the wider agenda of economic competitiveness, decarbonisation and the transition to a "clean" industry.

In this context, the bioeconomy is conceived as a tool that simultaneously aims to:

- strengthen the EU's strategic autonomy in raw materials and energy,
- create new market opportunities for agriculture and rural areas,
- contribute to the achievement of the EU's climate and environmental objectives.

Agriculture is thus positioned not only as a food producer, but also as a provider of renewable biological resources that form the basis for the development of bio-based industries and circular value chains.

Growth of bio-based materials and biomanufacturing

One of the main development pathways is the expected **growth of bio-based materials and biomanufacturing**, including advanced processing of agricultural biomass. Agricultural production and its by-products will increasingly be used as inputs for the manufacture of bio-based chemicals, materials, packaging and other high value-added products. This trend supports a **shift away from low-value uses of biomass towards cascading and value-oriented processing**, thereby increasing economic returns for farmers and regions. At the same time, it strengthens linkages between agriculture and industry, in line with the EU's strategic objective of developing innovative, technologically advanced and low-carbon production chains.

Development of biogas, biomethane and associated nutrient flows

Another area is the **development of biogas and biomethane**, which is expected to play a significant role in future EU agriculture, both in terms of energy security and circular nutrient management. Biogas and biomethane technologies enable the efficient processing of slurry, manure, post-harvest residues and other biological materials, while producing renewable energy and outputs that can be reused in agriculture. Of particular importance are digestate and related fertiliser streams, which can partially replace mineral fertilisers and contribute to improved soil fertility. In this way, biogas and biomethane become not only energy solutions but also agronomic and environmental tools that support nutrient cycling and reduce agriculture's dependence on external inputs.

Agroecological practices as a "productive function" of the farm

A significant shift in the conception of future agriculture is the growing role of **agroecological practices**, which are increasingly recognised as a fully-fledged productive function of the farm. These include practices that contribute to **carbon sequestration in soils, biodiversity protection, improved water regulation and enhanced resilience of agroecosystems**. Such practices are no longer perceived merely as environmental measures but are becoming an integral part of the bioeconomy's economic model, in which ecosystem services are valued through public payments, market mechanisms or a combination of both. Farms are thus able to generate income not only from the sale of physical products but also from the provision of environmental functions.

5.3.2. Competition for Land (Food vs. Energy and Materials vs. Nature Conservation)

Competition over the use of agricultural land is among the most sensitive issues in the development of the EU bioeconomy. Growing demand for biomass for energy and material purposes, together with the need to safeguard food security and meet environmental objectives, creates tensions between the different functions of the agricultural landscape. Effectively managing this competition is therefore a prerequisite for the long-term sustainable development of the bioeconomy.

Biomass hierarchy as a replicable framework

The concept of a **biomass hierarchy** is widely regarded as the most replicable and politically feasible framework for addressing these tensions, as it establishes clear priorities for the use of biological resources. This approach makes it possible to reconcile economic, food and environmental objectives without resorting to absolute bans or rigid restrictions.

The priority in the hierarchy is **the production of food and feed**, which remains the core function of agricultural land. Preserving this priority is essential for both the EU's food security and the social legitimacy of bioeconomy policies. The second level of the hierarchy focuses on the **use of by-products and residues** generated in agriculture, food processing and related sectors. This approach enables the development of the bioeconomy without additional land take and without direct competition with food production. Residues and by-products represent the least conflict-prone source of biomass while offering substantial potential for circular economy models.

Only the third level of the hierarchy involves the **cultivation of dedicated energy or material crops**, and only when these are fully compatible with local soil, water and ecological conditions. This approach emphasises that the use of land for bioenergy or biomaterial purposes should not be widespread, but rather selective and conditional on sustainability considerations.

Translating the biomass hierarchy into concrete policies

To ensure that the biomass hierarchy does not remain merely a declaratory principle, it must be **systematically embedded in the design and implementation of policies at both the EU and Member State levels**.

1. **The first step is the prioritisation of support for projects based on residues and by-products**. Such projects have a lower impact on land use, pose a reduced risk of negative environmental externalities, and enjoy higher social acceptability. Support for these projects

should be designed in a way that makes them economically attractive compared to projects based on primary biomass production.

2. **A second instrument is the spatial and regional planning of bioenergy and bio-based industry development**. A regional approach makes it possible to consider specific natural conditions, agricultural structures, biomass availability and ecosystem sensitivity. This reduces the risk of unbalanced land use and supports the functional integration of bioeconomy activities into the landscape.

3. **The third step is the conditioning of support for dedicated crops on strict environmental criteria**. These should include assessments of impacts on soil, water resources and biodiversity, as well as consideration of the risks of ILUC. Such an approach helps limit negative externalities while still leaving room for innovative systems that deliver clear environmental benefits.

Special attention should be given to **multifunctional production systems**, such as cover crops, agroforestry or combined land-use systems. These systems enable biomass production for the bioeconomy while simultaneously improving soil fertility, biodiversity and the resilience of agroecosystems. From a policy perspective, they represent a compromise that helps mitigate conflicts among the different functions of land.

5.3.3. Farmers' Engagement in Future Bioeconomy Pathways

The involvement of farmers in future bioeconomy initiatives in EU agriculture will not be determined primarily by farm size, but rather by a combination of production structure, managerial capacity and position within the value chain. The bioeconomy places new demands on farms, not only in terms of biomass production, but also in cooperation, planning, data management and long-term contractual relationships.

Farms with stable biomass flows

The highest likelihood of engagement lies with farms that have **regular and predictable biomass flows**. These typically include livestock farms and mixed farming systems, where slurry, manure, bedding and other by-products suitable for energy or material use are generated. The stability of these flows is crucial for bioeconomy value chains, as it enables capacity planning, long-term contracts and economic returns on investment. Such farms therefore enjoy a structural advantage in participating in biogas, biomethane, organic fertiliser production or residue processing projects.

Farms located close to processors and bioeconomy clusters

Another decisive factor is the **geographical and logistical position** of the farm. Bioeconomy activities are often constrained by the high costs of transporting bulky biomass with relatively low unit value. Farms located near processing facilities, energy plants or regional bioeconomy clusters have a significantly higher likelihood of participation. This aspect highlights the importance of **regional disparities** and confirms that bioeconomy development will remain uneven unless supported by targeted spatial policies. At the same time, it demonstrates that the bioeconomy is not solely a matter of individual farm decisions, but also of the structural configuration of the regional economy.

Farms with higher managerial and data capacity

Bioeconomy projects often require **advanced managerial skills**, the ability to work with data, and compliance with administrative and reporting requirements. These include, for example:

- monitoring of biomass and nutrient flows;
- environmental and carbon reporting;

- risk management and investment planning;
- use of digital tools and precision technologies.

Farms that already possess these capacities face lower transaction costs when entering bioeconomy initiatives and are more attractive partners within value chains. This factor may lead to some selectivity unless complemented by targeted support for advisory services and training.

Cooperatives and producers capable of collective investment

Cooperatives and other forms of collective organisation of farmers play a particularly important role in the development of the bioeconomy. Bioeconomy investments are often capital-intensive and associated with risks that individual farms cannot bear on their own.

Collective structures enable:

- sharing of investment and operating costs;
- achievement of the required biomass volumes;
- stronger bargaining power vis-à-vis processors and financial institutions;
- more efficient use of EU policy support instruments.

5.3.4. Strengthening the Bioeconomy for Sustainability and Farm Incomes

One of the key criteria for the success of bioeconomy initiatives in agriculture is their ability to contribute simultaneously to **environmental sustainability** and to **stable income growth** for farmers. An analysis of existing experience shows that bioeconomy models that are viable in the long term typically combine several sources of income and cost savings. Most often, three complementary "income channels" can be identified.

Payments for environmental services

The first, and often fundamental, income channel consists of **payments** for the provision of **environmental and climate services**, primarily through eco-schemes and related interventions under the CAP. These payments compensate farmers for the additional costs and risks associated with changes in farming practices and provide a stable baseline income that is independent of market volatility. In the context of the bioeconomy, eco-schemes are particularly important because they support practices that are also prerequisites for the efficient use of biomass, such as improving soil structure, increasing soil organic matter, diversifying crop rotations and improving nutrient management. In this way, they contribute not only to environmental objectives but also to the long-term productivity and resilience of farms. Payments for environmental services thus fulfil a dual **function**: they provide short-term economic stability while simultaneously supporting structural changes that enable farms to participate in bioeconomy value chains.

New revenues from biomass and residues

The second income channel consists of **new revenues** generated from the sale of biomass and by-products that were previously considered waste or had low economic value. These include, for example, the sale of slurry, manure, straw, digestate, catch crops or other biological materials to processors, energy facilities or the bio-based industry. To achieve stable and predictable income, it is essential that these revenues are based on **long-term contractual relationships**. Contracts with processors reduce market risk, enable production planning and increase farmers' willingness to invest in the necessary infrastructure and technologies. This mechanism is particularly important for more capital-intensive bioeconomy projects, where stable cash flow is a key determinant of economic viability. **From a policy perspective, it is therefore important to support the establishment and**

functioning of such contractual relationships and to strengthen transparency and fair value distribution within value chains.

Input cost savings through circular flows

The third, often underestimated but economically highly significant, channel consists of operational **cost savings** resulting from the introduction of circular flows of nutrients and energy. The use of digestate, compost or other organic fertilisers can partially replace the purchase of mineral fertilisers and contribute to cost stabilisation in an environment of fluctuating input prices. Similarly, the use of renewable energy from biogas or other bioenergy sources can reduce farms' dependence on external energy supplies. Precision agriculture and targeted input application further increase resource-use efficiency and reduce environmental pressures. These savings are particularly important during periods of high price volatility, as they increase the income resilience of agricultural enterprises and reduce their vulnerability to external shocks.

