M21 July 2025

Deliverable D4.4

Methodology for innovative business models

WP4 Assessment of regulatory and economic instruments

NENUPHAR

New governance models to enhance nutrient pollution handling and nutrients recycling

Co-funded by the European Union

The project is supported by the European Union under grant agreement № 101082169. Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Document control page

Project	NENUPHAR
Project, full title	New governance models to enhance nutrient pollution handling and nutrients recycling
Project number	101082169
Project start	November 1st, 2023
Project end	April 30th, 2027
Deliverable number	D4.4
WP number and name	WP4 Assessment of regulatory and economic instruments
Document title	Methodology for innovative business models.
Version	V1
Responsible author	Mireia Carrera and Carla Febrer, UVIC – UCC
Contributors	Csaba Bálint, Enikő Zita Vigh and Krisztina Miskó, AKI Lucia Baldoni, Bárbara Palacino and Marina Cárdenas, CIRCE Ilze Kārkliņa**,** LUKA Frederick von Netzer, SIG Dārta Gātere, ZSA
Date of delivery	July 30st, 2025
Due date of deliverable	July 31st, 2025
Type	Document, Report
Language	R — Document, report
Rights	Copyright 'NENUPHAR – New governance models to enhance nutrient pollution handling and nutrients recycling'
Dissemination level	PU - Public

Disclaimer of warranties

This document has been prepared by NENUPHAR project partners as an account of work carried out within the framework of the Horizon Europe GA contract № 101082169.

Neither Project Coordinator, nor any signatory party of NENUPHAR Project Consortium Agreement, nor any person acting on behalf of any of them:

- makes any warranty or representation whatsoever, express or implied,
    - with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or
    - that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or
    - that this document is suitable to any particular user's circumstance; or
- assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if Project Coordinator or any representative of a signatory party of the NENUPHAR Project Consortium Agreement has been advised of the possibility of such damages) resulting from your selection or use of this document or any information, apparatus, method, process, or similar item disclosed in this document.

This project is supported by the European Union and its members under grant agreement № 101082169.

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

VERSION RECORD			
Version	Name (Partner)	Description of changes	Date
ToC	**UVIC-UCC**	Proposed table of contents	March 13th, 2025
V0.a	**UVIC-UCC**	First Draft	July 27th, 2025
V0.b.	**CIRCE, AKI, SIG**	Reviews and validation of contents	July 10th, 2025
V1.a.	**UVIC-UCC**	Second Draft	July 28th, 2025
V1.b	**CIRCE**	Second review	Add
V1.c	**UVIC-UCC**	Final V1 for submission	Add

VALIDATION	
Authors	Reviewers
Mireia Carrera and Carla Febrer (UVIC – UCC)	Bárbara Palacino, Lucia Baldoni and Marina Cárdenas (CIRCE) Krisztina Miskó (AKI) Frederick von Netzer (SIG)

Executive summary

The NENUPHAR Deliverable 4.4 presents a comprehensive framework to design and implement innovative circular business models in the context of nutrient recovery from waste streams, with a focus on biobased fertilizers. The deliverable examines the shift from linear to circular systems in fertilizer production, highlighting the potential of waste streams such as pig slurry, dairy wastewater, and sewage sludge as valuable resources. It includes a market analysis of biobased fertilizers, assesses the environmental, economic and social impacts of the current linear fertilizer production, and identifies where value can be added in circular business models. Key strategies and actors for enabling the transition are outlined, together with the barriers that must be addressed, and the deliverable proposes relevant economic indicators for evaluating profitability and long-term viability. Findings are used to propose a sequential methodology to ease the transition to and development of circular business models.

The findings underscore that both the supply and demand sides of the market must be considered for establishing long-term, sustainable and stable circular business models of biobased fertilizers from waste, particularly the role of farmers as end-users in emerging bioeconomy value chains, as consumer acceptance is key in new markets.

The analysis also explores key risks, scaling challenges, and the types of policy and financing support needed for the transition. By identifying critical barriers and enabling factors, this deliverable lays the ground for regionally adapted, economically viable, and socially accepted circular business models that align with the European Green Deal and circular bioeconomy strategies.

The conclusions point to a systemic and collaborative approach for the transition to work and be implemented in a fair way for all stakeholders, but specifically the local agents involved in the different value chains. By identifying enabling conditions and potential barriers, this deliverable contributes to the development of circular business models that can be economically viable but also locally adapted and socially inclusive. It emphasises that successful circular transitions rely as much on collaboration, regional engagement and acceptance as they do on technological solutions.

Table of contents

List of abbreviations and acronyms

CA – Consortium Agreement

CAGR – Compound Annual Growth Rate

CAP – Common Agricultural Policy

CAPEX – Capital Expenditures

CDTI - Centro para el Desarrollo Tecnológico y la Innovación

CoM – Community of Members

CSR – Corporate Social Responsibility

CSRD - Corporate Social Responsibility Directive

D – Deliverable

EC – European Commission

EEA – European Environment Agency

EGD – European Green Deal

EMAS – Eco-management and Audit Scheme

ESG – Environmental, Social and Governance

GA – General Assembly

GRI – Global Reporting Initiative

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

IRR – Internal Rate of Return

LCA – Life Cycle Analysis

NENUPHAR- New governance models to enhance nutrient pollution handling and nutrients recycling

NPV – Net Present Value

OEF – Organizational Environmental Footprint

OPEX – Operational Expenditures

PC – Project Coordinator

PEF – Product Environmental Footprint

RIVs - Regional Innovation Valleys

RIV4BFS - Regional Innovation Valleys for Bioeconomy and Food Systems

ROI – Return on Interest

SBTN – Science Based Target Network

SMEs – Small and medium enterprises

TBL – Triple Bottom Line

TNFD - Taskforce on Nature-related Financial Disclosures

WP – Work package

Index of figures

Index of tables

Index of equations

1. Introduction

Transitioning from the business-as-usual linear way of doing things in the agricultural sector, where resources are extensively used but all waste produced is discarded, to circular approaches is becoming increasingly important. However, this shift must be economically viable, socially just, and environmentally impactful. A holistic approach to value creation in these new recovery streams is crucial.

Following on Tasks 4.1, 4.2, and 4.3 of the NENUPHAR project, which looked at regulatory and financial instruments for the management to build resilient and sustainable value chains for nutrient recovery, this deliverable focuses on the important factors to achieve sustainable circular business models at the long-term. The aim is to understand how practical systems can be built to turn waste into valuable products, and how these systems can become both economically viable and scalable.

The European Commission has been prioritizing the transition to circularity for quite some time, but there is still a big gap between policy and practices in the agricultural sector. Circular business models must bridge this gap, translating innovation and technological potential for nutrient recovery into specific market activities, business infrastructure, and sustainable income value chains.

The identified waste streams in NENUPHAR, pig slurry, dairy wastewaters, and sewage sludge represent underused sources of nutrients that can replace mineral fertilizers, reduce environmental impacts, and decrease the costs associated with waste management. By integrating these materials, which are regarded as waste and a burden in linear systems, into new circular product cycles, they also create opportunities for revenue generation and energy recovery.

Moreover, these models promote integration across different sectors, as the cascading use of biomass increases value creation and supports regional bioeconomy's. In doing so, jobs are created, and rural areas' economic resilience and autonomy are increased while contributing to climate and sustainability goals.

This deliverable focuses on identifying and analysing the types of business models that capture these opportunities. It explores value creation, cost structures, revenue mechanisms, and stakeholder roles in circular business models, together with the risks and potential needs of this transition. The inputs and conclusions regarding financial tools in the European context from deliverables 2.3, 4.1, 4.2 and 4.3 are used for the governance, financial and regulatory definition of transitioning to circular business models. A general methodology provides the foundation for strategies that can enable the local transition from linear to circular strategy, developing the emerging market for biobased fertilizer derived from waste.

2. Market analysis of nitrogen and phosphorus products in the EU

2.a Market overview

Fertilizers are particularly important for sustaining high agricultural output while adhering to environmental regulations that promote sustainable farming practices. The growth of this segment is driven by the high demand for high-yielding and consistent crop production to meet global food demand (FAO, 2024). The European Union has been focusing on the efficient and responsible use of fertilizers to ensure global food security, promoting eco-friendly alternatives to the current model to reduce environmental impact.

Nitrogen and phosphorus are two of the most essential fertilizers for modern agriculture. However, their overuse can lead to significant environmental issues, making their processing and application an issue to achieve responsible and sustainable agricultural practices.

Phosphorus based fertilizers

Current agricultural uses phosphorus derived from phosphate rock, a non-renewable resource estimated to be depleted in 50-100 years. Phosphorus demand is expected to increase, while the quality of the reserves decreases, and extraction and production becomes more expensive. Apart from the environmental issues caused by its extraction, it is also an energy intensive process, with around 39% of the embodied energy in phosphate fertilizers associated with the energy used in their processing (Daramola & Hatzell, 2023).

Morocco currently holds around 70% of the world's resources, and together with Russia, China, Saudi Arabia and the USA, they hold two-thirds of global production (Chojnacka et al., 2020). Global exports of phosphorus fertilizers decreased by 17 % between 2021 and 2022, highlighting the impact of geopolitical tensions, supply chain disruptions and policy changes on the global fertilizer market (FAO, 2024). Although the use of phosphorus is already becoming more efficient, as farmers are trying to avoid over-fertilization and looking for new practices, such as plough the soil with straw or the use of animal manure, looking for new sources of phosphorus is crucial to sustain global food security.

Nitrogen-based fertilizers

Nitrogen used for fertilizer production is taken from the air and refined to ammonia and nitric acid. This process is quite energy-intensive, with 10% of the embodied energy in nitrogenous fertilizers being associated with the energy used in the process, with most of this energy consumption related to a steam generation process required to produce hydrogen from natural gas. In the case of granular nitrogen, most of the process energy is associated with urea production, which supplies 74% of the solid synthesised nitrogen (Daramola & Hatzell, 2023).

In the nitrogen fertilizer market, Russia, China, Qatar, Saudi Arabia and the United States accounted for 46% of global nitrogen exports in 2022, with Russia holding the largest share with 16% of the total. This highlights the decrease in nitrogen-based fertilizers in 2022, as the Ukraine conflict disrupted the value chain for natural gas (FAO, 2024).

2.a.1 Global market trends and value

Global demand for food is rising due to increases in population and a shift in dietary patterns, particularly in emerging markets. This surge in demand puts pressure on the agricultural sector to increase productivity and maximize crop yields, with fertilizers playing a key role in this process, to improve soil fertility and reach high levels of agricultural output.

Additionally, the depletion of soil nutrients because of exposure to harmful chemicals from pesticides has contributed to declining agricultural productivity, also increasing the need for fertilizers to replenish soil health and support sustainable farming practices (Spherical Insights, 2022). The adoption of innovative technologies in the agricultural sector is also disrupting the fertilizer market. As precision is enhanced through predictive analytics, monitoring and automation, increasing crop productivity and reducing the impact, fertilizer use decreases (Research and Markets, 2025).

The global market of fertilizers accounted for 191.41 bn EUR in 2024 and is projected to reach around 254.77 bn EUR in 2032, expanding at a Compound Annual Growth Rate (CAGR) of 2.9% in this period (Spherical Insights, 2022). The Asia Pacific and Africa regions are the largest consumers of fertilizers, due to population numbers and a shift to modern agricultural practices (Precedence Research, 2024).

Biobased fertilizers compete with chemical/mineral fertilizers, which are still cheaper and more accessible while having a higher market value. Mineral fertilizers have a fast-acting quality and can be formulated to fulfil the specific needs of individual plant species. Additionally, these fertilizers are simple to use because they come in a variety of forms, including dry granules, liquid concentrates, and powders that dissolve in water. Biobased products are emerging due to the global pressure to convert wastes, such as agricultural waste, food waste, wastewater, and sewage sludge, to potential nutrient-rich sources (Kurniawati et al., 2023).

The global mineral fertilizers market size was 192.26 bn EUR in 2024, clearly surpassing the biobased fertilizer market, as can be seen in Figure 1. It is projected to grow at a 2.55% CAGR and reach a value of 247.24 bn EUR in 2034 (Precedence Research, 2024). In terms of quantities, between 2002 and 2022, global use of mineral fertilizer per hectare of cropland increased from 90 to 113 kg, showing a shift toward more intensive farming. At the same time, the use of inorganic fertilizer relative to the value of agricultural production declined from 53 to 44 kg per $1000, suggesting efficiency improvements in fertilizer use. It seems that these two effects compensated each other, as fertilizer use per capita remained roughly constant at around 23 kg per capita (FAO, 2024).

The value of biobased fertilizers in the global market is estimated to be at 8.10 bn EUR in 2024 and projected to grow with a CAGR of 5.84%, reaching up to 14.28 bn EUR in 2034 (Future Market Insights, 2024). This market sector is growing due to increased awareness about sustainable agricultural practices and food origin, increased demand for organic foods, tighter regulations on the use of chemical fertilizers and concerns about soil and water pollution. The European Union and the United States are the largest organic farming communities globally, backed by a favourable regulatory framework (Research and Markets, 2025).