Synergies between income channels

The greatest contribution of the bioeconomy to both sustainability and farm income is achieved when these **three channels are combined**. Payments for environmental services provide a stable foundation, new revenues from biomass generate additional income, and input savings improve overall cost efficiency. This combination reduces farmers' dependence on a single income source and enhances the long-term economic sustainability of bioeconomy models. **From a policy-making perspective, it is therefore crucial to support integrated approaches that link environmental, investment and market-based instruments**.

5.3.5. The Value-chain Perspective

The shift from isolated, farm-level projects to value-chain-integrated models makes it possible to overcome several economic, technical and institutional barriers that have so far limited the wider uptake of the bioeconomy.

One of the most important **benefits of a value-chain-based approach** is the reduction of investment risk. Bioeconomy projects are often capital-intensive, and their economic viability depends on the long-term stability of outlets for biomass or bio-based products. From the perspective of financial institutions, it is therefore not only the technical parameters of a project that matter, but above all the predictability of future cash flows. Projects embedded in a functioning value chain and secured by long-term off-take contracts exhibit a significantly **higher degree of bankability**. Banks and other investors are generally more willing to finance projects based on contracted cash flows than those relying solely on technological potential or expected market growth. The value-chain perspective thus enables the mobilisation of private capital to complement public support, which is essential for scaling up bioeconomy initiatives.

Another major advantage of the value-chain approach is the possibility of introducing **quality standards** for biomass and by-products. At present, one of the main obstacles to the development of the bioeconomy is the high variability in the quality of input materials, which complicates processing, increases transaction costs and limits the large-scale deployment of technologies. Integrating farmers into value chains enables definition of clear parameters for quality, collection methods, storage and delivery of biomass. Standardisation is a prerequisite for:

- technological reliability of processing facilities,
- reduced costs for control and sorting,
- the development of tradable markets for biomass and bio-based products.

From a policy perspective, support for standardisation represents an important instrument for bridging the gap between pilot projects and the industrial scale of the bioeconomy.

The value-chain perspective also has significant **socio-economic implications**, particularly regarding the position of farmers. If farmers are integrated into value chains only as raw-material suppliers without the ability to influence the terms of cooperation, there is a risk that most of the value added will be captured by downstream segments of the chain. By contrast, if their position within the chain is actively supported by policies, farmers can:

- negotiate fairer contractual conditions,
- participate in decision-making on the organisation of the chain,
- capture a share of the higher value added generated by bioeconomy products.

Strengthening the position of farmers in value chains has long been part of the **agenda of the European Parliament and the AGRI Committee**, particularly regarding the functioning of the food supply chain. The bioeconomy extends this framework to new types of value chains, where similar principles need to be applied from the outset.

The combination of reduced investment risk, quality standardisation and a stronger position for farmers makes the value-chain-based approach a fundamental prerequisite for scaling up bioeconomy initiatives. Without functioning value chains, projects remain isolated, difficult to finance and limited to local pilots. **From a policy-making perspective, this implies that support for the bioeconomy should not focus solely on the farm level or on individual technologies, but on the entire value chain, including contractual relations, standards, investments and market conditions**.

Box 3: Preconditions for Scaling the Bioeconomy in EU Agriculture

The successful transition to a scalable agricultural bioeconomy in the EU requires a robust policy framework anchored in the residues-first principle, which prioritizes the valorisation of by-products and waste to resolve land-use competition between food, energy, and material production. Scaling these models effectively depends on the establishment of long-term contractual frameworks and standardized quality parameters that provide the market certainty needed to make bio-based investments bankable. To mobilize the necessary capital, EU policies must move toward a systemic integration of eco-schemes and investment support, combining payments for sustainable practices with targeted funding for bioeconomy-enabling infrastructure. Central to this transition is the development of cooperative infrastructure, which allows primary producers to aggregate biomass, share technological risks, and capture a fairer share of the value added within new value chains. The deployment of risk-sharing mechanisms, including blended finance and guarantees, is essential to bridge the gap between pilot innovations and commercial reality, ensuring that the bioeconomy contributes to the long-term economic resilience and sustainability of EU farms.

6. POLICY OPTIONS FOR THE EU WITH A FOCUS ON THE AGRI REMIT

KEY FINDINGS

Scaling the agricultural bioeconomy requires an integrated policy framework under the post-2027 CAP that combines different measures, investment support and risk-sharing instruments to make bio-based technologies and value chains economically viable for farmers.

Strengthening value-chain integration through long-term contracts, transparent pricing mechanisms and harmonised biomass quality standards is essential to reduce investment risk and improve farmers' bargaining power within emerging bio-based markets.

The residues-first principle should guide EU bioeconomy development to avoid competition for land, prioritise the use of agricultural by-products and support environmentally sustainable circular models at regional level.

Large-scale uptake of bioeconomy investments depends on blended finance, guarantees and EIB-supported instruments that enable cooperatives and regional clusters to build shared infrastructure such as biogas plants, composting facilities or small-scale biorefineries.

Scaling the bioeconomy requires a major reinforcement of AKIS and advisory systems, enabling farmers to access expertise in nutrient circularity, carbon accounting, contract negotiation and digital monitoring, which are prerequisites for participation in advanced value chains.

Policy options must explicitly address farm heterogeneity, ensuring that both small mixed farms and large arable enterprises can meaningfully engage in the bioeconomy through differentiated support, collective structures and regionally embedded solutions.

Before presenting concrete policy options, it is essential to briefly summarise the key insights emerging from the analysis in the previous chapters. The findings highlight that the development of a scalable and sustainable agricultural bioeconomy requires a **coherent combination of circular practices, regional value-chain integration, stable market conditions, and investment-ready frameworks**. These elements form the basis for the policy options outlined below, some of which are complementary. They aim to support the transition of EU agriculture towards a competitive, resilient and resource-efficient bioeconomy.

6.1. Policy Options

6.1.1. Option A: A strategically targeted CAP to scale up the bioeconomy

While support mechanisms already exist, the post-2027 CAP framework could help turn the bioeconomy into a mainstream model by moving beyond isolated measures toward integrated risk-sharing models and blended finance that scale bio-based value chains.

The proposal for the post-2027 CAP[5] has the potential to contribute not only to "improve practices" but also to enable the scaling-up of bioeconomy models.

What can be strengthened within the proposed agri-environmental and climate actions:

- Interventions that directly create sustainable biomass flows without exerting pressure on land: cover crops, diversified crop rotations, practices increasing soil organic matter (and thus yield stability and biomass quality), agroforestry, and carbon-farming practices where agronomical appropriate.
- Precision application of inputs (nutrients, pesticides) as a standard enabler of circularity; this reduces losses, increases the efficiency of organic fertilisers, and facilitates the transition to circular nutrient management.
- Linking payments to result-based logic where feasible (e.g. soil cover, diversity, erosion risk, landscape features) in order to strengthen incentives to maintain changes over the long term.

Where carbon-farming practices are supported, CAP implementation should also enable credible measurement, reporting and verification and certification approaches, so that soil carbon outcomes can be trusted and translated into stable payments or market-based revenue streams for farmers.

In line with the CAP proposal's emphasis on interactive innovation and knowledge exchange, bioeconomy solutions should not be developed as a one-way "transfer" from research to farms. They should be co-created with the farming community and other relevant actors (advisors, cooperatives, processors, local authorities) through a multi-actor approach, ensuring that innovations respond to farmers' concrete operational needs and constraints and are jointly owned by those who will implement them.

What can be strengthened under the proposed support for investments and for knowledge sharing and innovation:

- Investments in "bioeconomy-enabling infrastructure" (biomass storage, separation, composting, digestate treatment, simple processing of by-products, shared machinery for harvesting/transport, and technologies for monitoring nutrient flows).
- Cooperation and collective projects (cooperatives, producer organisations, local cluster projects), where scaling effects are greatest because unit costs are reduced and farmers' bargaining power increases.
- Targeting the "missing middle": measures that bridge the gap between pilot projects and commercial deployment (e.g. demonstration facilities, standardised business models).

CAP implementation (and future adjustments of the framework) should give **greater priority to interventions that demonstrably lead to repeatable bioeconomy flows** while remaining compatible with environmental ambition. Improved guidance for Member States on how **to combine agri-environmental and climate actions, investments and cooperation into functional packages** would also be beneficial.

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[5] The proposal for a regulation establishing the conditions for the implementation of the Union support to the CAP for the period from 2028 to 2034 was put forward by the European Commission in July 2025 and it is currently under examination by the European Parliament and the Council. The proposal is available at the following link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2025:560:FIN

How to measure success (indicators):

- Number/area of farms applying practices that support circularity and stable biomass flows (cover crops, diversification, agroforestry).
- Volume of residues and by-products entering value chains.
- Reduction in mineral fertiliser use per unit of output while maintaining stable yields.
- Number of operational cooperative projects (shared infrastructure).

6.1.2. Option B: Value-chain contracts and standards

Without market certainty, many bioeconomy initiatives remain confined to the pilot stage. Scaling up requires stable offtake arrangements and predictable cash flows for farmers, as well as reliable and standardised input quality for processors. Strengthening value-chain instruments also responds to a long-standing concern of the European Parliament's AGRI Committee: improving farmers' position within the supply chain.