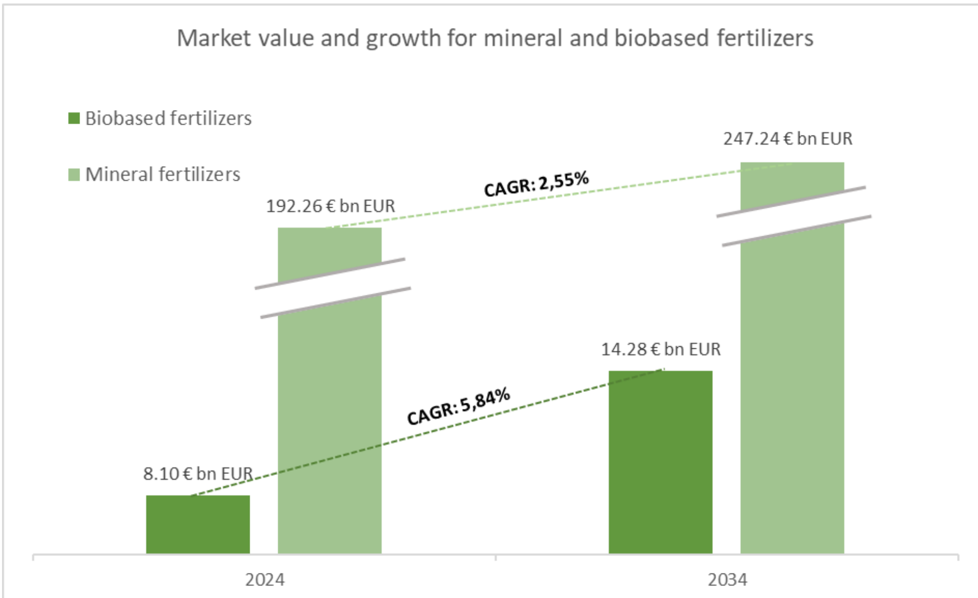

Figure 1. Market value and growth for mineral and biobased fertilizers. Source: own elaboration.

2.a.2 The European market trends and value

Mineral fertilizers

Europe is a net importer of mineral phosphate, as it lacks any reserves. Thus, apart from environmental issues, this also poses a geopolitical problem, due to the high dependence on other countries. In Europe, contrarily to the rest of the world, the quantity of inorganic fertilizer application declined between 2002 and 2022 by 9%, from 22 Mt to 20 Mt. Furthermore, in 2022, mineral fertilizer consumption in the EU experienced its biggest decline since 2009; a 16%, with a phosphorus use reduction of 21%, while nitrogen and potassium use dropped 14–16%, compared to the previous year. This decline can be explained by the energy crisis triggered by the Russian invasion of Ukraine, which severely impacted the European industry and drove natural gas prices up and disrupted the supply chain, which contributed to uncertainty and less availability. Additionally, intense droughts in Western Europe intensified the situation decreasing the demand for fertilizers from this region (FAO, 2024).

This reduction trend was already observed during the 2008 crisis. During that time, governments also restricted exports of fertilizers to ensure domestic availability, further disrupting global supply chains. Both cases highlighting the extent that economic shocks, supply chain disruptions and government policies can impact fertilizer use trends (FAO, 2024).

Consumption is currently returning to pre-war levels slowly, with an increase of 1.2% for nitrogen, 8.4% for phosphate, and 7.0% for potash fertilizer in 2024, and it is expected to keep growing. In the long term, a normalization to previous levels is forecasted. Nitrogen fertilizers consumption over the next 10 years is foreseen to reach 9.0 million tons applied to 122.1 million hectares of fertilized farmland. Phosphate and potash consumption will continue to remain below the levels recorded prior to the 2008 economic downturn, reaching respectively 2.4 and 2.6 million tons, as can be seen in Figure 2 (Fertilizers Europe, 2023).

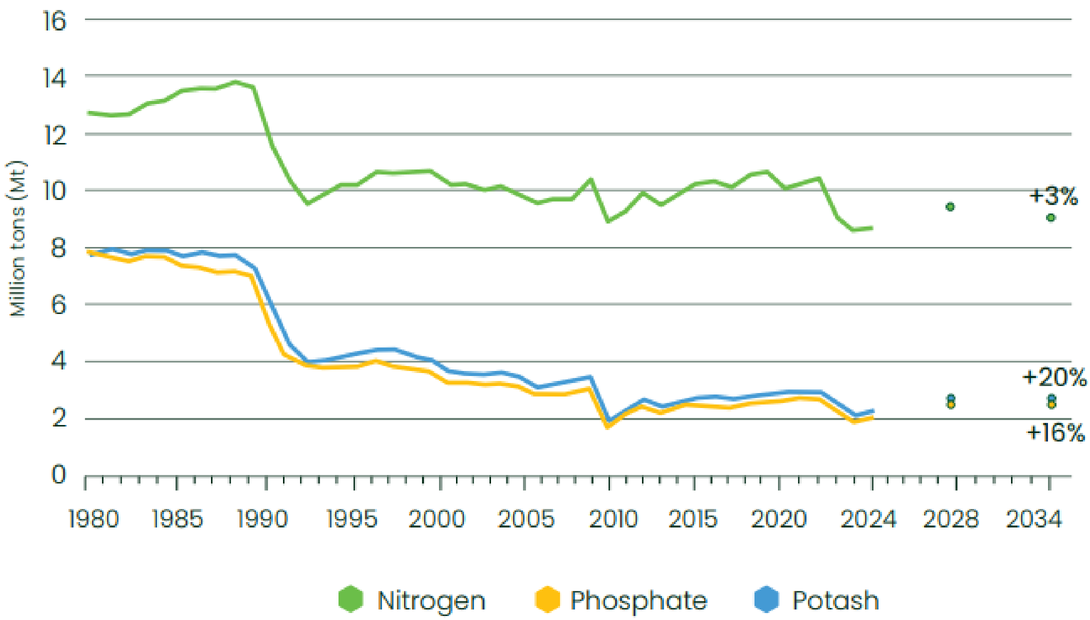

Figure 2. Forecast of mineral fertilizer use in the EU-27, the UK and Norway. Source: Fertilizers Europe, 2023

Nitrogen is leading the inorganic fertilizer market in Europe, taking 66% of the total applications, with phosphorus taking 16% of the market, and potassium fertilizers 20%, as can also be seen in Figure 3 (FAO, 2024). Differences between regions in relation to agricultural systems are also evident, with Europe showing intermediate demand for fertilizers. Africa's low fertilizer use per hectare indicates challenges in terms of access to inorganic products, while the high values in Asia and the Americas point towards the dominance of intensive agriculture and high-yielding crop systems.

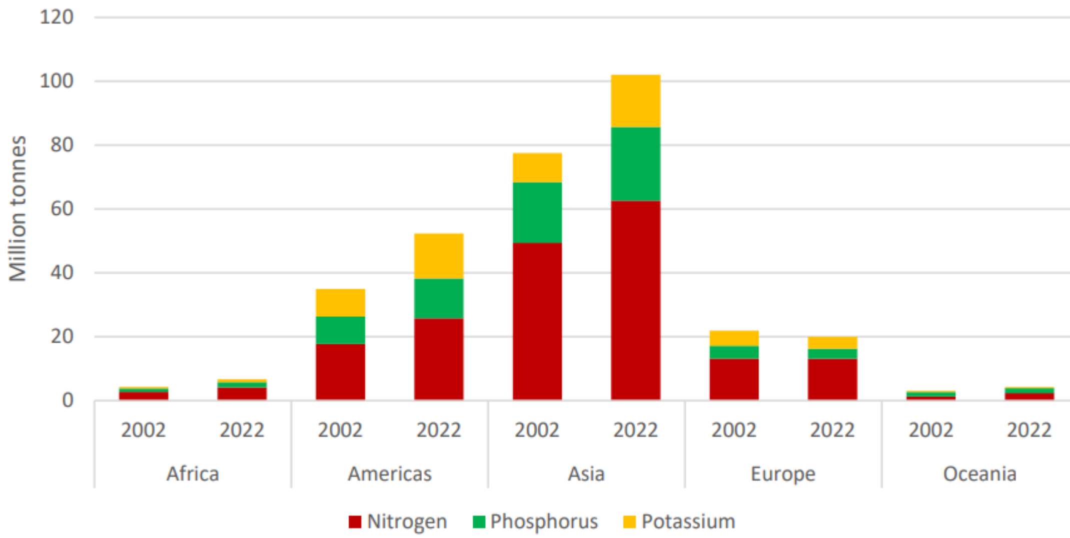

Figure 3. Inorganic fertilizers agricultural use by nutrient and region. Source: FAO, 2024

Biobased fertilizers

The general demand for fertilizers in Europe is partly being sustained by a growing consumer preference for more organic and eco-friendly products, while awareness of chemical pollution continues to rise, favouring the rise in biobased fertilizers. This shift is reinforced by government policies and regulations, which provide subsidies and incentives to farmers, accelerating demand for organic and biobased fertilizers and a transition towards more sustainable production models (Precedence Research, 2024).

In the specific case of biobased fertilizers coming from manure, the availability of organic nutrients varies significantly across Europe. This is due to differences in the number of livestock present on the national territories, with higher availability in France, Spain, Germany and the United Kingdom, which also show higher levels of consumption of these products (Fertilizers Europe, 2023).

Within biobased fertilizers, the consumption of organic fertilizers coming from livestock has been stable for the last 10 years. In 2023, as can be seen in Figure 4, a similar quantity of organic livestock-derived nitrogen was applied to European crops compared to nitrogen coming from mineral fertilizers. For phosphate, more organic derived nutrient was consumed, complementing phosphate from mineral fertilizers, and this dynamic was even more emphasized for potash (Fertilizers Europe, 2023).

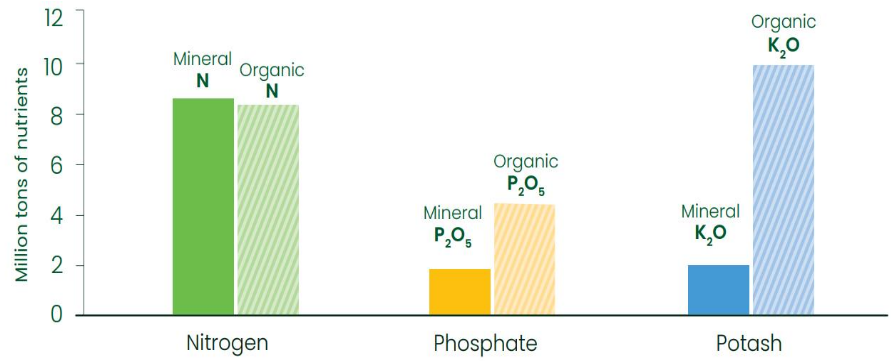

Figure 4. Mineral nutrient consumption and organic nutrient availability in 2023 in Europe. Source: Fertilizers Europe, 2023

Biofertilizers produced from urban waste are gaining popularity in the market, driven by the rise in sustainability awareness and the need for more environmentally friendly farming practices. Despite the various innovative projects focused on recycling organic waste to convert it into agricultural inputs, these types of fertilizers are still at an emerging stage, with very limited available market data.

2.b Adoption of biobased products in Europe

2.b.1 Drivers and barriers for adoption

Companies are showing increased interest in adopting biobased materials, driven by the need to meet sustainability goals and respond to growing consumer demand for environmentally friendly products. According to the 2021 European study "*Switching to Biobased Products – The Brand Owner Perspective*" (Febrer & Boy, D2.4 2025; Febrer & Boy, D4.1 2024; Gaffey et al., 2021) 75% of companies expect a strong growth in consumer demand for biobased products over the next five years, motivated by greater awareness of sustainability issues, opening opportunities for green marketing.

Market trends reflect a clear trend towards sustainable and technologically advanced solutions. However, the adoption of biobased fertilizers still faces significant challenges to reach the same level of productivity as chemical fertilizers. While biobased fertilizers contribute to soil health, they generally contain lower nutrient concentrations. Their physical and biological characteristics also make them harder to store, transport and apply, with microorganism stability posing a challenge under extreme climatic conditions or during prolonged storage periods (Kurniawati et al., 2023).

Additionally, their composition complicates large-scale production while also complying with regulations and safety levels. These challenges drive up costs and prevent social acceptance, creating a mismatch between price and expected quality among farmers, which in turn increases the barrier for adoption.

Regional differences also influence market dynamics. In continental Europe, costs and uncertain consumer demand are the biggest challenges, while in northern Europe, concerns are more focused on functionality and effectiveness. On the other hand, biobased fertilizers are often locally produced using regional resources, allowing them to be tailored to specific economic, social, and environmental conditions, which may facilitate adoption (Kurniawati et al., 2023).

Despite growing enthusiasm, high costs, functional performance and supply chain reliability of materials remain critical barriers. To achieve market penetration, significant investment in infrastructure, technological development, regulation and a greater willingness to pay for biobased solutions are essential.

However, Deliverables 4.1 and 4.2 conclude that, for now, regulation is often too rigid and, therefore, it can act as a barrier in the nutrient recovery system, as it prevents more flexible and local approaches for recycling, particularly in countries with a high agricultural production and for small farmers and producers (Febrer & Boy, D4.1, 2024; Laborda & Cebrian, D4.2, 2024). Additionally, the lack of regional legislation in some countries can also limit the ability to adapt broader policies to the local needs, reducing the effectiveness of such initiatives.

2.b.2 EU incentives – Regulatory framework

The development of biobased materials is key in the European Union's initiative to achieve a carbon-neutral, circular and pollution-free economy. The EU is continuously working on legislative developments regarding sustainability and biobased products, including processes that use waste as feedstock.

A comprehensive analysis of EU regulatory instruments and economic incentives relevant to nutrient management and recycling has been presented in Deliverable D4.1 (Febrer & Boy, D4.1, 2024). Key instruments, including the European Green Deal (EGD), the Circular Economy Action Plan, and the Farm to Fork Strategy, provide the broader policy context for the development of circular business models. These policies, however, also reveal gaps and barriers which must be addressed to enable market deployment of biobased fertilizers.

Within the EGD, the Farm to Fork Strategy and the Zero Pollution Action Plan set the goal to reduce by 50% nutrient losses from both organic and mineral fertilizers to the environment by 2030 while preserving soil fertility. This is expected to reduce fertilizer use a 20% at least, with efforts on developing an Integrated Nutrient Management Action Plan to this end (Kurniawati et al., 2023).

The farm-to-fork strategy also sets the target of having 25% of EU agricultural land under organic farming by 2030. The Common Agricultural Policy (CAP) has been developed to support this transition, providing financial support through eco-schemes, among other actions.

Strategies to reuse nutrients from waste streams also support the circular economy, backed up by the European Commission. The Circular Economy Action Plans emphasise waste management, including nutrient recovery from waste streams. They review directives on wastewater treatment and sewage sludge to prevent pollution and lessen eutrophication from agricultural nutrients. The Zero Waste Programme also emphasizes the need for strategies to increase sustainable waste management.