A key element is the broader use of written contractual frameworks, including transparent pricing formulas and clearly defined risk-sharing mechanisms. Instruments such as indexation to energy or fertiliser prices and to biomass quality parameters can help reduce volatility and investment uncertainty. This is particularly important in the bioeconomy, where traded materials, such as straw, digestate or other agricultural by-products, often represent relatively new commodities. In the absence of contractual clarity, even modest investments may face financing constraints. This is consistent with the empirical finding that higher OGA engagement is associated with greater income variability, underscoring the importance of contractual arrangements that provide farmers with predictable revenue streams.

Equally important is the establishment of quality standards for biomass and by-products. Defining minimum parameters, such as moisture content, contamination levels, trace elements and homogeneity, together with harmonised procedures for collection and storage, reduces transaction costs and technological risks. Standardisation can thus be regarded as a prerequisite for the broader industrial integration of bio-based value chains.

Where carbon farming is linked to market schemes, standardised monitoring, reporting and verification and certification rules are equally important to ensure credible claims and reduce transaction costs.

Finally, ensuring fair value distribution along the chain remains essential. Building on previous legislative efforts to strengthen farmers' bargaining power in the food supply chain, similar principles can be extended to emerging bioeconomy sectors, including bio-based materials, energy, and agricultural inputs. Both legislative and non-legislative measures may contribute to improving the enforceability of fair-trading practices, promoting the use of standardised contract templates and guidelines, and reducing administrative barriers for producer organisations and cooperatives.

How to measure success (indicators):

- Share of bioeconomy biomass flows covered by long-term contracts.
- Number of standards/technical specifications used in practice.
- Change in the share of value added captured at the farm level (where estimable).

These measures can be explicitly integrated into the EU farm policy through **reinforced provisions on unfair trading practices**, **mandatory written contracts for biomass and by-products**, and **strengthened producer cooperation rules under the Common market organisation (CMO) Regulation**, all of which fall directly under the AGRI Committee's legislative remit.

6.1.3. Option C: "Residues first" as a principle for addressing competition for land

When the bioeconomy starts to rely on "dedicated" crops, conflicts quickly arise: food versus energy/materials versus nature. The "residues first" principle ensures that the growth of the bioeconomy is primarily based on residues, by-products and waste streams, thereby reducing pressure on land and sensitive ecosystems.

In policy practice, applying the "residues first" principle mainly means a differentiated design of support schemes that favours projects focused on processing by-products and residues over projects based on primary biomass production. Such an approach reduces pressure on agricultural land and limits direct competition with food production, while also supporting the development of circular flows within existing agricultural and food systems. Preferential conditions may take the form of higher support rates, simpler administrative requirements, or targeted calls specifically aimed at the use of residual material streams.

A prerequisite for the effectiveness of this approach is regional planning of bioeconomy infrastructure. The use of residues is economically viable only if adequate logistics and processing capacities are available within a reasonable distance from the point of biomass generation. Without such capacities, biomass becomes economically "non-transportable", and the potential of the bioeconomy remains untapped. Projects supported under the EU CAP Network that focus on the CBE therefore work with local and regional scaling of bio-based solutions, linking farmers, processors and other actors into functional territorial systems.

At the same time, it is necessary to clearly define the conditions under which dedicated crops may be used for bioeconomy purposes. Their support should be conditional on meeting strict environmental criteria for soil protection, water resources and biodiversity, as well as on limiting the risks of ILUC. Priority should be given to multifunctional production systems such as cover crops and agroforestry, or systems in which biomass production is understood as a secondary function contributing to improved soil fertility and ecological stability. Such a framework enables the development of the bioeconomy without undermining the core environmental and food functions of agricultural landscapes. It is therefore possible to advocate for "residues first" to become an explicit principle in recommendations and implementation guidance, and for stronger support of regional models of the CBE.

How to measure success (indicators):

- Share of bioeconomy projects based on residues versus dedicated crops.
- Impacts on soil organic matter and erosion risk (for cover crops/agroforestry).
- Logistical efficiency (average biomass transport distance).

The residues-first principle can be operationalised in the future CAP by **prioritising residue-based bioeconomy projects within the various CAP interventions**, and by **aligning eligibility rules for sustainability criteria** under AGRI-led legislation, including soil protection and nutrient management provisions in the post-2027 CAP framework.

6.1.4. Option D: Investment packages and financial instruments

Scaling up the bioeconomy in agriculture is primarily constrained by the high capital requirements associated with investments in technologies and infrastructure, such as biogas and biomethane plants, facilities for processing by-products, composting plants, digestate separation systems, digital solutions for managing biomass and nutrient flows, and storage capacities. Large-scale investments in bioeconomy infrastructure inherently increase the share of fixed costs, which can potentially amplify income volatility when revenues fluctuate. The empirical analysis suggests that targeted subsidy support can partially offset this effect, reinforcing the case for combining investment instruments with stable direct payments rather than relying solely on investment grants. For these types of projects, stand-alone grant funding often proves insufficient or economically inefficient, particularly where the objective is to reach larger scale and long-term operational stability. For this reason, it is essential to combine grants with financial instruments such as guarantees, concessional loans, or their combinations (blending).

The practical design of this support should be based on the principle of risk sharing. Under a blending model, the grant component can cover part of the investment risk and improve the project's economic viability, while financial instruments (guarantees, concessional loans) increase the overall investment volume and mobilise private capital. This approach is particularly effective for cooperative projects and regional infrastructure, where the greatest multiplier effects of public funding arise through cost sharing, achieving the necessary scale, and better utilisation of capacities. In addition, risk-sharing and blended finance can be tailored to smaller, modular investments that are often more accessible to SMEs and cooperatives, such as small-scale biogas/biomethane units and small-scale or modular biorefinery solutions linked to local residue streams. Supporting these "right-sized" projects helps bridge the gap between pilot initiatives and bankable commercial deployment, while keeping value added and energy/nutrient loops within the region.

At the same time, financing of bioeconomy investments should be systematically conditional on the existence of secured offtake, for example, through long-term contracts or other forms of contracted cash flow. For banks and other financial institutions, the stability of future revenues is a key prerequisite for providing loans or guarantees. This directly links investment support with a value-chain approach and with instruments aimed at strengthening value chains. Such linkage increases the bankability of projects, reduces the risk of investment failure, and creates the conditions for genuine scaling of bioeconomy solutions in agricultural practice.

The EIB explicitly positions itself as an investor across the agri-food and bioeconomy value chain and supports innovative and sustainable bio-resource pathways. At the same time, EIB financing for agriculture/bioeconomy amounting to several billion euros has been communicated, with the aim of unlocking investment volumes several times higher through co-financing with other institutions. It is therefore recommended to advocate for **clearly defined bioeconomy investment priorities that are compatible with CAP objectives**, to support **simpler access for small and medium-sized farms** (guarantees, standardised products, risk sharing), and to **coordinate agricultural, regional and financial instruments** so that they do not form a disconnected "mosaic".

How to measure success (indicators):

- Volume of private investment mobilised per €1 of public support.
- Number of projects that have moved from pilot to commercial operation.
- Reduction in unit costs (high capital expenditure per tonne of processed biomass) in replicated models.

In legislative terms, these investment and risk-sharing instruments can be embedded in the post-2027 CAP through **dedicated bioeconomy-focused interventions**, including supported guarantees and blended finance, while ensuring that future legislation explicitly recognises **cooperative and regional bioeconomy infrastructure as priority investment areas**.

6.1.5. Option E: Capacities and advisory services

A recurring barrier to the development of the bioeconomy at the farm level is not limited to technological or financial constraints but increasingly relates to competences. Effective participation requires the ability to plan biomass and nutrient flows, comply with quality standards, manage contractual arrangements, ensure operational coordination, and address carbon reporting, traceability and digital requirements. Without systematic skills development, there is a substantial risk that bioeconomy opportunities will remain confined to a limited group of highly capable actors or will deliver suboptimal performance.

Strengthening advisory capacities is therefore essential. The EU CAP Network highlights that advisors must go beyond traditional technical guidance and assume the role of innovation brokers. This involves identifying farmers' needs, facilitating cooperation among actors, supporting the uptake of innovative solutions and ensuring the dissemination of results. Such a role requires targeted training and continuous upskilling of advisory professionals.

Within the CAP 2023–2027 framework, the AKIS is recognised as a central pillar of the cross-cutting objective of modernisation, encompassing knowledge transfer, innovation and digitalisation. Member States are required to articulate their AKIS strategies in their CAP Strategic Plans, reinforcing their structural importance in policy implementation. Farm Advisory Services represent the main operational channel through which these objectives can be translated into practice. The European Commission emphasises that advisory systems should address the economic, environmental and social dimensions of the CAP and provide farmers with independent guidance, including on innovation and digital transformation.

To become genuinely "bioeconomy-ready", advisory services must move beyond isolated technical recommendations towards an integrated management perspective that encompasses both farm-level and value-chain dynamics. Core competences include biomass and residue management, with a focus on quality assurance, appropriate storage and logistics, all of which are prerequisites for stable integration into bioeconomy value chains. Advisory support should also address nutrient circularity, including the effective use of digestate and compost, preparation of nutrient balances and precision input application, thereby reducing losses while improving agronomic and environmental performance.

Equally important is the development of value-chain literacy. Advisors should be able to support farmers in negotiating contractual arrangements, understanding pricing mechanisms and establishing risk-sharing frameworks. As environmental and climate objectives gain prominence, advisory services must also provide expertise in monitoring, reporting and verification systems, covering carbon flows as well as biomass and bio-based product traceability. These competences are increasingly indispensable for accessing public support schemes, financial instruments and market contracts.

This includes practical support for soil carbon monitoring, reporting and verification and certification requirements (data collection, monitoring approaches, documentation), which are necessary for farmers to access credible carbon-farming payments or schemes.