The Waste Framework Directive promotes the prevention of waste and regulates the collection and management of food and animal waste, as well as other nutrient-rich waste, to promote safe nutrient re-use and recycling. In Table 1, an overview of the main waste-related regulations is summarized. Materials that contain nutrients can cease to be waste and be used as fertilizing materials on agricultural land if they comply with quality requirements and conditions laid down in EU legislation (Grizzetti et al., 2023). The NENUPHAR project aims to achieve this "End-of-waste" status for the different biobased materials, so that they can be used for specific purposes while ensuring they meet safety conditions.

The fertilizing products derived from waste streams are regulated through Regulation (EU) 2019/1009 on fertilizing products, which sets limit values for nutrients in conventional fertilizers, to ensure safety, transparency and harmonization across the EU and prevent over-fertilization and nutrient pollution. According to this regulation, compost and digestion are included in substance lists allowed in the composition of fertilizers, provided they comply with the requirements (Kurniawati et al., 2023).

Table 1. Non-exhaustive list of EU legislation impacting the management of nutrient-rich waste streams. Source: own elaboration from Deliverable 4.1.

Non-exhaustive list of EU legislation impacting the management of nutrient-rich waste streams, with an emphasis on biowaste, sewage sludge, processed manure and industrial waste.
Waste Legislation framework
Directive 2008/98/EC on waste framework
Regulation 1069/2009 on materials derived from animal by-products, concerning manure and composting
Directive 91/271/EEC on wastewater treatment
Directive 1999/31/EC on the landfill of waste
Directive 2010/75/EU on industrial emissions, concerning waste incineration
Directive 2024/3019 on urban wastewater treatment
Use on land
Directive 91/676/EC on the protection of waters against pollution caused by nitrates from agricultural sources
Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture
Placing of the products on the market
Regulation 2019/1009 on making available on the EU market fertilizing products, for specific streams such as compost and digestate

The analysis presented in Deliverables 4.1 and 4.2, regarding the state of regulation in Europe and how it is affecting member states and the demo sites studied in the NENUPHAR project, outlines key barriers and gaps that prevent the effective recovery and reuse of nutrients within the EU (Febrer & Boy, D4.1, 2024; Laborda & Cebrian, D4.2, 2024). A main issue identified is the lack of integration among policies and regulations, as well as misplaced incentives for actual nutrient recovery. This absence of harmonised management rules also limits the scalability of circular practices.

Regulatory fragmentation and administrative burdens difficult the use of recovered nutrients into productive use, while strict environmental, waste and water management regulations restrict their application, particularly in agriculture.

Overall, Deliverables 4.1 and 4.2 highlight the importance of aligning and harmonisation regulation, while also taking a more market-oriented approach. Policies must ensure consistency, while also allowing for regional flexibility, together with developing stronger economic incentives and the implementation of financial mechanisms that reduce the barriers to adopting nutrient recovery technologies.

2.c Product commercialization

Understanding the market, especially pricing, is crucial to introducing new products. Given the significant investment that nutrient recovery and reuse technologies need, this is specifically true for biobased fertilizer products.

Biobased products still need time for supply chain stakeholders and downstream manufacturers to adapt their equipment and processes to gain efficiency in their product commercialisation and pricing. Moreover, successful commercialisation depends on capturing market share to scale production and reach maturity.

This is considerably easier for green products that have a direct conventional counterpart, mineral fertilizers in this case, because they can be integrated into the existing infrastructure and established markets of these alternatives. Despite this advantage, many established industries can be hesitant to invest in new materials because they have a high risk of failure, so effort from small and research companies is required to demonstrate the scalability of biobased products (Kong et al., 2019).

Using waste as an input to produce fertilizers offers multiple advantages, such as lower operating costs, less price sensitivity to raw materials, and a lower environmental footprint compared to alternative inputs. The composition, type, production process, quality, packaging and presentation influence fertilizer pricing. In Table 2, a price comparison of biobased and chemical fertilizers can be seen, confirming that biofertilizers are still not economically competitive with commercial horticulture fertilizers.

Table 2. Price comparison for biobased fertilizers and chemical fertilizers in literature. Source: own elaboration

Biobased fertilizer	Chemical/inorganic fertilizer	Source
0.8 – 1.19€/kg	0.28€/kg	(Elias et al., 2022)
1.09€/kg of fruit	0.73€/kg of fruit	(Coppens et al., 2016)

However, chemical fertilizer prices are extremely sensitive to their raw materials, which have a high market fluctuation. After the COVID-19 pandemic, fertilizer prices rose significantly due to disruptions in the global economy (with the increase in natural gas prices), as shown in Figure 5 for nitrogen-based fertilizers. Fertilizer prices have since dropped two-thirds but are still 20% higher than late-2019 levels (Tierney, 2023). Nitrogen-based fertilizer average cost decreased from 78.52€/100kg in 2022 to 34,11€/100kg in 2023, and a decreased tendency was also seen in phosphorus-containing fertilizers, which went from 71.52€/100kg in 2022 to 64.38€/100kg in 2023 (Will & Aernouts, 2024).

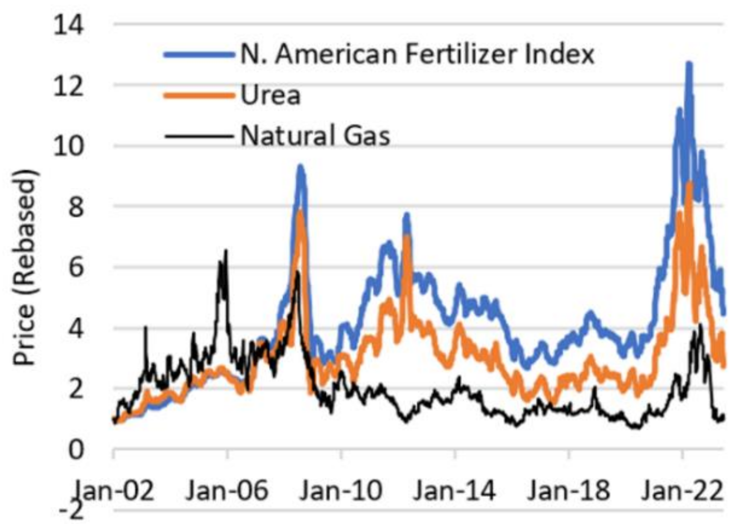

Figure 5. Price comparison for nitrogen-related products over time. Source: Tierney, 2023

3. Linear business models

A business model defines the strategic framework and core activities of a company to create, deliver, and capture value to achieve long-term economic sustainability. It also influences investment attraction, talent acquisition and operational efficiency. Businesses, either new or established, must regularly update their models to remain competitive when facing market trends and global challenges. While no universal business model exists, because companies generate revenue in different ways, many companies today operate within a framework based on the linear economy.

The linear economy, often referred to as the "take-make-waste" model, has dominated industrial growth and business practices since around 1970, especially in high-income countries. In this system, raw materials are extracted, processed into consumer goods and eventually discarded, only to be replaced by new products sourced from raw materials. The main goal of this model is to maximize economic profit and resource productivity, with no concern for environmental and social consequences.

The linear economy has contributed to material wealth in high-income nations. However, over the last two decades, this paradigm has been questioned due to a growing awareness of its environmental and social effects and an increased pressure on resources to fulfil global demand. Until recent years, regulatory frameworks had not provided any incentives to account for the negative externalities of this production system either.

The linear configuration of the economic model has created a continuous demand for raw materials, driving up pollution, waste generation, and environmental degradation. Additionally, because the system is based on cheap raw materials, it has become more cost-effective to generate waste than to recycle and reuse it (Chojnacka et al., 2020).

Over the past century, the use of natural resources has risen at an unprecedented rate. Since the 70s, global material extraction has tripled, rising from 27 billion tonnes per year to over 90 billion tonnes, with projections reaching 167 billion tonnes by 2060 (EEA, 2024). This sharp increase has been accompanied by a parallel rise in waste and emissions, with resource extraction and processing now accounting for 80% of biodiversity loss and 50% of climate emissions. In 2022 alone, the EU used approximately 5 billion tonnes of materials, with 35% of it becoming waste, while the rest accumulates as material stock in buildings, equipment and machinery (EEA, 2024).

The food sector is among the leading drivers for global material demand, accounting for 90% of global resource consumption when combined with the construction, mobility and energy sectors (EEA, 2024). Moreover, by 2050, the demand for crops will have increased by 100–110% from 2005, exceeding the feeding capacity of the planet and increasing the consumption of resources (Chojnacka et al., 2020).

The production of inorganic fertilizers is one of the factors raising doubts about the sustainability of the current agricultural production. The linear models for fertilizer production are based on the extraction of virgin materials and on energy-intensive industrial processes, which generate greenhouse gas emissions, pollute water bodies and increase pressure to non-renewable natural resources, among others. The products are applied to agricultural land without consideration for nutrient recovery or recycling.

Additionally, around 50-70% of nitrogen and 70% of phosphorus applied to soil are lost before human consumption through atmospheric emissions, leaching, surface runoff and erosion, contributing to environmental problems (Chojnacka et al., 2020; Daramola & Hatzell, 2023). Due to their overuse, the quantities of these nutrients being introduced into the environment are surpassing the natural capacity of global ecosystems to reabsorb them without adverse effects (Sporchia & Caro, 2023).

These models prioritize short-term efficiency and a high-volume output, with the production and the final consumption of mineral fertilizers usually being geographically disconnected, and raw materials and products travelling long distances before reaching the end-users. This is corroborated by the origin of phosphate consumed in Europe, mentioned in the previous section (Morocco, China, etc.) and of nitrogen (Russia, China, etc.).

This long supply chain increases environmental impacts, apart from creating dependencies on volatile international markets and geopolitical dynamics. Farmers may face higher prices and less reliable access to fertilizers, increasing inequalities in agricultural productivity and food security. This spatial distance highlights the need for a more localized nutrient management.

All these environmental externalities are not accounted for in the production of mineral fertilizers. As a result, the true cost (including the impact on the planet and human health) of producing mineral fertilizers and extracting raw materials is not included. This allows for their production to be kept at a competitive price, with the final product being sold at a cheaper price than their biobased counterparts. This price disparity manipulates the market and discourages the adoption of more environmentally friendly nutrient management strategies.

To address this issue, policy mechanisms should be introduced to internalise the negative externalities of mineral fertilizer production in linear business models through polluter-pay approaches such as environmental taxes or carbon pricing schemes. This principle should be applied at different points of the mineral fertilizer value chain for a just distribution of costs, putting more weight on the upstream processes (extraction and production), which tend to be more polluting, and trying to go lighter on end-consumers (farmers) who tend to be at more economic and social risk.

4. The transition to circular business models

4.a Added value in circular business models

Circular business models emerge as a viable economic alternative in the transition towards sustainability. These models focus on reusing and recovering materials, reducing waste, and using renewable resources. The circular economy aims at creating a regenerative system where businesses profit not from continuous product sales, but from the continuous flow of materials and products over time (Figure 6). This model promotes the retention of value over time and the optimal use of materials in the long-term, emphasizing the need to treat waste and pollution as systemic failures.

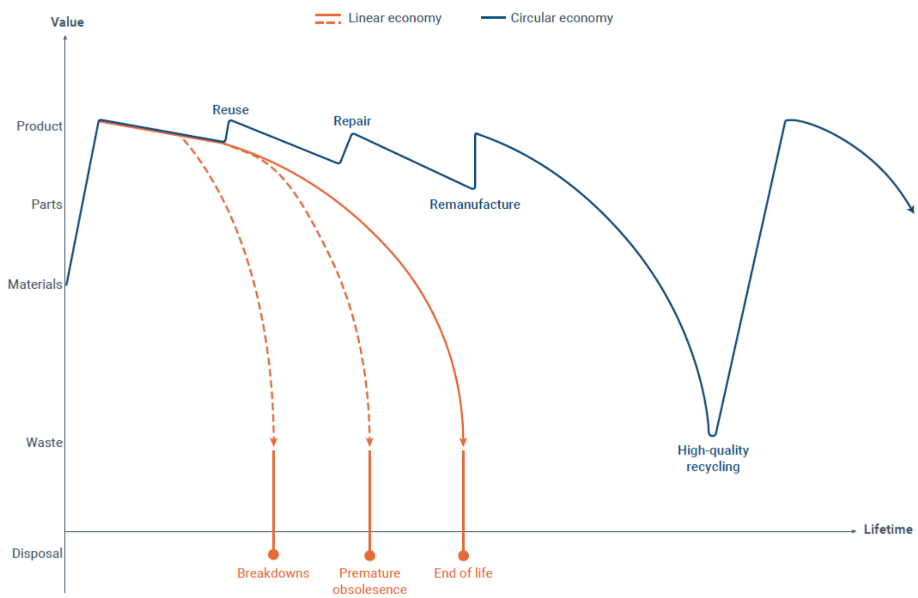

Figure 6. Circular actions and their effect in maintaining product and material value. Source: EEA, 2024

In this context, resource recovery plays a central role. Circular business models that focus on the valorisation of waste aim to capture the residual value of discarded materials and transform them into new forms of value through technological or biological processes like recycling and nutrient recovery (Vermunt et al., 2019).

A circular approach to nutrient use is essential for environmental sustainability to minimize waste, reduce nutrient loss, and lower reliance on phosphorus extraction and synthetic nitrogen production, by recovering nutrients from animal and wastewater streams (Daramola & Hatzell, 2023; Sporchia & Caro, 2023). Retaining nutrients within the supply chain diversifies resource availability, minimizes leakage and lowers dependency on imports. It creates logistical and economic advantages by sourcing inputs closer to waste discharge points, reducing transportation costs and energy consumption. Adopting these practices not only improves nutrient efficiency and reduces environmental impact but also strengthens regional systems to support global food supply (Daramola & Hatzell, 2023).

The general business model for biobased fertilizers production is to reduce environmental impact. Although making fertilizers from waste still uses some energy and materials, the overall emissions are usually lower. Instead of treating waste, these models turn it into a resource, avoiding the pollution caused by waste disposal and the extraction of raw materials for mineral fertilizers. These models also bring social benefits by creating green jobs and providing an extra revenue for farmers, since they can sell their waste instead of paying to get rid of it.

Furthermore, these models improve customer relationships and general resilience. They shift relationships from one-off transactions to ongoing collaborations, such as closed-loop supply chains between farmers and nutrient recyclers, helping businesses expand into sustainability-driven markets and increase customer loyalty (Ellen Macarthur Foundation, 2021).

They also help mitigate key risks associated with traditional linear systems, particularly in the agricultural sector, which is increasingly exposed to volatile supply chains and environmental pressure. By keeping nutrients in circulation, these models enhance resilience, reduce dependence on external inputs, and help stabilize both economic and environmental costs (Ellen Macarthur Foundation, 2021). As these risks become more visible, circular practices offer a good long-term strategy for stability and resilience.

However, exploiting waste in a profitable way is still a complex and multidisciplinary issue which requires expertise on the material, the technologies, the market and any socio-economic issues related to the side-stream valorisation.

The suggested economic impacts of implementing these circular business models are associated with lower prices for waste as material, avoided costs for waste treatment, and the possibility of using or selling any by-products (such as energy or methane). However, the costs and benefits for waste valorisation are not automatically allocated fairly to all stakeholders. For example, fertilizer production from waste treatment tends to be subsidized, but this value stays with manufacturers, while farmers might still face high prices. This opens a discussion on the responsibility to split the benefits of circular business models focused on fertilizer production between the generators of waste used for production, the manufacturers of the product (nutrient recyclers) and the end-users of the obtained biobased fertilizer. Therefore, business models must be created in a way that the output and value created is fair and distributed to all parties, linking the waste valorisation to business opportunities with a cross-sectoral vision (Donner et al., 2020).

A critical issue is that the environmental and social benefits of circular business models, such as avoided emissions, increased resilience or job creation, are usually not captured in traditional accounting methods. This makes circular models often appear less profitable when evaluated through a linear economic lens (Ellen Macarthur Foundation, 2021).

Therefore, the perceived profitability from circular business models remains limited unless environmental and social value is properly monetized. Putting a monetary value on ecosystems, ecoservices, and environmental impacts is dependent on many factors, and there is no defined model for this. Tools like Life Cycle Analysis (LCA) help measure environmental impacts, but do not translate them to monetary terms. A more holistic economic analysis would integrate these dimensions and provide a clearer picture of circular models' true value.

Another difficulty in the quantification of benefits and costs of circular strategies is that they can have different implications depending on the perspective. For example, an increase in labour costs from remanufacturing activities can be considered a negative economic impact, but a positive impact from the social perspective, as new jobs are created. Therefore, it is key to distinguish the focus and level of the impact of each action in the linear and circular value chains when comparing the models, to see the potential implications and trade-offs between them in the economic and non-economic dimensions of sustainability (Reim et al., 2019).

The environmental value through which the bioeconomy, and therefore circular strategies, increase sustainability is undeniable. Companies must ensure the realization of environmental gains through their business model's design (Reim et al., 2019). So, conducting an economic analysis of this transition requires not only looking at direct cost savings, but also trying to monetize externalities, valorising ecosystem services, and recognizing benefits that might be hidden in conventional accounting.

Public policy plays a vital role in bridging this gap. Subsidies, tax incentives, and regulatory measures, such as carbon pricing, synthetic input taxes, and certification schemes, can help internalize externalities and level the playing field for biobased products. Governmental subsidies are an important pillar in increasing the revenue stream and establishing new markets in the biobased sector. Policies need to account for the socioeconomic benefits that are not included in the market price, either through subsidies to nutrient recyclers or users of biobased products, or through taxes to the counterpart actors (Reim et al., 2019).

The European Commission has already started to push for a shift towards a more circular economy through strategies such as recycling, eco-design or industrial symbiosis, all aimed at achieving a zero-waste and zero-pollution economy (Chojnacka et al., 2020). However, the transition to circular business models is challenging, with only 7.2% of businesses globally adopting such models. Despite this, there is growing interest in its development, with the European Commission at the forefront and Europe showing a circularity rate of 11.5% in 2022, and all Member States reporting the integration of circular elements in policies relating to waste management (EEA, 2024), though much work remains.

4.b The role of the bioeconomy

In this European transition to the circular economy, developing a strong bioeconomy is crucial. The bioeconomy uses renewable natural resources to produce food, materials, and energy, supporting greener, more cost-effective value chains and industrial processes. As the renewable segment of the circular economy, urban areas become hubs where organic waste can be transformed into valuable biobased products (European Commission: Directorate-General for Research and Innovation, 2018).

To strengthen and scale up the biobased sector, the EC supports public and private investment in research, new markets and solutions, with the aim of promoting local economies while respecting the natural boundaries. Deliverable 4.3 analysed these current financial tools in place among the Member States (Miskó et al., D4.3, 2025).

Small-to-medium scale solutions that can be replicated and adapted in different locations and contexts are key to expanding sustainable biobased value chains. Developing new forms of collaboration through open innovation spaces that allow for the integration of different actors across the value chains to reach feasible synergies adapted to local conditions is also important (European Commission: Directorate-General for Research and Innovation, 2018).

EU regions play a vital role by combining innovation and sustainability in a decentralized way. They are key in promoting local value chains, optimize feedstock use, and providing jobs in rural areas, while managing their resources in a sustainable way, considering environmental and social factors. The European Commission's Knowledge Centre for Bioeconomy identified 359 regional bioeconomy strategies across the EU27. These regional plans reflect geographic, economic, and political specificities, helping tailor solutions to local needs, and are shaped by factors like decentralization (more regional strategies are likely to develop if a country is big and decentralised) and the existence of national strategies (European Commission: Directorate-General for Research and Innovation, 2018; Joint Research Centre, 2022).

The 2017 review of the EU Bioeconomy Strategy confirmed progress in creating new value chains and promoting regional bioeconomy's. However, it also identified the need for more investment, regulatory coherence, policy predictability, better monitoring and indicators, and stronger engagement from governments. A long-term perspective is important to stabilize the biobased sector and help attract investment. Additionally, aligning conditions for biobased and fossil-based industries, such as phasing out fossil subsidies and accounting for environmental costs, is essential to level the playing field (European Commission: Directorate-General for Research and Innovation, 2018). The Bioeconomy Strategy has been under consultation at the beginning of this year and is due for adoption by the end of 2025. The goal is to advance innovation and maintain the EU's leadership in this area, proposing actions to reach the market, generate green jobs and set conditions to help new business models. It also helps in aligning the Bioeconomy Strategy with recent EU initiatives (Directorate-General for Environment European Commission, 2025). Some of the feedback received in the consultation already highlights the need to create a levelled playing field for biobased products, the need for specific financial mechanisms to support scale-ups in this sector, and addressing consumer acceptance (European Commission, 2025).

The biobased sector is a highly dynamic part of the bioeconomy in terms of jobs and turnover growth. However, despite high employment rates in the bioeconomy, many regions, particularly in Central and Eastern Europe, still show low added value due to a focus on less productive sectors and underused biomass. Hence, there is still room for more development and contribution of cities to the bioeconomy and regional waste streams (European Commission: Directorate-General for Research and Innovation, 2018).

As part of the EU's push for the bioeconomy, the Regional Innovation Valleys (RIVs) initiative has been launched. RIVs are regional ecosystems that focus on different technological and thematic areas that are key to the green and digital transition of Europe. The EU plans to build 100 deep-tech innovation valleys, with an emphasis on Central and Eastern European countries, in a bottom-up approach that fosters regional development and cooperation (European Commission: Directorate-General for Research and Innovation, 2023).

The Regional Innovation Valleys for Bioeconomy and Food Systems (RIV4BFS) focus specifically on the bioeconomy and food systems principles. These valleys are designed to be flexible in size and stakeholder composition, so that they can adapt to biological resources that are available locally and can be sustainably sourced. Their main objective is to scale up and implement circular and sustainable bioeconomy solutions, using underused biomass streams and combining technological innovation and human skills to address local and global challenges (European Commission: Directorate-General for Research and Innovation, 2023).

RIV4BFS promote high TRL innovations to accelerate market penetration. By testing and scaling solutions, they want to create a favourable environment for business scalability and ecosystem growth. They emphasise mutual learning, education, and skills development across European regional innovation ecosystems, for a better interconnectedness that helps in increasing reproducibility and the exchange of best practices. The pilot projects developed under the NENUPHAR initiative should align with this framework and take advantage of the RIV4BFS opportunity.

4.c Circular business models for resource recovery

Circular business models emphasize collaboration and cooperation, communication with a wide range of actors, to create economic, environmental and social value in the long-term. They are encouraged to use external resources and ideas as input for innovation, in an "Open Business Models/Innovation" mindset. One common way for more profitable biomass valorisation is the spatial clustering of different businesses, called industrial symbiosis or eco-industrial parks. Such structures are more present in the petrochemical or chemical sector, but some projects are arising for the valorisation of agricultural by-products (Donner et al., 2021).

Business models that valorise agricultural waste and by-products can do so through cascading (diversified and consecutive valorisation paths, such as an integrated biorefinery) or a simple closed-loop strategy (following a single valorisation path, like a biogas plant). For an effective use of agricultural waste and by-products, innovative upgrading technologies must be linked to new business models and marketing strategies (Donner et al., 2021).

There is a wide range of agricultural waste and by-products that can be valorised, such as pig, horse or chicken manure, fruit and vegetable residues or woodchips. The valorisation processes and technologies vary, going from natural conversion like composting up to highly specialized and patented technological processes (Donner et al., 2021). In Table 3, various examples of circular business models related to the recovery of resources from waste can be observed.

Table 3. Examples of circular business models focused on resource recovery from waste. Source: Donner et al., 2020

Type of business model	Value proposition	Revenue streams
Resource recovery, bioenergy (e.g. biogas plant)	Conversion of organic waste into biogas and digestate through anaerobic digestion.	Sale of electricity, heat, and digestate; provision of waste treatment services.
Material upcycling	Transformation of low-value agro-industrial by-products into high-value materials (often biodegradable).	Large diversity of end-market applications (textile, construction material, furniture, food and drink).
Cascading use, waste stream integration (e.g. environmental biorefinery)	Integrated facility using cascading processes to produce multiple biobased outputs and energy.	Energy, marketable products (like chemicals, biofuels, food, feed ingredients, biomaterials).
Shared infrastructure, collaborative circularity (e.g. agricultural cooperative)	Collaborative and voluntary partnership approach to jointly manage by-products, share infrastructure and capacities.	Joint access to valorisation options and efficiency gains for members' by-products.
Industrial symbiosis, agropark	Spatial cluster of related neighbouring economic activities to exchange residuals (e.g. water/heat/gas).	Savings and revenues from shared logistics, energy, and waste management. Closing material loops and finding synergies.
Network coordination, capacity building, support structure	Organizational or institutional innovation for cooperation beyond geographic proximity, based on material flows, sectors, or value chains.	Consulting, facilitation, and coordination of circular model development in a region or sector.

The principal waste streams addressed by the NENUPHAR project are pig slurry, dairy wastewaters and sewage sludge. These streams, traditionally considered waste management burdens, are increasingly being used as resources in circular business models, opening various revenue opportunities through the development of different end products.

Manure and sludge can create biogas through anaerobic digestion, which can be used to generate heat or electricity, be upgraded to produce biofuel, recover CO_2 or CH_4, which can be sold to different industries, as gas or liquified natural gas. Compressed biomethane could then be used within the livestock industries as an alternative vehicle and machinery fuel. With minimal treatment, the biogas produced through anaerobic digestion can be used onsite to offset the heating and electricity requirements of a building. This can help farmers, specifically those in rural areas, in their dependence on volatile energy prices. A modelled scenario producing biogas from piggery effluent showed a 25% reduction in fossil energy use (Ramirez et al., 2021).

Digestate, the solid and liquid residues from anaerobic digestion, offers several valorisation options. It is more uniform in consistency than untreated organic waste and has a higher proportion of plant-available nutrients. To be effective as a biofertilizer, it must be processed for a balanced nutrient content. The microbial activity during digestion enables the production of value-added products such as energy, fertilizers, and protein-rich livestock feed. Alternatives to anaerobic digestion for energy production include combustion or pyrolysis, which use dry inputs, and hydrothermal liquefaction of wet wastes to produce liquid fuels. Both pyrolysis and liquefaction processes produce biochar as a by-product, which can also be used as a valuable soil conditioner (Ramirez et al., 2021).

Dairy wastewaters usually go through a solid-liquid separation step and then are treated to obtain the nutrients from the liquid effluent. Some frequent techniques are struvite precipitation, ammonia stripping or membrane processes, through which fertilizers are obtained (Hjorth et al., 2010).

In the case of dairy wastewater and sewage sludge, there is also the possibility to obtain clean non-potable water to be used for cleaning or cooling systems, decreasing utility costs and water withdrawal (Ramirez et al., 2021).

Hence, the different potential revenue streams for these circular business models are:

- Sale of biofertilizers, sale of biogas and production of digestate for purposes other than biofertilizers
- Sale of carbon credits or renewable energy certificates
- Avoided fees for waste treatment
- Public subsidies, CAP funding, EU Green Deal incentives

Lastly, business models for pig slurry and dairy wastewaters tend to be more localized, due to the nature and size of the waste itself, while wastewaters and sewage sludge are already treated in bigger facilities, which tend to be more decentralized and cover more territory.

In circular business models, these three streams are no longer treated as waste to be disposed of (with the pertaining waste treatment cost it entails) and become a valuable source for biogas, energy, and multiple biofertilizer products. This opens different revenue streams and builds a potential closed loop between farmers (who become the waste providers but also the final product users), technology providers/waste treaters and local governments.