At EU level, and within the remit of the AGRI Committee, this implies recognising AKIS and advisory services not as peripheral instruments but as core components of bioeconomy implementation under the CAP. Strengthening the systematic exchange of methodologies and practical experience at the European level, through peer-to-peer learning and on-farm demonstration activities, as promoted by the EU CAP Network, further enhances knowledge transfer, reduces project risks and supports broader and more effective uptake of bioeconomy models in agricultural practice.

How to measure success (indicators):

- Number of advisors trained in bioeconomy-related topics.
- Uptake of practices (precision application, organic fertilisers, cover crops) among farms receiving advisory support.

- Reduction in error rates/project failures (e.g. technology without markets, poor biomass quality).

Strengthening AKIS can be directly anchored in the post-2027 CAP by expanding mandatory Member State requirements on advisory systems, digital skills and innovation brokerage. These are areas in which the AGRI Committee has full legislative competence when shaping the modernisation and knowledge-transfer provisions of future CAP.

6.2. Implications for policy-making

The development of the bioeconomy in agriculture is not primarily a matter of individual technologies or isolated measures, but of the overall system design. It is essential to link support for sustainable farming practices with functional value chains, investments in infrastructure and sufficient human capacities. The bioeconomy can scale up only if farmers have stable market outlets, a fair position within the value chain, and access to advisory services and financing that reflect its complexity. Bioeconomy development must be steered to reduce pressure on land and natural resources, in particular through better use of residues and circular flows. We therefore emphasise the need for a coordinated and long-term approach within the CAP that connects environmental objectives with the economic viability of agricultural holdings.

The analysis shows that farmers' engagement in the bioeconomy is selective and conditioned by a range of structural factors. This implies (see Table 2) that a one-size-fits-all approach to bioeconomy support is unlikely to be effective. EU policies should reflect the heterogeneity of agricultural enterprises and tailor measures in a way that supports a wide range of farms, rather than focusing exclusively on capital-intensive or technologically advanced actors.

Table 2: Policy Implications for Inclusive Bioeconomy Development in the EU Agricultural Sector

Policí Area	Problem	Recommended Instruments and Measures	Expected Impact
Differentiated Targeting by Farm Type	Farms differ in biomass stability, resource endowment, and innovation capacity	Combine agri-environmental and climate actions, investment aid and cooperation by farm type; cut entry barriers for low-capital farms; help innovative farms scale and integrate into value chains.	More precise allocation of public support and improved inclusiveness
Strengthening Cooperation	Small and medium-sized farms face limited individual access to bioeconomy projects	Support cooperatives and producer organisations; prioritise collective projects in funding calls; invest in shared infrastructure (processing, storage, logistics)	Improved economic accessibility and stronger bargaining power within value chains
Enhancing Managerial and Digital Capacities	New skills in investment planning, data management, and environmental reporting	Strengthen advisory services, training, and digital support, especially for SMEs	Prevent concentration of opportunities among a narrow group of advanced enterprises

Linking Bioeconomy Support with Regional Development	Biomass availability and logistics are spatially concentrated	Support regional bioeconomy clusters; consider local processing capacities; coordinate agricultural, energy, environmental, and industrial policies	Higher investment efficiency and more balanced regional development
Reducing Administrative and Transaction Burdens	High administrative and transaction costs limit smaller farms' participation	Simplify rules for collective projects; standardise contractual and reporting frameworks; improve coordination across policies and funds	Broader participation beyond large enterprises
Ensuring Social Legitimacy	Limited inclusion may undermine political and societal support	Promote inclusive participation of small and medium-sized farms	Greater acceptance of policies, reduced land-use conflicts, policy stability
Value-chain Integration and Contractual Relations	Fragmented markets, unstable demand, and weak bargaining power of primary producers; lack of quality standards and predictable offtake	Promote long-term written contracts with transparent pricing and shared risk mechanisms; develop harmonised quality standards for biomass and by-products; support formation of producer organisations for collective negotiation; link investment support to secured offtake agreements	More predictable cash flows, reduced investment risk, improved bankability of projects; stronger farmer position within emerging bio-based value chains; higher adoption of bioeconomy technologies

Source: Own

6.3. Conclusions – Summary of Policy Options

Option A – Strengthening the CAP to scale up the bioeconomy

This option focuses on using the CAP as a key driver for developing the agricultural bioeconomy. It proposes reinforcing measures that support circular nutrient management and biomass-enhancing practices, increasing investments in "bioeconomy-enabling" infrastructure, and promoting cooperative projects that reduce costs and strengthen farmers' bargaining power. The approach also highlights the need for risk-sharing financial instruments and better integration of policy tools into coherent support packages. CAP support for carbon-farming practices should be paired with credible monitoring, reporting and verification and certification to turn soil carbon outcomes into reliable income streams.

Option B – Value-chain contracts and quality standards

This option addresses market uncertainty as a key barrier. It promotes written contracts with transparent pricing and risk-sharing mechanisms to give farmers predictable outlets for biomass. It also stresses the need to establish harmonised quality standards for residues and by-products to reduce transaction costs and enable industrial scaling. Fair value distribution throughout the chain is an essential element.

Option C – "Residues-first" principle to manage land-use competition

This option prioritises the use of agricultural residues, by-products and waste streams over purpose-grown biomass, reducing pressure on land and avoiding conflicts between food, feed, energy and materials. It calls for support schemes that favour residue-based projects, regional planning to match biomass supply and processing capacity, and strict sustainability criteria for dedicated crops. Multifunctional systems such as cover crops or agroforestry are encouraged.

Option D – Investment packages and financial instruments

This option proposes combining grants with guarantees, concessional loans and blended finance to support capital-intensive technologies (biogas/biomethane, residue processing, composting, nutrient separation, digital monitoring). A key condition for financing should be securing long-term offtake agreements to ensure bankability. Cooperative and regional infrastructure projects are highlighted as providing the highest multiplier effects.

Option E – Strengthening capacities and advisory services (AKIS)

This option recognises that one of the greatest barriers is not technology but skills and management capacity. Strengthening AKIS is essential to help farmers plan biomass flows, handle nutrient circularity, meet quality and reporting requirements, negotiate contracts and adopt digital tools. Advisors are expected to act as innovation brokers linking farmers with research, industry and financing. The option calls for systematic upskilling, harmonised methodologies and increased support for on-farm demonstrations. AKIS should explicitly build advisory capacity for soil carbon monitoring, reporting and verification and certification, enabling farmers to meet reporting requirements and participate in carbon–farming schemes.

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ANNEX A

ECONOMIC IMPACTS OF THE BIOECONOMY IN EU AGRICULTURE: AN ECONOMETRIC ASSESSMENT

A.1 MODEL FOR ASSESSING THE ECONOMIC IMPACTS OF THE BIOECONOMY IN EU AGRICULTURE

A.1.1 Unit of Analysis, System Boundaries, and Reference Scenario

Assessing the economic impacts of bioeconomy activities requires a clear definition of the unit of analysis, system boundaries[6], and the reference scenario against which impacts are evaluated.

A.1.1.1 Unit of Analysis

The unit of analysis[7] in the proposed model is the **agricultural holding (farm)**, understood as an economic entity combining land, labour, capital, and inputs to produce agricultural commodities and related outputs. The model is designed to be applicable across a wide range of EU farms, regardless of legal form, size, or production specialization.

Selecting the farm level reflects the fact that decisions on adopting bioeconomy activities are primarily made at this level, while their costs and benefits materialize in overall business performance. Farms differ significantly in size, production structure, capital endowment, and access to technology, which strongly influences their capacity to engage in the bioeconomy. At the same time, market signals, policy incentives, and institutional constraints converge at the farm level, shaping distinct adaptation strategies and responses to changes in prices, policies, and technologies.

The farm is treated as an integrated system rather than a set of isolated activities. Economic impacts are therefore assessed in terms of their effects on overall performance and stability, taking into account synergies, trade-offs, and time-distributed effects arising from the implementation of bioeconomy solutions.

A.1.1.2 System Boundaries

System boundaries are defined to capture the **direct economic impacts of bioeconomy activities at the farm level** without extending the model to related sectors or macroeconomic effects. The focus remains on the farm as the decision-making unit. All economically relevant flows that directly affect farm performance are included, whether monetary or imputed, provided they are significant for business decisions. The model covers in particular:

- changes in operating costs (e.g. inputs, energy, fertilizers, waste management),
- changes in revenues from main and secondary production,
- additional income streams linked to bioeconomy activities (e.g. energy, materials, services),
- investment costs and their economic implications (e.g. depreciation, operating costs),

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[6] System boundaries define which processes, costs and benefits are included in the assessment and which lie outside its scope.

[7] The unit of analysis specifies the entity for which economic impacts are assessed; in this study, it is the agricultural holding.

- public support schemes and incentives with a direct impact on farm economics.

Excluded are broader macroeconomic effects, upstream and downstream value chain impacts beyond the farm, environmental externalities not reflected in market or policy mechanisms, and wider social costs and benefits addressed in separate environmental or socio-economic assessments.

This delimitation is intentional and consistent with the model's objective: to assess whether and under what conditions bioeconomy activities improve the farm's economic position. Environmental and social benefits are considered only when they translate into measurable economic effects, such as cost savings, payments for practices, or market premiums, ensuring consistency with a farm-level economic perspective.

A.1.1.3 Reference Scenario and the Principle of Incremental Assessment

A methodological element of the model is the use of a reference scenario, representing a **hypothetical situation in which the farm continues operating without the assessed bioeconomy activity**. Economic impacts are expressed as the incremental difference between this baseline and the scenario with the bioeconomy intervention.