4.d Market demand for recovered products

In the transition to circular business models, it is also crucial to address the demand for the final products. Despite the EC support for circular business models and the bioeconomy's potential to address global climate challenges, the success of these models also depends on demand uptake. Promising products and technologies sometimes fail to reach the market despite their proven potential, in a situation known as the "Valley of Death" (Gatto & Re, 2021). Hence, understanding farmers' needs, incentives, and adoption behaviours is key to unlocking the full potential of the circular bioeconomy.

While farmers have traditionally been suppliers of primary products (most importantly food), as new value chains develop, farmers are increasingly involved in the production of primary materials for innovative products and the management of sustainable agricultural systems. This shift diversifies farmers' income sources and increases the economic efficiency of resource use. Given this changing role, it is essential to analyse farmers not only as producers but also as key actors on the demand side of the market as end-users for the produced biobased products.

Achieving this requires consideration of both the supply and demand sides of the market, balancing technology-push and market-pull dynamics. Technology-push refers to innovations that originate from research and development efforts, often driven by scientific or technical potential. In contrast, market-pull arises from consumer demand or a specific market gap. A successful innovation or product typically emerges from the overlap between both perspectives, aligning scientific advancements with market needs (Gatto & Re, 2021).

In biobased products recovered from waste, this balance is challenged by the trade-off between biomass availability, quite self-explanatory, and the feasibility of scale-up. Biobased innovations are usually research-intensive and dependent on public funding and scaling up the product or technology for commercialization needs substantial capital, making this an important barrier for market entry (Gatto & Re, 2021). Overall, the success of circular bioeconomy models depends not only on technological progress but also on aligning innovation with the market reality.

The circular economy provides a framework to move from a technology-push scenario (focused on waste diversion and recovery) to a market-pull scenario, where waste is transformed into resources for which there is an available market. Hence, the presence of markets for these secondary materials is crucial to ensure the circulation of good-quality recovered materials. To achieve this, it is essential to design products that meet specific consumer needs and contexts (EEA, 2024; Reim et al., 2019). However, the European Environment Agency (EEA) has found that the secondary market for biowaste is still not a well-functioning market due to limited size, weak demand, insufficient end-of-waste criteria, lack of consumer trust, and inadequate technical specifications, despite the supportive policies (EEA, 2024). Deliverable 4.2 identified regional, national and European regulations, and analysed their impact on each region, concluding that, indeed, even some apparent supportive policies undermine the actual development of a market for biowaste.

Therefore, there is a need to focus on the economic feasibility and business model innovation of such initiatives in the market, because technological innovations alone are insufficient. Users must trust and be willing to adopt these secondary raw materials. Efforts must be made to standardize performance and ensure the functionality of recovered products. Effective collaboration between waste managers and the government for good recycling practices to ensure maximum quality and safety of the waste streams, together with public incentives, are crucial in this process (EEA, 2024). Building market demand and consumer trust requires the use of reliable tools and information, such as eco-labels. Comparability across products is important, as well as setting some quality standards related to biobased products to achieve accountability and consumers' trust (European Commission: Directorate-General for Research and Innovation, 2018; Reim et al., 2019)

Additionally, literature emphasizes that many bioeconomy-related products are not yet profitable and must compete on price with conventional products. Low-cost pricing or policy subsidies may be necessary to build market demand and balance the scales, securing stable revenues that otherwise would be highly uncertain (Reim et al., 2019).

In this context, farmers are the main end users of the product developed through the circular value chains identified in the NENUPHAR project. Hence, consumer acceptance must focus on them to reach long-term sustainability of the value chains. However, farmers are a traditional sector, usually resistant to changing practices. Barriers include limited awareness of environmental impacts, lack of training, insufficient guidelines, and restricted access to technology. Additionally, too many rules regarding subsidies and incentives, together with conflicting or changing policies, makes them more reluctant to dive in mitigation or circular practices using waste streams (EEA, 2024).

A country-specific survey was conducted regarding the challenges of using biofertilizers by Croatian farmers. Cost remains the biggest obstacle, cited by over 53% of respondents, followed by lack of technical equipment (28.7%), regulatory issues (10.7%). Only 2% of respondents use biobased fertilizers, while 33% rely on mineral fertilizers. However, results also showed that almost 60% of respondents are willing to try new fertilizers, especially if they are cheaper (38%) or if the benefits are clearly communicated (20%), highlighting the need for transparent information (Šatvar Vrbančić et al., 2025).

Acceptance varies depending on the source of the biobased fertilizer: animal manure has the highest level of acceptance, followed by urban green waste and composted plant residues, while sewage sludge is one of the least accepted. Hence, it can be concluded that it is easier for farmers to accept biobased fertilizers coming from organic and natural sources than from waste coming from the food industry and households (Šatvar Vrbančić et al., 2025).

Technical and financial support for investments and specific advice at farm level can be available under the CAP. These elements could lead to a faster transition and better implementation of a variety of policy mechanisms. Their acceptance can also be increased through consumers and other agri-food actors who show interest in organic products and practices (EEA, 2024).

So, while technological innovation in the circular bioeconomy is important, these innovations must be aligned with market demand. Building functioning markets for biobased products is essential to fully realize the potential of circular bioeconomy models in addressing both environmental and economic challenges. Farmers, as key actors in the bioeconomy, require support, clear information, and policy frameworks to overcome technical, financial, and regulatory barriers.

4.e Insights from experts on the transition to circular business models

Interviews were carried out with experts in the sector, to provide more insights regarding the benefits for transitioning to a circular business model and the development of biobased products. The received answers can be found in Annex I.

Based on the responses to the questions "*In the context of circular business models focused on producing biobased fertilizers by recovering nutrients from agricultural wastes such as pig slurry, are farmers reaping the benefits of said transition and strategy?*" and "*How are the generated revenues distributed across the value chain (waste treaters, manufacturers, farmers, end consumers…)?*", the current situation appears asymmetrical in terms of information and understanding among stakeholders, with small companies and individuals often at a disadvantage. As a result, it becomes difficult for these small players to reap benefits from this transition. Big companies are actively disclosing sustainability-related information motivated by the financial advantages it offers. In contrast, while they ask their suppliers (SMEs, Small and Medium Enterprises) to do the same, these often lack the knowledge or resources to use it to their advantage.

SMEs are often unable to issue green bonds, for example, as these financial instruments typically require a minimum scale or volume that smaller operations cannot meet. Therefore, the bigger the player, and the greater the concentration along the value chain, the easier it becomes to capture economic benefits. In the agricultural and food industry, (conventional) fertilizer manufacturers and retailers are usually the dominant actors. A key point would be to incentivize cooperation with the smaller or more fragmented players in the value chain to promote value creation and equitable distribution.

5. Potential risks when implementing circular business models

5.a Risk factors of circular business models

Risk factors differ across circular business models and local contexts. Hence, firms must analyse their environment to accurately tackle the right barriers and apply the best solution. There are, however, certain challenges that appear more frequently, especially in models focused on resource recovery. In a survey conducted by Vermunt et al. (2019) most firms with a resource recovery model identified logistic barriers (67%), institutional barriers (56%) and market barriers (50%) as the most significant challenges they faced (Vermunt et al., 2019).

Barriers and risks have been extracted from literature and deliverables 2.4, 4.1, 4.2 and 4.3. Their insights have been also applied in Section 7, linked to the specific demo sites of the NENUPHAR project. To better understand and respond to these challenges, the following sections break down the key risk categories into four groups: logistics, financial, institutional and market barriers. These findings are summarized in Table 4, in section 6c.

Logistic and technical barriers

Circular business models that valorise waste streams face several technical and logistical challenges. One of the main barriers is the heterogeneity in the quality of the waste inputs, which vary by season, location and source, making it difficult to establish consistent processing methods and value chains. Furthermore, these streams are often bulky and perishable, requiring efficient logistics for storage and transportation. Additionally, a small volume of available residues or a lack of partners may be insufficient to justify investment in large-scale processing facilities in some regions, as well as creating competition for the same feedstock, if multiple uses arise (Donner et al., 2020, 2021; Vermunt et al., 2019).

From a technological perspective, upscaling technologies is also risky, as innovations must be proved to be viable at industrial and commercial scale while keeping a balance between innovation exploitation and exploration (Reim et al., 2019). Also, the need to adapt traditional agricultural practices also represents a significant barrier.

Building new infrastructures for waste processing might be constrained by land availability, proximity to waste sources and community opposition, such as odour emissions. Additionally, if production takes place too far from where waste is originally generated (such as farms and municipalities), local actors may not benefit from the value generated, despite supplying the raw material (Donner et al., 2021).

Economic and financial barriers

Access to finance and cost competitiveness are key barriers in circular business models. Although biomass and other feedstocks are often cheaper than virgin resources, their cost must still be competitive. Currently, biobased products are still struggling to compete with fossil-based or mass-produced alternatives in terms of cost (Donner et al., 2021). Bulky waste such as pig slurry or sewage sludge is expensive to transport, making proximity to source important, for cost-effective but also to generate value in rural areas (European Commission: Directorate-General for Research and Innovation, 2018).

High initial investment discourages private investors, who are already hesitant due to regulatory, technology and market uncertainty (European Commission: Directorate-General for Research and Innovation, 2018). As a result, profitability usually ends up depending on subsidies, which is sometimes insufficient or misaligned with project timelines and can raise concerns on the long-term economic viability of the project (Donner et al., 2021).

Deliverable 4.1 also concludes that many farmers and SMEs struggle to meet the high up-front costs of nutrient recovery infrastructure, creating an additional barrier for developing circular business models that could integrate these systems into existing agricultural practices.

Government support is essential to circular models, particularly in the beginning. However, public funding can be difficult to obtain and is frequently insufficient to scale from the pilot to full-scale operations (Donner et al., 2021). The development of stronger economic incentives is essential, including the creation of a market for recycled nutrient products and the implementation of financial mechanisms that reduce the barriers to adopting nutrient recovery technologies (Febrer & Boy, D4.1, 2024).

Deliverable 4.3 explored the absence of adequate financial incentives, discussing that the financial landscape in the EU for the agri-food sector, particularly for green and circular economy investments, is characterized by substantial unmet demand and structural challenges, especially for SMEs. These struggle to access funding due to higher perceived risk, but also because of the requirement of a high budged for projects.

Governance and policy barriers

Regulatory and institutional obstacles are equally critical. While collaboration and networking are key for the success of circular initiatives, this can be difficult due to individual-specific priorities, focus on short-term planning, limited internal capabilities, and challenges in ensuring a stable flow of resources across the value chain (Reim et al., 2019). Currently, it is considered that EU regulation disfavours smaller farmers, as the way that water pollution and environmental protection is addressed, places emphasis on high output and lower resources demand, favouring larger agricultural enterprises (Misko et al, D4.3, 2025).

Additionally, waste coming from agricultural sources deals with lots of small farms disaggregated in some parts of Europe, needing a strong collective approach for management and cooperation (European

Environment Agency, 2022). Insufficient representation of key actors in decision-making processes, can threaten inclusivity and reduce the effectiveness of governance initiatives (Febrer & Boy, D2.4, 2025).

Regulatory complexity and variation between regions and between national and European policies, frequent changes in legislation and a lack of standardized definitions for waste and residue streams pose a threat for business stability, scaring off investors and complicating planning (Donner et al., 2021; European Commission: Directorate-General for Research and Innovation, 2018; Vermunt et al., 2019). Bureaucratic complexities in obtaining the necessary licenses or permits are also a barrier (Laborda & Cebrian, D4.2, 2024), together with monitoring and compliance to adhere to EU regulations, which demands strong enforcement mechanisms that can be resource-intensive (Febrer & Boy, D2.4, 2025).

The absence of regional legislation in some countries is a significant legislative barrier, as it impedes adaptation to local needs, limits the efficiency and effectiveness of policies, creates inequalities in implementation, and delays responsiveness to emergencies or changes in local conditions (Laborda & Cebrian, D4.2, 2024).

As for now, regulatory inflexibility is considered a barrier, as it does not take into account local variations in waste production and nutrient needs. For example, strict regulations on the application of waste to soils limit its use in agriculture, while water management regulations impose additional restrictions, complicating the adoption of circular practices (Laborda & Cebrian, D4.2, 2024).

Market barriers

Market uptake for recovered products can be slowed by low social awareness and trust in biobased products coming from waste. The general public might be put off with food products that have been cultivated with waste-based fertilizants. Hence, reliable and available information is crucial to overcome resistance of the final end-consumer

However, in the case of biofertilizers, farmers act as the main consumers, hence, little knowledge among farmers regarding their own impacts, but also a lack of training and advisory services also hinders penetration of biobased fertilizers and their use (European Environment Agency, 2022). Limited communication, low public understanding and education can result in weak demand and adoption of biobased products like biofertilizers (Reim et al., 2019; Vermunt et al., 2019).

A survey carried out in Croatia (Šatvar Vrbančić et al., 2025) found that farmers do not have knowledge on biobased fertilizers, with a total of 46.31% of respondents stating they are not informed about factors such as regulations, certification, control, costs and profits. Nevertheless, the biggest obstacle to the use of biobased fertilizers seemed to be the cost, with 50% of respondents citing this as a major barrier for adoption (Šatvar Vrbančić et al., 2025). Strong societal and economic dependence on fossil-based resources and the low cost of virgin materials make it difficult for circular alternatives to gain traction (Donner et al., 2021; Vermunt et al., 2019).

Another barrier for market uptake is the low price of virgin materials and mineral fertilizers, when comparing with biobased alternatives, together with the high dependency of society to fossil-based options (Donner et al., 2021). Corrective financial tools can be put in place to overcome this barrier, as explored in Deliverable 4.3, where tax systems for fertilizers as well as subsidies are analysed. Currently, it is difficult to tax fossil-based fertilizers, because they are hard to quantify, so the best approach to internalize the impacts would be a targeted upstream excise tax, that would target the inputs that lead to emissions. They are also reluctant to propose a subsidy method, as subsidies can sometimes increase total market size or fertilizer use (as detailed in the following sub-section, "The Rebound Effect").

5.b Efficiency in circular business models

Concepts related to long-term efficiency and performance potential, which are also relevant for linear business models, are equally critical to consider for circular business models. It is important to understand how circularity may influence or be influenced by these more systemic factors for their viability.

The Rebound Effect

The rebound effect, described as the Jevons paradox during the Industrial Revolution, describes the scenario where increased efficiency in the production of a good leads to an increase in consumption, offsetting the intended environmental or economic benefits, in a backfire effect (Godinot et al., 2024a). Over time, the rebound effect has surpassed its original boundaries and has extended to material flows within circularity.

Indeed, some circular business models might require more spare parts, storage, or industrial processes, which might not be in the same geographical location. This can lead to a rebound effect in logistics and transportation between organizations that benefit from each other's waste streams (Castro et al., 2022).

At a more organizational level, the creation of secondary markets for these recovered products can reshape consumption patterns. Instead of replacing conventional goods, circular alternatives might become a complementary product. In agriculture, this can lead to the simultaneous use of both organic and synthetic fertilizers, increasing total fertilizer consumption. Additionally, misconceptions about the efficiency of biobased products may lead to over-application, resulting in nutrient runoff, pollution, and greenhouse gas emissions that undermine the environmental benefits of waste recovery. For example, (2024b) reported that crop farms receiving manure often failed to reduce synthetic nitrogen use, leading to intensified production.

At a policy level, the implementation of circular strategies in Europe to enhance the manufacturing sector and create new jobs locally might lead to a rebound effect outside the borders where the measures are implemented, compromising jobs and resources in other sectors or countries (Castro et al., 2022).

Therefore, a systems thinking approach when designing and implementing circular strategies must be taken. Anticipating any potential rebound effects with a long-term perspective in mind is crucial to ensure long-term sustainability in circular innovations and motivate solid changes in behaviour acting (Castro et al., 2022).

Economies of scale

Economies of scale refer to the costs saved when production volume increases, usually driven by better organisational, logistic efficiency and the use of higher quantities of inputs. In projects and businesses, efficiency is estimated to improve overtime through improved labour specialisation or improved sharing techniques.

In nutrient recovery systems, scaling up operations can reduce the cost of recovery, treatment, and distribution per unit. Larger facilities benefit from more efficient processing technologies, greater access to funding, stronger integration with their surroundings (industrial symbiosis), and more capacity to invest in research and development.

Scaling up also enhances the use of by-products, reducing waste output that smaller facilities might not be able to use due to capacity limitations. Partnering with external stakeholders to use any material surplus that might arise in the processes of waste recovery (for example, biogas) increases both the economic and environmental performance of the plant. This also increases opportunities to expand the number of biobased products generated through the operations. Moreover, larger-scale operations can easier achieve standardization in nutrient content, pathogen control, and storage stability.

Nevertheless, circular business models based on waste feedstock have several potential barriers for scaling to a certain size, as one of the core principles of such models is regional integration. Being close to both the waste producers, manufacturers and end-users, to maintain local relevance. This localized perspective can limit the scale to reach efficiency, so a good balance between the benefits of scale with the need for local adaptation remains a challenge for circular economy strategies involving nutrient recovery.

6. Methodology for Transitioning from Linear to Circular Business Models

6.a Proposed Methodology

The transition from linear to circular business models in the context of nutrient recovery requires a holistic, systemic approach that addresses not only technology and economics but also governance, policy, and stakeholder dynamics. The methodology outlined in this deliverable integrates insights from prior NENUPHAR studies (Deliverables D4.1, D4.2 and D4.3) with established academic frameworks for sustainable and circular business model innovation, described in this deliverable. The transition also relies on collaborative governance structures established across regions, as explored in Deliverable D2.3, which demonstrated the importance of engaging diverse stakeholders through Community of Members (CoM) frameworks to co-design governance solutions and support circular value chains (Febrer & Boy, D2.3, 2025). The objective is to establish a methodical, sequential process for the conception of viable, inclusive, and regionally adapted business models that facilitate the valorisation of nutrient-rich waste streams and support the emerging circular bioeconomy (Bocken et al., 2014). A summary of these steps can be found in Figure 7.

1. **Policy and Regulatory Landscape Analysis**

The initial step in the transition methodology is to conduct a comprehensive analysis of the policy and regulatory landscape. This analysis identifies the key European Union policies, directives, and national regulations that directly influence nutrient recovery and circular economy practices, building upon the findings of Deliverables D4.1, D4.2 and D4.3. The objective of this step is to map regulatory drivers, constraints, gaps, and economic instruments that might either enable or hinder the implementation of circular business models. The analysis of policy frameworks such as the EGD, the Circular Economy Action Plan, and the Farm to Fork Strategy (European Commission, 2020) results in a regulatory matrix that highlights both opportunities and barriers relevant for designing business models in the nutrient recycling sector.

2. **Stakeholder Mapping and Community Engagement**

Stakeholder mapping and engagement are critical elements of the methodology. The present phase draws from the stakeholder identification and CoM frameworks developed in Deliverable D2.3, with the focus being on the recognition of the diverse actors involved in nutrient management, including representatives from public institutions, the private sector, research organisations, and civil society. The process involves the implementation of participatory methods, including interviews, workshops, and collaborative discussions. The objective of these methods is to facilitate an understanding of the interests, influence, concerns, and potential contributions of stakeholders. The result of this step is a stakeholder engagement plan and a detailed understanding of the socio-institutional landscape, ensuring that business models are context-specific and socially acceptable.

3. **Value Chain and Market Analysis**

Following the regulatory and stakeholder assessments, the methodology continues with a comprehensive value chain and market analysis. This step employs insights from Deliverable D4.3 and D4.4, in conjunction with external market reports, to assess the current and projected market size, trends, and demand for mineral and biobased fertilizers, develop regional cooperatives, product alliances or purchase agreements to facilitate market entry and secure long-term demand.

The study investigates pricing structures, product quality attributes, regional demand, and consumer acceptance levels for biobased products derived from waste streams. A robust market analysis must be done to ensure that the biobased products address real market needs and will be actually used, and how to communicate safety, performance and environmental benefits of the product for consumer trust. The objective is to identify economic opportunities, determine potential market barriers, and establish value creation points that can inform the design of competitive and viable circular business models (Lewandowski, 2016).

4. **Circular Business Model Design**

Utilising insights from regulatory frameworks, engaging relevant stakeholders, and conducting market analysis, the methodology then transitions to designing circular business models. This step involves the application of concepts derived from the domain of circular economy literature together with definitions found in Section 4 of this deliverable, including resource recovery, cascading use of materials, industrial symbiosis, and product-as-a-service models (Ellen MacArthur Foundation, 2015). The process entails the delineation of customer segments, value propositions, revenue streams, cost structures, and key partnerships, which are indispensable for the implementation of circular business initiatives. The business model design process ensures that new ventures are not only environmentally sustainable but also economically attractive and tailored to the specific conditions of each regional context within the NENUPHAR project. This step is further developed in the following sub-section *Technical steps for circular business model design*.

5. **Risk and Barrier Assessment**

Recognising that innovative circular business models face numerous uncertainties, the methodology incorporates a systematic assessment of risks and barriers. This step is informed by the analysis presented in Section 5 of Deliverable D4.4, and its purpose is to identify technical, financial, regulatory, and social risks that could hinder successful implementation. The assessment involves evaluating the severity and likelihood of each risk, as well as formulating mitigation strategies to address challenges such as regulatory uncertainty, market volatility, technology adoption hurdles, or stakeholder resistance (Bocken et al., 2014). The result is a risk management plan that supports the robustness and resilience of the proposed business models.

6. Economic and Financial Evaluation

A pivotal step in the methodology is the economic and financial evaluation of the proposed business models. D4.3 proposes a methodology to choose the right economic tools that can help in financing the transition. They acknowledge that this transition intensifies financing challenges, specifically for SMEs. Currently, circular business models carry high upfront costs unfamiliar risks, and long payback periods, which are poorly matched to traditional financing assessment frameworks; therefore, it is of the most importance to choose the right financing tools for a project, as well as being aware of all existing fiscal and economic incentives to assist both public and private entities.

Additionally, Section 8 of this deliverable defines different economic analysis to carry out for the calculation of capital expenditures (CAPEX), operational expenditures (OPEX), revenue projections, and profitability indicators. Such indicators include Net Present Value (NPV), Internal Rate of Return (IRR), and Return on Investment (ROI). The evaluation draws from examining cash flows, potential market fluctuations, and policy-driven incentives or constraints. Sensitivity analyses are conducted to understand how changes in key variables might affect financial performance, ensuring that business models are both profitable and resilient under various future scenarios.

7. Integration with Governance Models

The final step in the methodology focuses on integrating circular business models into regional governance and policy frameworks. This approach is intended to ensure that the proposed business models align with local governance structures, regulatory requirements, and regional bioeconomy strategies, as elaborated in deliverables D2.3 and D4.1. The integration of circular business models within established governance mechanisms, such as the CoMs, has been identified as a key step in facilitating stakeholder collaboration, regulatory compliance, and long-term sustainability. The result is a practical implementation roadmap that bridges technical innovation with institutional support, helping circular business models move from concept to reality.

Policy and Regulatory Landscape Analysis	• Regulations • Incentives
Stakeholder Mapping and Community Engagement	• Actors • Participation
Value Chain and Market Analysis	• Demand • Economics
Circular Business Model Design	• Innovation • Strategy
Risk and Barrier Assessment	• Challanges • Mitigation
Economic and Financial Evaluation	• Profitability • Feasibility
Integration with Governance Models	• Aligment • Implementation

Figure 7. Steps for the methodology proposed for the transition to circular business models. Source: own creation.

6.b Technical steps for Circular Business Model Design

The general steps defined fit within the broader context of transitioning to circularity; however, practical logistic actions aimed at product development and value capitalization must also be addressed. Designing an effective circular strategy for waste recovery requires a multidisciplinary approach that considers the region, available technologies and logistics, regulatory frameworks, and the market.

There are three different demo sites being analysed in the NENUPHAR project, each one tackling one type of waste: pig manure, dairy wastewaters and wastewater sludge. In the Ebro River Basin region, in Spain, 5,016 waste flows of mainly pig slurry were identified. The Danube River Basin, in Hungary and Slovakia, has important waste flows from dairy wastewater, especially from cheese production. Lastly, the Lielupe River Basin, in Latvia and Lithuania, focuses on waste from WWTPs. In all three demo-sites there are still data gaps to cover when talking about potential nutrient recovered quantities, due to a lack of reliable data and regional variation.

The following steps, which are summarized in Figure 8, outline the technical factors to consider when implementing a circular system:

- Design an efficient waste collection system: a waste collection framework must be established, adapted to the specific characteristics of each waste stream. For pig slurry and dairy wastewater, a decentralized collection system may be more appropriate, as farms tend to be more dispersed and the absence of large-scale collection infrastructure. In contrast, for sewage sludge, which is usually already collected at municipal wastewater treatment plants, the focus should be on optimizing routing, identifying suitable recovery facilities, and determining the optimal quantities for valorisation to ensure efficient logistics and resource allocation. The most appropriate ways of transport must be explored, trying to take advantage of existing logistic routes and infrastructures.

- Define the pretreatment technology and protocol to reach homogeneity and safety standards: analyse what are the best technologies to apply for the geographical and seasonal variability of the waste streams of the area. Aim for compliance with EU standards regarding waste to meet safety and environmental policies. Meeting such standards enables the potential certification of final products, like eco-labels or standards, which increase trust and acceptance from farmers and other stakeholders.

- Define the revenue route for the produced biogas (in the case of pig slurry and sewage sludge): assess the regional energy demands (such as heating, electricity, transport fuels) and the existing infrastructure capacity to integrate the biogas into the local energy grid, transport sector or directly to farmers. Look for synergies with ongoing decarbonisation initiatives in the area to improve the viability of these strategies. Biogas is one of the most important by-products that can be obtained in the transformation of manure and sludge to biofertilizers, as it can be quite easy to capitalize.

- Define the composition of the final biobased fertilizer products: the formulation of biofertilizers should be adapted to the specific nutrient requirements of local systems as much as possible. Analysing the current fertilizers used by local farmers will help in ensuring that these new biobased products can replace or complement them, instead of leading to a rebound effect of fertilizer over-application. Look for collaboration with farmers, manufacturer and soil experts for this step, but also for policy experts to make sure that the final products comply with all agricultural and waste regulation.

- Develop monitoring strategies along the entire value chain: monitoring and evaluation are key to control system performance, optimize process efficiency, and ensure compliance with regulatory standards. Involve digital technologies that can be used by all stakeholders, most importantly farmers, accompanied by proper training.