The reference scenario assumes:

- continuation of the existing production system,
- a comparable level of output and technology,
- no additional investments directly linked to bioeconomy activities,
- stable market and policy conditions.

This approach isolates the specific contribution of bioeconomy solutions from general trends in prices, productivity, or policy changes. It captures the farmer's decision logic, change versus continuation, and ensures comparability across farms and regions. The incremental perspective is particularly important within the EU, where farms operate under diverse initial conditions. The model therefore evaluates not absolute economic performance, but the change in economic parameters induced by a specific bioeconomy activity.

A.1.1.4 Time Horizon and the Static Nature of the Model

The model is designed as a **static**, annual analytical tool assessing the economic impacts of bioeconomy activities in a typical year of operation. Investment costs are incorporated through annual equivalents, such as depreciation or annuitized costs[8], allowing comparison between farms with different capital structures. The choice of a static approach is intentional. It ensures simplicity and practical applicability, enables the use of commonly available data, and supports comparability across EU Member States. Dynamic effects, such as technological learning, price developments over time, or long-term environmental benefits, are not explicitly modelled in the core framework but can be addressed through scenario or sensitivity analyses in follow-up assessments.

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[8] Annuitized costs refer to the annual equivalent of an investment's total cost, calculated by distributing that cost evenly over the entire expected lifetime of the asset.

A.1.2 Economic Dimensions and the Evaluation Structure of Bioeconomy Activities

Based on the definition of the unit of analysis, system boundaries, and the reference scenario, the core structure of the economic evaluation is established. The model assumes that the economic effects of bioeconomy activities at farm level are multidimensional and operate through several interrelated mechanisms influencing performance, stability, and decision-making capacity. It identifies four economic dimensions common to different types of bioeconomy activities, although their relative importance varies depending on the farm's production structure, regional conditions, and institutional context.

A.1.2.1 Costs and Input Savings

The first area examined is how bioeconomic activities affect a farm's **cost structure**. At farm level, bioeconomy is reflected less in higher output and more in more efficient use of inputs and resources. The focus is therefore on operational cost savings from improved use of energy, nutrients, biomass, and by-products.

Key aspects include:

- reduced spending on external inputs (e.g. fertilizers, energy, feed),
- substitution of purchased inputs with on-farm bio-based resources,
- lower waste management costs,
- changes in operating costs linked to new technologies.

This area is particularly important in the context of input price volatility, a major source of economic vulnerability for EU farms. Bioeconomic activities can enhance stability even if gains are not immediately visible in revenues. Evaluation should therefore use standardized indicators such as cost per unit of output, percentage input savings, and cost volatility across scenarios.

A.1.2.2 Revenues and Output Diversification

This area examines how bioeconomic activities affect **farm revenues**. It captures new or expanded income streams arising from bioeconomy involvement and their **role in diversifying** the farm's economic base.

It includes:

- income from by-products (energy, bio-based materials, intermediates),
- new market outputs based on biomass or residue valorisation,
- revenues from bioeconomy-related services,
- payments and subsidies directly linked to bio-based practices.

The focus is not only on the total amount of new income, but also on its structure, stability, and connection to core production. Special attention is paid to whether bioeconomic activities reduce dependence on a single dominant commodity market and thus enhance economic resilience.

A.1.2.3 Value Added and Intra-Farm Integration

This dimension focuses on **value creation** at the farm level. The bioeconomy enables a shift from selling raw primary products toward greater processing, integration, and internal use of biomass.

It examines:

- higher value added per unit of output,
- internalization of activities previously outsourced (energy, fertilizers, processing),
- a stronger position of the farm within the value chain.

Assessing value added is crucial for the long-term competitiveness of EU agriculture. Bioeconomic activities are seen not merely as a supplement to production, but as a structural shift in the business model that can influence how value is distributed between primary producers and downstream sectors.

A.1.2.4 Economic Stability and Farm Resilience

The fourth, cross-cutting dimension examines the impact of bioeconomic activities on farm **economic stability and resilience**. It links cost and revenue effects and focuses on the farm's capacity to withstand shocks, uncertainty, and long-term structural change.

It includes:

- reduced exposure to input and output price volatility,
- more predictable cash flows,
- risk diversification across multiple activities,
- improved ability to absorb external shocks (energy, prices, regulation).

This dimension is particularly relevant for policy evaluation, as it connects the bioeconomy with broader EU objectives related to farm resilience, income stability, and sustainable rural development. The proposed model does not assess these dimensions in isolation but as an interconnected system of economic effects. Bioeconomic activities may increase both costs and revenues, strain cash flow in the short term, yet enhance long-term stability. The model therefore captures these trade-offs and presents results in a way suitable for both analytical and policy use.

This structure provides the basis for developing specific indicators, which are outlined in the following subsection.

A.1.3 Indicators and Model Calculation Logic

Based on the defined economic dimensions, this subsection presents a **set of indicators and the calculation logic** used to quantify the economic impacts of bioeconomic activities at the farm level. The aim is not to build a complex econometric model, but to provide a transparent, replicable, and data-efficient framework that enables comparable estimates across different farm types, regions, and bioeconomic activities.

The main output is the change in the farm's economic performance, disaggregated into components corresponding to the economic dimensions defined in Section 4.3.

A.1.3.1 Basic Calculation Structure

The model is based on comparing the farm's annual economic balance under two scenarios (a reference scenario without the assessed bioeconomic activity, a bioeconomy scenario in which a specific activity or combination of activities is implemented). The economic impact is expressed as the net annual change in economic performance, calculated as the sum of:

- changes in operating costs,
- changes in revenues,

- annualized investment costs[9],
- relevant subsidies or support payments.

This approach captures both direct financial effects and structural changes in farm management.

A.1.3.2 Cost Indicators

Cost dimension indicators capture changes in farm operating costs resulting from bioeconomic activities, focusing on items where adjustments can realistically be expected.

Core indicators include:

- changes in energy costs (fuel, electricity, heat),
- changes in fertilizer and soil input costs,
- changes in feed costs,
- changes in waste and by-product management costs,
- changes in other operating costs linked to the bioeconomic activity.

Calculations are based on the difference between costs in the reference and bioeconomy scenarios. Where precise data are unavailable, the model allows the use of standard technical coefficients, reference prices, or interval estimates, provided that all assumptions are explicitly stated.

A.1.3.3 Revenue Indicators

The revenue dimension captures new or modified income streams resulting from bioeconomic activities, focusing on revenues that would not arise, or would arise differently, in the reference scenario.

It includes:

- revenues from the sale of energy, bio-based products, or intermediates,
- income from by-products and residue valorisation,
- payments and subsidies directly linked to bioeconomic activities.

The model clearly separates market revenues from public support to assess the economic viability of bioeconomic activities independently of policy incentives or under changing policy conditions.

A.1.3.4 Accounting for Investment Costs

Bioeconomic activities often require additional **investments in technology, infrastructure, or organizational changes**. To ensure comparability with annual operating effects, investment costs are incorporated as annual equivalents. This includes depreciation of investments, related operating and maintenance costs, where relevant, and simplified annual capital costs.

This approach enables comparison across farms with different investment structures and avoids bias in favour of capital-intensive solutions.

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[9] Annualised investment costs convert a one-time investment into a yearly cost using depreciation or annuity formulas.

A.1.3.5 Composite Indicator of Economic Impact

The final output is a **composite indicator**[10] expressing the annual change in the farm's economic performance resulting from bioeconomic activities. It can be presented in absolute terms (e.g. EUR/farm/year), normalized per hectare, unit of output, or labour unit, disaggregated by economic dimension for interpretation. The composite indicator is not a standalone decision tool, but a synthetic summary of interconnected economic effects that must be interpreted in the context of farm structure and regional conditions. The model acknowledges significant differences in data availability across farms and Member States. It therefore allows the use of interval values instead of point estimates, a scenario approach (conservative – baseline – optimistic), and transparent documentation of assumptions. Uncertainty cannot be eliminated, but it can be made explicit and manageable, which is essential for sound policy interpretation.

A.2 ECONOMETRIC EVIDENCE ON THE ECONOMIC IMPACTS OF BIOECONOMY ENGAGEMENT

A.2.1 Data and Panel Structure

The empirical analysis draws on the Farm Sustainability Data Network (FSDN) Standard Results database published by the EC. Rather than individual farm records, the dataset contains aggregated observations, with each unit representing an average farm across a specific combination of country, region, farming type, and economic size class.

The panel spans 2018–2023, with the cross-sectional dimension defined by FSDN categories based on Member State, region, one of 14 Types of Farming, and Economic Size class. The United Kingdom is retained in the sample, as FSDN reporting for UK farm groups continued throughout the covered period.

The explanatory variable captures farm involvement in bioeconomy-related activities through the share of Other Gainful Activities (OGA) in total farm output. OGA encompasses non-primary income sources recorded under *SE700*, including processing of animal products (*SE705*) and crops (*SE710*), forestry (*SE715*), contract work (*SE720*), agritourism (*SE725*), and other on-farm activities (*SE730*). Since these activities typically draw on agricultural resources, capital, or by-products, OGA output serves as a proxy for farm diversification and integration into biomass-based value chains.

In addition to the OGA-based measure, an alternative composite index of bioeconomy engagement was explored. A composite index of bioeconomy engagement was constructed by combining indicators of diversification (OGA share), processing activities (SE705, SE710), and input intensity such as fertilizer (SE295) and energy (SE345), both expressed per hectare. Input intensity indicators, fertilizer and energy, were reverse-coded, since lower input use is associated with higher bioeconomy engagement. All variables were normalised using min–max scaling and aggregated with equal weights. Alternatively, z-score normalization can be applied. However, the results appear sensitive to the choice of normalisation and weighting scheme, leading to potentially unstable and difficult-to-interpret estimates. For this reason, the analysis focuses on OGA share as the main explanatory variable.