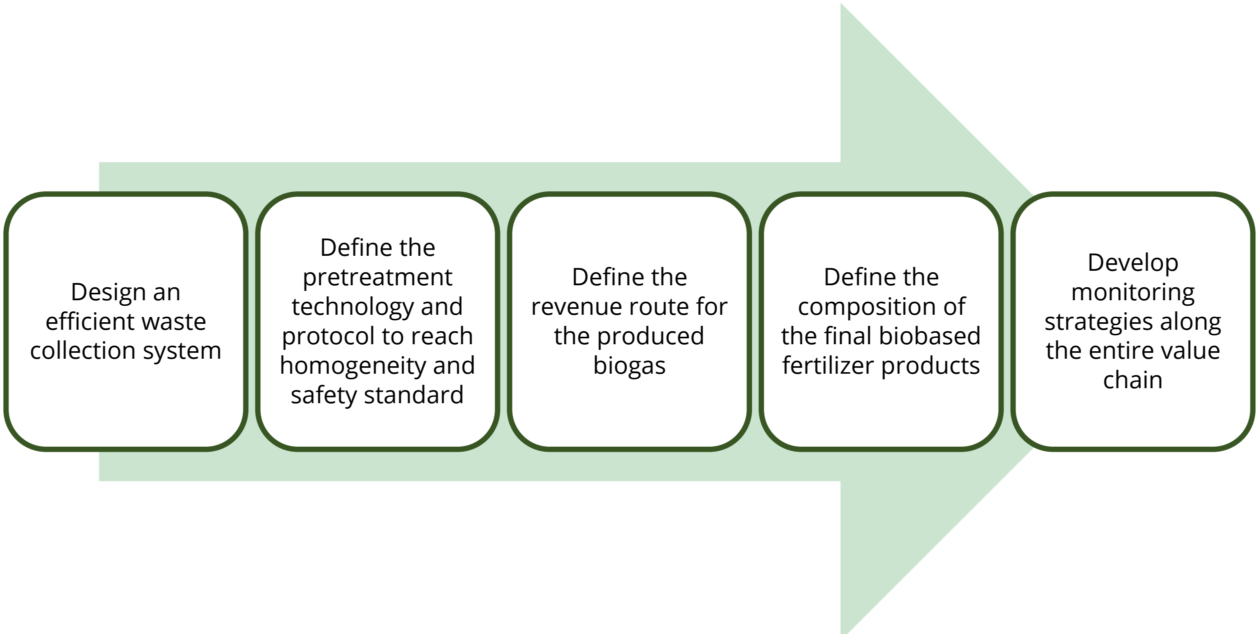

Figure 8. Technical steps for designing the circular business model. Source: own creation.

6.c Strategies to overcome barriers

Some strategies and solutions are proposed to address the potential barriers that might be faced when transitioning to a circular business model. This requires coordinated action across technological, financial, institutional, and social dimensions.

A key strategy is stakeholder proximity (including farmers, manufacturers, policy makers and consumers) to reduce transport needs, storage time, secure feedstock availability, foster innovation through collaboration, and build consumer trust (Donner et al., 2021; Reim et al., 2019). Locating processing facilities close to both waste sources and end-users lowers logistical costs and enhances the economic viability of circular initiatives.

Scaling up innovative technologies and supporting joint R&D and demonstration projects can spread risk and improve feedstock management. Designing models in a way that economies of scale can be reached, as well as allowing for energy savings and the sale of by-products (such as biogas) offer another revenue stream to help with financing (Donner et al., 2021).

Promoting regional collaboration helps build synergies and supports vertical integration along the value chain. This enables cross-industry cooperation, expands innovation capacity, and diversification of products. Engaging local governments, citizens, entrepreneurs, and NGOs through public-private partnerships ensures broad support and a more inclusive and sustainable development (Donner et al., 2021). In this sense, the European Commission's support for the bioeconomy such as the Circular Bioeconomy Thematic Investment Platform come in handy, as they provide funding in the sector by aligning various EU programs, such as InvestEU and the CAP (European Commission: Directorate-General for Research and Innovation, 2018).

To overcome a gap in education and knowledge in agricultural impact and the use of biobased fertilizers, training and advisory services should be financed for farmers and other local actors (European Environment Agency, 2022). To make biobased fertilizers more attractive for farmers clearer accessible information, better training, financial support, investment in the right equipment and improved regulations is needed (Šatvar Vrbančić et al., 2025).

Finally, designing models around local potential helps in using waste streams more efficiently, creates rural jobs and know-how, and increases dissemination of the product or technology. The recognition of certain regions as agricultural development areas can further attract investment and support regional growth (Donner et al., 2021).

Table 4. Risks and solutions to set up circular business models dealing with agricultural and municipal waste. Source: own creation from cited sources in section 5a and 6c.

Risks and potential solutions for circular business models
Logistic and technical factors
Risk factors • Heterogeneous output quality • Availability of feedstock • Technology has to be up scaled • The bulky nature of waste streams needs efficient logistics (transport, conservation, storage) • Spatial feasibility **Potential solutions** • Geographical proximity of the different stakeholders and of the waste stream to the manufacturing plant • Look for synergies between different elements and parties to make efficient use of waste, public/private partnerships • Search for European funding to move from the R&D innovation phase to markets
Economic and financial factors
Risk factors • High initial investment costs • Dependency on subsidies for long-term sustainability • Farmers and municipalities may not benefit from the added value generated products if there is no proximity to the manufacturing plant • Unmet demand and structural challenges in financing for SMEs and farmers **Potential solutions** • Reach economies of scale

- Economic promotion of the local area
- Design processes that allow to save energy and for the selling of by-products to reduce costs
- Vertical integration with various stakeholders for cooperation, innovation and joint investment

Governance and policy factors

Risk factors

- Uncertainty with future legislation
- Lack of alignment between regional and European policy
- Lack of standardised definitions and standards
- High focus on individual company interests
- Rigid regulation directed at big players
- Bureaucratic and monitoring complexity
- Absence of regional legislation

Potential solutions

- Public European financial support
- Public-private partnerships between the EU and biobased and innovation regions are encouraged
- Create networks and collaboration groups in the region

Market factors

Risk factors

- Lack of consumer/farmers trust due to a lack of perceived quality, information or resistance to change
- High dependency of the society on fossil-based systems
- Low price of virgin materials and mineral fertilizers
- Difficulty in quantifying mineral fertilizers for taxing purposes

Potential solutions

- Support the rising trend of awareness in ecological products through the promotion of the local area and consumer education
- Finance training and advisory services to overcome the knowledge gap
- Call for standards and ecolabelling
- Involve local governments, citizens, entrepreneurs and NGOs in the process

7. Stakeholder analysis

Building on the analysis from previous sections and the findings of Deliverable 2.3, 4.1, 4.2 and 4.3, a comprehensive review of the NENUPHAR project's demo sites has been carried out. This assessment covers policy frameworks, financial instruments, market demand and existing circular business models. It also incorporates important remarks from the NENUPHAR partners, who were interviewed for this task. To deepen the understanding of the transition to circularity, questions were sent to the project partners, focusing on barriers for each demo site, potential initiatives and mechanisms, and circular practices in place. Their responses can be found in Annex II.

Three main demo sites and two smaller replicators have been defined in the NENUPHAR project:

- Ebro basin: located in Spain, across two regions (Catalonia and Aragon). The flow to recover nutrients from is manure waste.
- Danube basin: located in two countries (Slovakia and Hungary) and across two regions (Nitra and Győr). The flow to recover nutrients from is dairy wastewater.
- Lielupe basin: located in two countries (Latvia and Lithuania) and across two regions (Zemgale & Kurzeme and Šiauliai). The flow to recover nutrients from is sewage sludge waste.
- Bornholm replicator: located in Denmark and one region (Bornholm). The flows to recover nutrients from are manure, sewage sludge and dairy wastewater.
- Cyprus replicator: located in one country and region (Cyprus). The flows to recover nutrients from are manure, sewage sludge and dairy wastewater.

A study conducted by the European Commission's Knowledge Centre for Bioeconomy mapped and analysed the deployment of bioeconomy strategies at regional level in the EU-27, around 2021. All regions studied demonstrate at least a minimum strategic commitment to the bioeconomy (Haarich et al., 2022), either at the national or regional level, suggesting that, despite differences in scale and scope, some form of institutional support can generally be expected across all the countries of the demosites under the NENUPHAR scope.

As of December 2022, ten EU member states have national strategies dedicated to the bioeconomy: Austria, Germany, Spain, France, Finland, Ireland, Italy, Latvia, the Netherlands and Portugal. Seven countries are currently developing their national strategies: Czech Republic, Croatia, Hungary, Lithuania, Poland, Sweden, and Slovakia (Febrer & Boy, D4.1, 2024).

Deliverable analysed the regulatory barriers and opportunities across the demo sites and per waste source; it found that waste (sewage sludge) and water are the most affected areas in several countries by regulation in place, while topics such as nutrients, soils, and fertilizers show depend more on regional regulation, with only a few countries reporting barriers in these areas (Febrer & Boy, D2.4, 2025).

At the country level, Denmark stands out with the highest number of regulatory opportunities across different topics, particularly in waste (manure), residues (sewage sludge), and fertilizers, while Spain and Hungary also show opportunities in the water sector. Topics such as nutrients and soils do not present opportunities in any of the countries (Febrer & Boy, D2.4, 2025).

It is important to mention that within the NENUPHAR project, initial steps have been taken to establish a CoM, with the goal of building a structured, collaborative network composed of key stakeholders from various sectors, including academia, civil society, public institutions, and private enterprises related to water and nutrients management. They are responsible for defining the challenges and steps to take, through a bottom-up approach, considering the local socio-economic conditions, practices, and environmental constraints. Discussions from stakeholders made clear that circular economy principles must be applied at the territorial level to develop practical and sustainable solutions for nutrient management.

In this process, the need for a good governance model to implement successful circular business models in the different regions is underscored. Having a CoM helps in increasing stakeholder engagement, knowledge sharing, facilitates cooperation between regions and providing specific policy recommendations. During the project, 5 CoMs have been developed, one per demo site/replicator.

7.a Ebro basin

The Ebro Basin runs across the Spanish regions of Aragon and Catalonia, which are leaders in pork production, with an important economic role with over 12,000 direct jobs and more than half of Spain's pig population. Livestock farms used to be small and dispersed, making pig slurry available to use as fertilizer for local agriculture. However, the intensification of pork production has increased the number of large farms, posing logistical and environmental management challenges. Approximately 34 million m^3 of pig slurry is produced annually, with only 12 biogas facilities in place and limited data on their digestate output.

Governance and regulatory landscape

The governance of the nutrient streams is complex, as these autonomous regions have separate agricultural policies, which can prevent collaboration and cohesiveness. The analysis from Deliverable 4.2 concluded that regulation in Spain, and in the two regions, is often too rigid for producing and applying manure and organic materials, and that compliance is especially hard for small farmers. It concluded that the sewage sludge, water, nutrients, manure, soil and fertilizers areas all are impacted by regulation in a negative way, due to limits in application or production. Despite some public support and investment for biogas plants, especially in Catalonia, recent legal changes have made it harder to market recovered nutrient products. National legislation also restricts the use of recovered nutrients, so there is a need for more flexible, locally adapted policies.

Spain agricultural policy is aligned with the EGD to promote organic fertilizers, reduce chemical inputs, and improve soil health. Spanish CAP Strategic Plan promotes sustainable practices like precision farming, cover crops, and reduced tillage. Farmers are supported by agri-environmental aid schemes that provide technical assistance and grants for nutrient management advisory services.

To address fragmented governance and regulation, the NENUPHAR project initiated a CoM to foster dialogue and cooperation among the public sector, private industry, civil society, and academia to co-develop sustainable nutrient governance strategies. Through this platform, stakeholders revealed several barriers: regionally misaligned regulations, financial constraints for farmers, low public awareness of agriculture's environmental impact, poor inter-stakeholder communication, and technological limitations in implementing sustainable practices.

Financing tools

There are several financial tools in place. The Centro para el Desarrollo Tecnológico y la Innovación (CDTI) CIEN projects support long-term R&D efforts, often involving consortiums of companies developing technologies fo nitrogen and phosphorus recovery. The Agri-Food PERTE (Strategic Project for Economic Recovery and Transformation) initiative funds circular economy and digital transformation projects across the agri-food value chain. In Catalonia, the Agroambiental Catalan Institute of Finance offers preferential loans for sustainability projects, including those related to nutrient recovery. However, high project budgets and complex administrative requirements might exclude SMEs in some cases.

Circular practices and initiatives

Regarding circular practices, multiple initiatives can be found in Aragon, which primarily focus on redesigning circular and climate-neutral cities (including industrial waste chains) and projects dedicated to the rural areas, fostering innovation in agriculture, livestock, and waste management.

Specific projects focused on waste revalorisation can found, such as "VALIQPORK" (valorisation of pig slurry to produce biofertilizers), "OPTIDIGEST" (improvement of anaerobic digestion of agri-food waste as digestate, biogas efficiency and nutrient recovery), "COWCOMPOST" (composting of cattle manure to create high-quality agricultural compost in a circular system), "FERTCAFÉ" (organic fertilizers from coffee waste from restaurants and the industry), and "AGROCIRCULAR 2030" (valorisation of agricultural and agri-food by-products for biodegradable packaging and organic fertilizers).

In this region, circular initiatives have multiple stakeholders, including public authorities, research, academic and technology centres, agri-food and environmental enterprises (such as cooperatives, livestock producers, waste management companies, SMEs), platforms for the industry and focused on innovation and NGOs and sectoral associations (who are involved in dissemination, training and stakeholder engagement, particularly important in rural groups).

The key factors behind circular initiatives in these regions are replicable, as they mainly focus on having strong institutional support, which provides clear direction and legitimacy. Financial risk is reduced by using EU and regional funding, which also incentivizes innovation. This combination of policy, funding, cooperation, and place-based design offers a strong, transferable framework for similar circular economy efforts elsewhere.

Market demand

Regarding the market for secondary materials valorised from livestock, agri-food, and organic waste, such as compost, treated digestate, and bio-based fertilizers, it is growing but still in an initial state in both regions. In Aragon, the mentioned products are the ones that seem easier to promote and scale-up, especially within cooperatives and farms committed to sustainable practices, as they tend to be more technically viable, aligned with the region's circular economy goals, and can build on previous pilot projects, quality labels, and public strategies such as the Aragon Circular Strategy.

Catalonia has also an emerging market for these secondary materials, as it has some important infrastructure and supportive projects in place. It operates around 25 composting plants and has some large-scale anaerobic digestion projects to produce digestate and biomethane.

Biowaste-based fertilizers are being used by some Catalan farmers, but mainly by those in pilot projects or within circular farming systems, so the market is still in its early stages. Compost is the most used product, and farm-scale slurry-based products showing strong local potential.

However, the market is not yet fully consolidated. Its development is limited by factors such as lack of standardization, low large-scale commercial demand, and limited awareness of the agronomic value of these alternatives compared to conventional fertilizers. So, incentivizing farmers to use these bio-based materials, along with certification and logistical support, is still needed to scale the market.