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[10] A composite indicator aggregates multiple economic effects, such as costs, revenues, value added and stability, into a single summary metric.

While it represents a partial measure of bioeconomy engagement, it is directly observed in the dataand thus provides a more transparent, robust, and interpretable proxy for on-farm diversification activities.

The analysis focuses on the main dimensions of economic performance: income levels, cost efficiency, and income stability.

Farm economic performance is assessed along three dimensions. Income per hectare relates Farm Net Income (*SE420*) to utilized agricultural area *(SE025*).

Cost efficiency is measured as the ratio of intermediate consumption (*SE275*) to total output (*SE131*).

Income stability is captured by the coefficient of variation (CV) of Farm Net Income computed for each farm group over the observation period. The CV normalizes dispersion relative to the mean, enabling comparisons of income volatility across farm groups with differing income levels. Three separate econometric models are estimated, one for each performance dimension.

To evaluate the economic implications of OGA engagement, three separate econometric models are estimated, each using one of the above performance indicators as the dependent variable.

This approach allows the effect of OGA share to be quantified across distinct dimensions of farm performance – income generation, cost efficiency, and income stability.

To obtain unbiased estimates of the OGA share effect, each model includes control variables addressing potential omitted variable bias. These account for systematic differences in farm size, labour intensity, capital endowment, and subsidy receipts, thereby isolating the partial effect of OGA share on representative farm performance. Table A3 provides an overview of variables and their FSDN-based definitions.

Table A3: Variable Definitions and FSDN Components

Variable	**Calculation**
OGA_share	*SE700 / SE131*
Income_per_ha	*SE420 / SE025*
Cost_ratio	*SE275 / SE131*
Income_cv	*σ(SE420) / μ(SE420)*
UAA	*SE025*
Labour	*SE010*
Depreciation per hectare	*SE360 / SE025*
Subsidies per hectare	*SE605 / SE025*

Source: Own calculations based on FSDN data

The raw FSDN dataset for the defined period contains 82 218 observations. Prior to analysis, the following cleaning steps were applied:

Missing values for variables (farm income, total output, subsidies) were removed, reducing the sample to 20 541 observations. Aggregated EU-level entries (EU27_2020, EU-28) were excluded, leaving 8 228 observations. Panel units observed for fewer than three years were dropped to ensure sufficient within-unit variation for fixed effects estimation and a small number of observations with negative or implausible values for output, UAA, and derived per-hectare indicators were removed (7 808 observations).

Logarithmic transformations were applied to income and structural control variables to address right-skewed distributions, allow approximate percentage interpretation of coefficients, and capture potential non-linearities. Observations with non-positive income were excluded as logarithmic transformation requires strictly positive values. For subsidies, the transformation was applied as log(subsidies_per_ha + 1) to retain zero-subsidy observations. The final analytical sample comprises **7 659 observations**.

A.2.2 Descriptive Analysis of Variables

Table A4 reports summary statistics of the main dependent variables used in the analysis before the logarithm transformation is applied. The statistics include the mean, standard deviation, and selected percentiles.

Table A4: Summary Statistics for Explained Variables

	mean	std	min	25%	50%	75%	max
income_per_ha	1,827.42	4,769.16	0.1	363.39	692.24	1,497.21	21,5199.8
cost_ratio	0.6	0.18	0.11	0.48	0.61	0.72	1.77
income_cv	0.35	0.2	0.01	0.2	0.31	0.45	1.25

Source: Own calculations based on FSDN data

Table A5 focuses on control variables.

Table A5: Summary Statistics for Control Variables

	mean	std	min	25%	50%	75%	max
uaa	97.46	210.15	0.6	14.5	39.8	95.6	1,938.50
labour	2.6	4.11	0.2	1.22	1.66	2.3	52.19
subsidies_per_ha	509.02	751.62	0.00	282.40	382.88	526.84	15,654.21
depreciation_per_ha	497.27	978.87	1.02	146.75	256.72	482.51	25,148.27

Source: Own calculations based on FSDN data

The summary statistics suggest that several variables have skewed distributions. In particular, variables such as income_per_ha show strong right skewness due to very large maximum values, while some variables appear to be moderately left-skewed.

Table A6 reports summary statistics for OGA share and output per hectare. The average OGA share is **5.3%**, with values ranging from 0 to 78.6%. The distribution is highly right-skewed, as indicated by the relatively low median (2%) compared to the mean. Thus, the majority of farms exhibit relatively low levels of OGA activity.

Table A6: OGA Share Descriptive Statistics

	mean	std	min	25%	50%	75%	max
oga_share	0.053	0.087	0	0.001	0.020	0.066	0.786
output_per_ha	5,825	17,690	205	1,148	2,015	4,374	593,667

Source: Own calculations based on FSDN data

Table A7 presents farm characteristics by OGA share category. Nearly half of the representative farms fall into the low OGA share category (0–5%), while farms with an OGA share above 20% represent only 6% of the sample. Around 20% of farms report no OGA output at all. Descriptively, farms with higher OGA shares tend to have lower output and income per hectare and larger agricultural area. The following section examines these patterns using panel data methods, controlling for other farm characteristics.

Table A7: Farm Characteristics by OGA Share Category

OGA group	OGA share	*N*	Share of sample (%)	Output per ha (mean)	Output per ha (median)	Income per ha (mean)	Income per ha (median)	Average UAA (ha)	Average OGA share
none	0%	1581	20.60%	6,889	1,738	2,626	830	76	0
low	(0%, 5%]	3739	48.80%	6,546	2,204	1,886	731	78	0.02

medium	(5%, 20%]	1863	24.30%	4,076	1,932	1,225	541	149	0.1
high	>20%	476	6.20%	3,481	1,965	1,073	606	119	0.32

Source: Own calculations based on FSDN data

The correlation matrix (Table A8) shows no substantial linear associations among the explanatory variables, suggesting multicollinearity is not a concern.

Table A8: Correlation Matrix between Explanatory Variables

	oga_share	**log_uaa**	**log_labour**	**log_subsidies_per_ha**	**log_depreciation_per_ha**
oga_share	1.000	0.094	-0.019	0.114	0.081
log_uaa	0.094	1.000	0.485	-0.235	-0.396
log_labour	-0.019	0.485	1.000	0.001	0.194
log_subsidies_per_ha	0.114	-0.235	0.001	1.000	0.398
log_depreciation_per_ha	0.081	-0.396	0.194	0.398	1.000

Source: Own calculations based on FSDN data

A.2.3 Modelling Methodology

This section describes the econometric framework used to analyse the relationship between bioeconomy engagement and farm economic performance. The dataset has a panel structure, where i denotes the farm representant defined by the combination of Member State, region, type of farming and economic size. The index t denotes the year.

A.2.3.1 Panel Models

To control for unobserved farm-specific heterogeneity and common time shocks, a two-way fixed effects model is estimated:

$$f(y_{it}) = \beta_0 + \beta_1 OGA\_share_{it} + \ln{(X_{it})'}\beta + \alpha_i + \tau_t + \varepsilon_{it} \tag{1}$$

where $f(y_{it})$ is the dependent variable, logarithm of income per hectare or cost ratio already in levels, α_i absorbs time-invariant farm heterogeneity, and τ_t captures common time shocks. The control vector X_{it} includes UAA, labour, depreciation per hectare, and subsidies per hectare. To account for potential nonlinear relationships, the model is estimated using logarithmic transformations of variables expressed in absolute values.

A random effects model is also estimated, replacing fixed farm effects with a random component u_i.

$$f(y_{it}) = \beta_0 + \beta_1 OGA\_share_{it} + ln(X_{it})'\,\beta + u_i + \varepsilon_{it} \tag{2}$$

where u_i represents the random individual effect. To determine whether fixed or random effects are more appropriate, the Hausman test is applied.

To relax the strict exogeneity assumption of the RE estimator, the **Mundlak correction** further augments the model with within-group means of all time-varying regressors:

$$f(y_{it}) = \beta_0 + \beta_1 OGA\_share_{it} + ln(X_{it})'\,\beta + \gamma_1 \overline{OGA\_share}_i + ln(\bar{X}_i)'\,\gamma + u_i + \varepsilon_{it} \tag{3}$$

A joint Wald test of $\gamma_1 = \gamma = 0$serves as a diagnostic equivalent to the Hausman test. If the null hypothesis is rejected, the correlated random effects model following Mundlak provides a consistent alternative.

All panel models are estimated with standard errors clustered at the representative farm level and weighted by the number of farms represented (*SYS02*).

A.2.3.2 Cross-Sectional Regression Model

Income CV is computed over the time dimension for each representative farm and therefore has no within-unit variation. It is estimated using a cross-sectional WLS model with HC3 robust standard errors to ensure robust inference in the presence of potential heteroscedasticity:

$$CV_i = \beta_0 + \beta_1 OGA\_share_i + ln(X_i)'\,\beta + \sum_j D'_{ij}\,\gamma_j + \varepsilon_i \tag{4}$$

where D_{ij} is a vector of dummy variables capturing categorical farm characteristics (e.g. farm type, size class, etc.).

A.2.3.3 Models Specification

Three dependent variables are analyzed. For the first two, panel data models are estimated – the baseline specification follows a two-way fixed effects framework, with robustness checks using random effects and the Mundlak correction. The third model, explaining income variability, is estimated as a weighted least squares cross-sectional model. The equations below present the baseline specifications including all control variables.

Income Model

Farm income performance is measured as the logarithm of farm net income per hectare:

$$\begin{aligned}\ln(Income\_per\_ha_{it}) \\ &= \beta_0 + \beta_1 OGA\_share_{it} + \beta_2 \ln(UAA_{it}) \\ &+ \beta_3 \ln(Labour_{it}) + \beta_4 \ln(Subsidies\_per\_ha_{it}) \\ &+ \beta_5 \ln(Depreciation\_per\_ha_{it}) + \alpha_i + \tau_t + \varepsilon_{it}\end{aligned} \tag{5}$$

Cost Ratio Model

Cost efficiency is measured as the ratio of intermediate consumption to total output:

$$\begin{aligned}CostRatio_{it} &= \beta_0 + \beta_1 OGA\_share_{it} + \beta_2 \ln(UAA_{it}) \\ &+ \beta_3 \ln(Labour_{it}) + \beta_4 \ln(Depreciation\_per\_ha_{it}) + \alpha_i + \tau_t + \varepsilon_{it}\end{aligned} \tag{6}$$

Income Variability Model

Income variability is measured as the coefficient of variation of farm net income across the observed time period.

$$\begin{aligned}CV_i &= \beta_0 + \beta_1 OGA\_share_i + \beta_2 \ln(UAA_i) + \beta_3 \ln(Labour_i) + \beta_4 \ln(Subsidies\_per\_ha_i) \\ &+ \beta_5 \ln(Depreciation\_per\_ha_i) + \gamma_k FarmType_k + \delta_k EconomicSize_k + \varepsilon_i\end{aligned} \tag{7}$$

A.2.3.4 Interpretation of Estimates for OGA Share

Since OGA share is expressed as a relative value on the scale 0–1, an increase of 1 unit would represent a 100 percentage point increase. That is an unrealistic scenario given the observed distribution of the variable, where the mean value reaches 0.05. All **interpretations are therefore based on a 1 percentage point increase in OGA share** ($\Delta = 0.01$), and the reported marginal effects are calculated accordingly as $\beta \times 0.01$. For dependent variables expressed in logarithms, such as log(income_per_ha), the percentage change in the dependent variable associated with a 1 percentage point increase in OGA share is calculated as: (e^(β × 0.01) – 1) × 100 %. For dependent variables expressed in levels, such as cost_ratio, profit_margin or income_cv, the interpretation is linear and the change in the dependent variable associated with a 1 percentage point increase in OGA share is calculated directly as: $\beta \times 0.01$.

A.2.4 Modelling Results

A.2.4.1 Income Model

The model estimates the effect of OGA share on farm income per hectare, controlling for UAA, labour, subsidies per hectare, and depreciation per hectare. A random effects model is estimated too and validated using the Hausman test. Results are reported in Table A9.

Table A9: Fixed Effect and Random Effects Model Comparison – Income Model

	FE model	**RE model**
Dependent variable	log_income_per_ha	log_income_per_ha
No. of observations	7,659	7,659
***R*-squared**	0.0563	0.9695
***R*-squared (Within)**	0.0507	–0.1160
***R*-squared (Between)**	–1.6529	0.9860
***R*-squared (Overall)**	–1.6460	0.9815
***F*-statistic**	74.0949	48,577.3952
***p*-value (*F*-stat)**	0.0000	0.0000
Log-likelihood	–3271.6619	–7237.8485

	FE model			***RE model***		
Variable	**FE coef.**	**Std. error**	***p*-value**	**RE coef.**	**Std. error**	***p*-value**
oga_share	0.1697	0.3336	0.6109	–1.8961***	0.3929	0.0000
log_uaa	–1.1417***	0.1327	0.0000	–0.0891*	0.0456	0.0506
log_labour	0.2822*	0.1633	0.0841	0.1485	0.1403	0.2897
log_subsidies_per_ha	0.0599	0.0431	0.1648	0.5681***	0.0857	0.0000
log_depreciation_per_ha	–0.2086***	0.0791	0.0084	0.5933***	0.0887	0.0000

Test	**Statistic**	***p*-value**
***F*-test Poolability**	17.3849***	0.0000
Hausman test	245.2493***	0.0000

Significance: *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$
Source: Own calculations based on FSDN data

The two-way fixed effects model is jointly significant ($F = 20.43$, $p < 0.001$), but within-R^2 is only 5.07%, reflecting limited within-farm variation in the dependent variable. The core identification problem is that OGA share exhibits near-zero within-farm variance over time (mean variance 0.00128, median 0.000096), leaving the FE estimator with insufficient variation to identify the OGA effect reliably. The OGA share coefficient is accordingly insignificant under FE.

The poolability test rejects pooling ($F = 17.385$, $p < 0.001$), confirming the presence of unobserved farm-level heterogeneity. The RE model yields a substantially higher R^2 (97%) with a negative and significant OGA share coefficient, but the Hausman test strongly rejects the assumption of uncorrelated individual effects ($p < 0.001$), rendering the RE estimator inconsistent.

Since FE cannot exploit between-farm variation, where most of the OGA variation resides, neither standard estimator is fully adequate, motivating the Mundlak correction.

Mundlak-corrected Random Effects Estimator

The Mundlak correction addresses this limitation by augmenting the RE model with farm-level means of all time-varying regressors, directly accounting for the correlation between individual effects and the regressors. Unlike standard FE, it retains between-farm variation and therefore exploits the dimension where OGA share varies most. Results are reported in Table A10.

Table A10: RE Mundlak Estimator for Income Model

	Mundlak RE Model
Dependent variable	log_income_per_ha
No. of observations	7,659
***R*-squared**	0.9719
***R*-squared (Within)**	0.0539
***R*-squared (Between)**	0.9861
***R*-squared (Overall)**	0.9823
***F*-statistic**	26,452.3248
***p*-value (*F*-stat)**	0.0000
Log-likelihood	–6919.4770

Variable	**Parameter**	**Std. Err.**	***T*-stat**	***p*-value**
oga_share	–0.4581	0.3464	–1.3224	0.1861
log_uaa	–1.1312	0.1133	–9.9846	0.0000***
log_labour	0.3254	0.1631	1.9946	0.0461**
log_subsidies_per_ha	0.1442	0.0488	2.9567	0.0031***
log_depreciation_per_ha	–0.1893	0.0705	–2.6845	0.0073***
oga_share_mean	–1.8844	0.7394	–2.5486	0.0108**
log_uaa_mean	1.0284	0.1216	8.4571	0.0000***
log_labour_mean	–0.1721	0.2126	–0.8097	0.4182
log_subsidies_per_ha_mean	0.4154	0.0934	4.4482	0.0000***
log_depreciation_per_ha_mean	0.8035	0.1287	6.2437	0.0000***

Significance: *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$
Source: Own calculations based on FSDN data

The Wald test confirms joint significance of all farm-group mean terms ($\chi^2(5) = 275.4$, $p < 0.001$), validating the Mundlak correction. Overall R^2 reaches 97.2% and between R^2 98.6%, reflecting strong fit across representative farms. Within R^2 remains modest (5.4%), consistent with limited year-to-year variation documented above. The majority of regressors are significant at the 5% or 1% level.

OGA Effect on Income per Hectare

The within-farm coefficient on OGA share is insignificant (–0.458, $p = 0.186$). In years farm income per hectare does not change significantly. Short-run fluctuations in OGA engagement have no measurable effect on income per hectare changes. This association is not statistically significant, consistent with the very limited within variation in the data.

The between-farm coefficient is negative and significant (–1.884, $p = 0.011$). Representative farms with a **structurally higher average OGA share exhibit significantly lower income per hectare.** A 1 percentage point increase in average OGA share is associated with approximately 1.9% lower farm income per hectare (calculated as (e^(–1.884 × 0.01) – 1) × 100 ≈ –1.87%).

Taken together, these results suggest that **OGA engagement is primarily a structural characteristic of farm organisation rather than a short-run margin of adjustment**. Its effect on farm income is only detectable at the level of persistent differences across representative farms, not in year-to-year fluctuations within them.

Control Groups Effect on Income per Hectare

Table A10 also reveals contrasting within and between effects for the control variables. Farm size (UAA) shows diminishing returns within farms (–1.131***) but economies of scale across farms (+1.028***). Labour input contributes positively to income in the short run (+0.325***) with no significant structural effect. Subsidies are positively associated with income both within (+0.144***) and between farms (+0.415***), suggesting that policy support has a stronger persistent effect than a short-run one. Depreciation per hectare reflects higher investment costs in the short run (–0.189***) but capital-intensive farms structurally generate higher income (+0.803***), consistent with capital as a driver of long-run productivity.

Summary – Income Model

The Mundlak specification of the random effects model was used to estimate within and between representant farm stratum effects, yielding the following results.

In years when a representative farm reports a higher **OGA share relative to its own time average**, farm **income per hectare does not change significantly**. Short-run fluctuations in OGA engagement have no measurable effect on changes in income per hectare. **Representative farms with a structurally higher average OGA share exhibit significantly lower income per hectare**. A 1 percentage point increase in average OGA share is associated with approximately 1.9% lower farm income per hectare. This is a large and economically meaningful effect when considered across the observed range of OGA share in the sample, suggesting that farms with a greater structural reliance on non-agricultural activities generate substantially less agricultural income per hectare.

A.2.4.2 Cost Model

This model examines the effect of OGA share on operational efficiency, measured by the cost as the intermediate consumption relative to total output. A lower cost ratio indicates that the farm produces more output per unit of operating cost. The estimation follows the same strategy as the income model. The Fixed Effects estimator was applied first, revealing the same identification problem: the limited within-holding variation in OGA share results in an imprecise coefficient estimate. The Hausman test subsequently rejected the Random Effects estimator (*p*-value = 0.000), confirming the presence of endogeneity. The estimation results are reported in Table A11.

Table A11: Fixed Effect and Random Effects Model Comparison – Cost Model

	FE model	**RE model**
Dep. Variable	cost_ratio	cost_ratio
No. Observations	7,659	7,659
No. Entities	1,444	1,444
***R*-squared**	0.0133	0.8921
***R*-squared (Within)**	0.0148	–0.0098
***R*-squared (Between)**	0.4731	0.9316
***R*-squared (Overall)**	0.4676	0.9204
***F*-statistic**	20.9812	15,822.54
***p*-value (F-stat)**	0.0000	0.0000
Log-likelihood	10508.12	5765.25

	FE model			*RE model*		
Variable	**FE coef.**	**Std. Err.**	***p*-value**	**RE coef.**	**Std. Err.**	***p*-value**
oga_share	–0.0073	0.0596	0.9026	0.0709	0.0686	0.3012
log_uaa	0.0704***	0.0237	0.0030	0.1158***	0.0123	0.0000
log_labour	–0.0391	0.0245	0.1101	–0.1439***	0.0307	0.0000
log_depreciation_per_ha	–0.0050	0.0125	0.6907	0.0543***	0.0055	0.0000

Significance: *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$

Source: Own calculations based on FSDN data

The Wald test confirms joint significance of farm-group mean terms ($\chi^2(4) = 95.6$, $p < 0.001$), validating the Mundlak correction. Overall R^2 reaches 92% and between R^2 93%, with within R^2 remaining low as expected. Results are presented in Table A12.

Table A12: RE Mundlak Estimator for Cost Model

	Mundlak RE Model
Dep. Variable	cost_ratio
Estimator	RandomEffects
No. Observations	7,659
***R*-squared**	0.8932
***R*-squared (Within)**	0.0168
***R*-squared (Between)**	0.9316
***R*-squared (Overall)**	0.9208
***F*-statistic**	7,995.5284
***p*-value (*F*-stat)**	0.0000
Log-likelihood	5803.0921

Variable	**Parameter**	**Std. Err.**	***T*-stat**	***p*-value**
oga_share	0.0593	0.0580	1.0225	0.3066
log_uaa	0.0926	0.0218	4.2481	0.0000***
log_labour	–0.0480	0.0225	–2.1285	0.0333**
log_depreciation_per_ha	0.0052	0.0113	0.4633	0.6432
oga_share_mean	0.0206	0.1271	0.1625	0.8709
log_uaa_mean	0.0224	0.0249	0.8978	0.3693
log_labour_mean	–0.1005	0.0424	–2.3704	0.0178**
log_depreciation_per_ha_mean	0.0498	0.0133	3.7507	0.0002***

Significance: *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$

Source: Own calculations based on FSDN data

OGA Effect on Cost Ratio

Within farm effect (+0.059, *p*-value = 0.307) – insignificant:

In years when a representative farm reports a higher OGA share relative to its own time-average, the cost ratio does not change significantly. Short-run fluctuations in OGA engagement have no measurable effect on cost efficiency.

Between **farm effect (+0.021, *p*-value = 0.871) – insignificant**:

No significant structural difference in cost ratio is detected between farm groups with higher and lower average OGA share. Farm groups with higher long-term OGA shares do not show systematically different cost ratios than other farms.

Unlike the income model, **OGA engagement does not appear to be associated with cost efficiency at either the short-run or structural level,** suggesting that OGA-oriented farms operate with similar cost structures to non-OGA farms.

Control Variables Effect on Cost Ratio

Farm size (UAA) increases the cost ratio within farms (+0.093***), i.e. larger operations incur higher operating costs per unit of output in the short run. There is no significant structural counterpart. Labour intensity is the most consistent driver of cost efficiency, with a significant negative effect both within (−0.048**) and between farms (−0.101**), as labour-intensive operations substitute purchased inputs with own labour. The structural effect is approximately twice the short-run response, suggesting labour intensity is an important driver of long-run efficiency. Capital intensity shows no significant short-run effect on cost ratio, but structurally capital-intensive farms exhibit higher cost ratios (+0.0498***), consistent with complementarity between machinery and purchased inputs such as energy and maintenance.

Summary – Cost Ratio Model

Even though the income model results suggest that although OGA engagement is structurally associated with lower farm income per hectare, it does not translate into measurable differences in cost efficiency. OGA-oriented farms appear to operate with cost structures similar to those of non-OGA farms.

A.2.4.3 Income Stability Model

Income stability is measured as the coefficient of variation of farm income over 2018–2023. Since this measure is time-invariant, a cross-sectional WLS model is estimated, with all time-varying variables averaged over the observation period. Weights correspond to the number of individual farms represented by each stratum (farms_count), ensuring proportional representation of the underlying farm population. Log UAA was excluded from the final specification due to collinearity with economic size class dummies (VIF > 10); all remaining VIF values are below 10. Results are presented in Table A13.

Table A13: Cross-Section Weighted Model for Income Stability

	WLS Cross-Section Model
Dep. Variable	income_cv
No. Observations	1,443
Df Residuals	1,420
Df Model	22
***R*-squared**	0.3227
Adj. *R*-squared	0.3122
***F*-statistic**	12.7895
***p*-value (*F*-stat)**	0.0000
Log-likelihood	95.3285
AIC	−144.6570
BIC	−23.3439
Covariance Type	HC3

Variable	**Parameter**	**Std. Err.**	***T*-stat**	***p*-value**
Intercept	0.2333	0.0974	2.3953	0.0166**
Mixed crops and livestock	0.0698	0.0387	1.8064	0.0709*
Mixed livestock	0.0735	0.0389	1.8904	0.0587
Permanent crops combined	−0.0257	0.0339	−0.7580	0.4485
Specialist COP	0.2104	0.0337	6.2467	0.0000***
Specialist cattle	0.0572	0.0331	1.7248	0.0846*
Specialist granivores	0.0376	0.0445	0.8449	0.3982
Specialist horticulture	−0.1672	0.0571	−2.9287	0.0034***
Specialist milk	0.0168	0.0305	0.5511	0.5815

Specialist olives	0.0448	0.0847	0.5286	0.5971
Specialist orchards – fruits	0.0334	0.0473	0.7061	0.4801
Specialist other fieldcrops	−0.0087	0.0326	−0.2663	0.7900
Specialist sheep and goats	−0.0046	0.0358	−0.1292	0.8972
Specialist wine	−0.0577	0.0373	−1.5481	0.1216
Size class 2	−0.0903	0.0439	−2.0571	0.0397**
Size class 3	−0.1123	0.0424	−2.6475	0.0081***
Size class 4	−0.1145	0.0422	−2.7125	0.0067***
Size class 5	−0.0853	0.0443	−1.9252	0.0542*
Size class 6	−0.0201	0.0644	−0.3117	0.7553
oga_share_mean	0.2463	0.1004	2.4523	0.0142**
log_labour_mean	0.0202	0.0238	0.8468	0.3971
log_depreciation_per_ha_mean	0.0741	0.0174	4.2583	0.0000***
log_subsidies_per_ha_mean	−0.0495	0.0213	−2.3246	0.0201**

Significance: *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$

Source: Own calculations based on FSDN data

The model achieves an R^2 of 0.323, indicating that farm type, economic size class, OGA share and control variables together explain approximately 32% of the variation in income stability across farm stratum representatives and is statistically significant as a whole ($F = 12.79$, p-value = 0.000). The relatively modest R^2 is expected for a cross-sectional model of income variability, as idiosyncratic factors such as local weather conditions and regional market dynamics are not captured in the data.

Both farm size class and farm type are included as control variables and prove statistically significant in the model for several dummy variables, confirming that income instability varies systematically across farm structures and production orientations.

OGA share (+0.246**, p-value = 0.014) shows that farms with a higher share of off-farm income on total output exhibit greater income instability. **An increase in OGA share by 10 percentage points** is associated with an **increase** in the coefficient of **variation of income** by approximately **2.5 percentage points** (calculated as 0.246 × 0.10 = 0.0246; converting to percentage points: 0.0246 × 100 = 2.46 pp).

If a farm with average income of €100,000 had income fluctuations of ± 20% across years, a 10-percentage point increase in OGA share would be associated with fluctuations of ± 22.5%, meaning income swings roughly €2,500 wider in either direction. Thus, farm representatives with a higher average OGA share exhibit greater income variability.

Other Variables Effect on Income Stability

Labour intensity has no significant effect on income variability. Capital intensity increases income instability (+0.074***), i.e. higher fixed costs create operating leverage, amplifying income declines when revenues fall. Subsidies have the opposite effect (−0.0495**), stabilising income by adding a predictable revenue component that dampens market-driven fluctuations, consistent with the expected stabilising role of agricultural policy.

Summary – Income Stability Model

For income variability, a cross-sectional weighted least squares model was estimated, as the coefficient of variation is by definition a between-farm measure computed over the entire observation period. Regarding the main variable of interest, **OGA share exhibits a significant positive effect on income variability**, indicating that farms with a higher share of off-farm income on total output experience greater agricultural income instability. A 10-percentage point increase in OGA share is associated with an increase in income variability of approximately 2.5 percentage points.

This study was prepared by the Policy Department at the request of the Committee on Agriculture and Rural Development (AGRI). It examines the bioeconomy's role in future EU agriculture, focusing on promoting farms' economic sustainability. The paper analyses policy frameworks, successful circular models, and trends in biomass valorisation to identify strategies for income diversification. Finally, it provides policy options to boost bioeconomy initiatives and strengthen value chains within the European farming sector.

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