Key takeaways

In summary, the main barriers in these areas to adopt circular business models in agriculture are a lack of trust or awareness in the effectiveness of biobased products, a lack of standardization, labelling, and certification, logistical costs for transporting and applying bulky organic materials, and a weak coordination between waste producers, processors, and farmers.

To overcome these challenges, it is crucial to ensure that biobased products perform as well as conventional fertilizers, that they are compatible with current farming practices (especially on large farms) and make information clear and accessible regarding usage, legal requirements, and long-term soil impact.

The most effective tools for building trust and awareness have been on-farm demonstrations, pilot trials, and collaboration with operational groups, allowing farmers to be active participants. These efforts, combined with technical workshops and regional awareness campaigns like the Aragon Circular Strategy and Circular Seal, have been efficient in raising awareness. Ultimately, increasing adoption depends on practical training, visible results, and strong institutional support.

7.b Danube basin

The Danube River Basin covers both Hungary and Slovakia and plays an important economic and ecological role in the regions, despite being under pressure from nutrient pollution caused by agricultural runoff, industrial waste, and outdated wastewater infrastructure. Roughly 65% of the river's length is classified as "at risk" due to excess nutrients, primarily nitrogen and phosphorus from fertilizers and livestock waste.

Governance and regulatory landscape

Deliverable 4.2 revealed that a key governance issue is the lack of regulation at the regional level, national strategies exist, but without regional adaptation, they often fail to address local needs. Also, no regulation or market system incentivizing the use of recovered nutrients was identified. There is also a problem with effective policy enforcement, as even when policies are in place, enforcement is weak. Hungary and Slovakia have regulatory barriers concerning sewage sludge, water, soils and fertilizers. Nutrients and manure have been considered not to be affected negatively by regulation.

Workshops under the NENUPHAR project revealed that effective nutrient management is slowed by poor coordination between institutions, outdated and inconsistent regulations, and fragmented data systems. Stakeholders stressed the need for regulatory reform, better stakeholder engagement, modern treatment systems, and better cross-border cooperation. Progress depends on aligning policy, data access, and supporting innovation to create a more sustainable and coordinated approach across the basin.

Financing tools

Deliverable 4.3 concluded that subsidies allocated to farms in Hungary between 2014 and 2021 supported economically weak farms instead of fostering real competitiveness or job creation. Subsidies had a positive effect on micro-enterprises but employment outcomes were worse among subsidized farms compared to their non-subsidized counterparts.

In contrast, Slovakia has various financial incentives in place. Farmers receive payments from startups like Carboneg for every ton of CO_2 stored in soil for regenerative farming. This is supported by an advisory system and financial tools, such as credit lines and overdrafts, often mediated by banks to complement CAP investments. However, high administrative and cumulative costs remain a challenge. Slovakia also provides environmental funding to support primary agricultural production, including a mineral oil tax refund. Additionally, a state aid scheme closed in 2023 compensated agricultural damages from severe weather events comparable to natural disasters.

Circular practices and initiatives

Regarding circular practices, there are a wide range of initiatives in these regions focused on carbon farming systems that support nutrient recovery and circular business models. One key area is voluntary soil carbon credit markets, supported by agritech startups like Agreena and Soil Capital, which reward farmers for sustainable practices (such as no-till farming, cover cropping, and reduced fertilizer use), encouraging nutrient-efficient approaches for carbon reduction goals. The successful replication of these models depends on robust monitoring systems, alignment with international standards, and strong financial incentives.

Regenerative farming platforms, such as Regrow and Farms4Climate, complement these markets by using tools to help track soil-friendly practices. These platforms promote collaboration between farmers, scientists, banks, and regulators through participatory events and peer-to-peer learning, helping to co-develop specific protocols for the region with both technical and financial perspectives.

At the policy and research level, EU-funded carbon farming projects provide broader strategic support. Projects like Carbon Farming Central Europe are testing different sustainable techniques in multiple countries while designing business models that support nutrient reuse and low-input agriculture.

In Hungary, the Circular Hungary platform provides a national engine for circular business models, bringing together more than 180 companies, universities, and public agencies to develop circular strategies across sectors. The initiative wants to integrate nutrient loops, minimize waste, and align with international best practices.

Across all these initiatives, common success factors include multi-stakeholder collaboration, strong links to EU frameworks, practical capacity-building efforts, and a shared vision for regional innovation. Together, they form a robust ecosystem for developing scalable, circular solutions that advance nutrient recovery and sustainable agriculture in Europe.

Market demand

In Hungary and Central Europe there is an incipient but growing market for secondary materials, especially for organic fertilizers, recovered phosphorus, digested sludge compost, and emerging waste-based biochar. Although mineral fertilizers still dominate the market, there is a trend to waste-recovered products in response to sustainability goals, regulation, and increasing interest in organic and regenerative agriculture practices.

Several Hungarian companies are already active in producing organic fertilizers using recovered nutrients from digestate and biomass. Research trials are also being conducted, and have demonstrated the agronomic effectiveness of these alternatives, particularly as phosphorus replacements.

Sewage sludge compost and digestate-based fertilizers are the easiest to scale due to existing research, regulatory openness, and interest from organic farms. Struvite, supported by EU regulations, also holds promise, while biochar-based products are gaining traction in early-stage pilot projects.

To drive adoption of circular bio-based fertilizers in Central and Eastern Europe, particularly Hungary, farmers need clear value propositions across five key areas: guaranteed agronomic performance and an easy use of the product, safety assurances, economic viability (such as access to green schemes, competitive pricing or evidence of reduced use of other inputs in the long term), all coming from trusted information sources.

However, uptake remains low due to limited awareness of products like digestate pellets, struvite, or biochar blends. Concerns about pollutants, regulatory ambiguity, and conservative buying habits further slow adoption. Infrastructure gaps, particularly in logistics and processing, also lower access to these products at a big scale. Without strong economic incentives or policy alignment, circular based products struggle to compete with conventional fertilizers.

Key takeaways

In summary, enabling factors of these regions are are a big voluntary stakeholder structure with sector-specific working groups, stakeholder platforms to connect all parties involved, support from institutions, activities related to capacity building (such as training, workshops and conferences), EU legislation which provides inputs to national strategies and regulation, an alignment with funding channels (supporting access to grants and promoting European and domestic R&D initiatives), and the adoption of circular metrics (tools to track data for companies). Certification schemes and preliminary projects are helping build trust and develop the market.

The best practices for social awareness and consumer education have been on-farm demonstration trials, particularly when tied to local conditions. Advisory services, such as Hungary's National Chamber of Agriculture or universities also play a key role in delivering technical knowledge. Circular economy platforms like Circular Hungary help coordinate and develop a farmer network, for better engagement. Labelling schemes and carbon credits help in raising confidence and potential income, together with rural awareness campaigns, while digital platforms help scale outreach and information sharing.

7.c Lielupe basin

The Lielupe River Basin covers parts of Latvia and Lithuania and is heavily shaped by agriculture, which significantly contributes to nutrient pollution and ecological vulnerability, due to low river flows and limited dilution capacity. While there exists treatment infrastructure, enforcement and operational practices often fall short. Sludge disposal is inconsistently reported and sometimes illegally managed, particularly in smaller plants. Latvia and Lithuania have regulatory barriers concerning sewage sludge, water. Nutrients, fertilizers and manure have been considered not to be impacted negatively by regulation.

Governance and regulatory landscape

Latvia and Lithuania both regulate sludge use in agriculture but have different approaches and effectiveness. In Lithuania, sludge management practices like composting and biogas production are increasingly adopted, but there are still gaps in treatment and monitoring. The country has a national law regulating sludge application to soils, requiring soil analysis and nutrient calculations before application. However, there are calls to make regulations more flexible and adapted to local soil conditions.

Latvia, on the other hand, has more structured nutrient recovery practices and has recently approved the Wastewater Sludge Management Plan 2024–2027, which supports sewage sludge composting and circular economy models. Water management companies, the main producers of excess sewage sludge, are actively involved in this process, along with the Ministry of Climate and Energy for legislative support, and the State Environmental Service as the supervisory authority. The NENUPHAR project also supports and promotes this collaboration by providing practical examples and results, helping implementation of the plan.

Financing tools

Latvia provides financial support for carbon sequestration efforts, though this system is still new and may not fully offset investment costs. The country lacks economic instruments for nutrient recovery, but is active in LIFE-integrated projects and collaborates with public institutions, creating potential for future incentives and structured nutrient recovery.

Circular practices and initiatives

In Latvia, sewage sludge is centralised in wastewater treatment plants who compost the sludge and treat it for soil application. Farmers must match nutrient application with soil needs but face a short post-harvest timeframe for the required testing, which limits effective application.

The country has no other major circular business models beyond NENUPHAR, but the potential for expansion is high given clear legislation and strong stakeholder cooperation. For example, involving grain processors in sludge composting could enhance circular business models. These processors, usually located near farms, could provide organic residues for composting, reducing production costs and improving logistics, and benefiting both compost producers and end users, while they also benefit by finding a sustainable way to dispose of their organic waste.

Market demand

The market for wastewater sludge compost was calculated in the Wastewater Sludge Management Plan and seemed quite promising due to the abundance of agricultural land and relatively low production volume, low animal density and lack of organic fertilizers. If implementation of a large-scale centralised production of sewage sludge compost is successful, a significant amount of quality organic fertilizer will be obtained from circular economy stakeholders.

However, demand from farmers remains limited, largely due to regulatory burdens and unfamiliarity with the product. Current legislation requires costly testing for contaminants like heavy metals, which are not really present in the region due to the low industrial activity, unlike Western Europe. In addition, including fertilizers companies in the transition is vital to avoid job losses in the conventional sector.

Adoption of bio-based fertilizers depends not only on technical viability but also on trust and awareness. Stakeholders advocate for labelling recovered nutrients to build market trust. Long-term field testing is essential to show efficacy across seasons and soil conditions and build trust. Clear quality indicators tailored to farmers' needs, like those piloted by NENUPHAR, can accelerate implementation.

Communication is also a major barrier. The public often has only a superficial awareness of these topics, and traditional informative methods are proving increasingly ineffective, so other forms of cooperation must be used, such as working with local communities and targeting specific user groups. Additionally, biobased fertilizer producers often lack the resources for commercial promotion, unlike conventional alternatives. Therefore, personal, practical engagement, through fairs, exhibitions, and one-on-one dialogue, is key to raise awareness and build trust.

Key takeaways

Despite these challenges, the framework in Latvia is promising and replicable, as it is based on clear criteria (legislation and circular economy principles). While the benefits of this model are not always reflected in direct financial terms, they contribute to broader environmental improvements and material circulation, benefitting society. Latvia's small market size allows easier coordination and knowledge transfer, but harmonizing monitoring practices and processes remains a challenge. Deliverable 4.2 from the NENUPHAR project identified overly restrictive regulations on composted sludge, lack of regional clarity, and difficulties promoting economic instruments for nutrient recovery.

Proposed solutions included establishing clear standards, simplifying regulations, offering financial support, and improving public education. To overcome these obstacles, legislative clarity is needed to support cooperation and provide assurance to stakeholders.

7.d Replicators

Bornholm replicator

Bornholm is a Danish Island of about 40.000 inhabitants located in the Baltic Sea. Two large industries operate on the island; a machine factory and a pig slaughterhouse where around 530.000 pigs/year are produced and slaughtered. In the early 1990's the existing WWTPs and extensive system of pump stations and pressure pipes for transporting the wastewater from the urban areas were build. Sludge from WWTPs and septic tanks are dewatered and composted, and both are used as fertilizer in agriculture. The flows to recover nutrients from are manure, sewage sludge and dairy wastewater.

With over 60% of its land used for agriculture and a large livestock export sector, the country has faced persistent nitrogen pollution challenges. Since the 1980s, the country has implemented a comprehensive mix of regulatory, fiscal, and voluntary tools aimed at reducing nitrogen losses while maintaining productivity, and they have one of most strict regulations in EU regarding heavy metals and organic micropollutants in sludge used in agriculture. These policies have reduced average nitrogen surplus, while significantly improving nitrogen use efficiency, hence reducing environmental impacts.

They have a fertilizer planning and invoicing system in place and a fertilizer tax, which helped reduce nitrogen fertilizer use by over 30% without lowering crop yields. Another agricultural emissions tax was announced in 2024, with the aim of taxing pork and dairy farms who emit above the permitted limit. They also promote technological innovation and have incentives in place for the use of biogas and waste treatment.

It was concluded in Deliverable 4.2 that Denmark presented more opportunities related to manure, sewage sludge, water and fertilizers, among all countries of the project. However, sewage sludge, manure and water are also affected negatively by regulation.

Despite progress, Denmark still struggles to meet the EU Water Framework and Habitats Directives. Initial nationwide regulation has helped, but it has been shown from experience that achieving higher levels of environmental protection demands spatially specific policies and ongoing innovation in farming and governance.

Cyprus replicator

Cyprus is an island in the Mediterranean Sea, with an area of 9,250 km2 and population of 850,000 inhabitants. It has one of the lowest compliance rates for the Urban Wastewater Treatment Directive, resulting in negative impacts on water quality and a lost potential for wastewater reuse and alleviation of water scarcity. Thus, it is considered one of the water poor countries of Europe with limited water resources and frequent occurrence of droughts. The country also struggles to implement EU waste policies and meet 2020 targets due to inadequate infrastructure for recycling and diverting biodegradable waste, poor coordination between administrative levels, insufficient local capacity, lack of waste management incentives, and weak producer responsibility schemes.

The quantities of the biodegradable fraction of municipal solid waste have been estimated for 2007 at 3,203,076 tonnes, with pig waste making the largest contribution at 49%. Municipal waste generation in Cyprus remains significantly higher than the 2017 EU average. The flows to recover nutrients from are manure, sewage sludge and dairy wastewater.

No strategies were identified at a regional level, and national programs are used instead. Despite the island being quite small, problems like water pollution and waste show that it’s hard to make these general policies work well. Without local rules, it's difficult to adjust the policies to fit the island’s needs.

8. Investment Profitability Analysis

8.a Profitability economic indicators

A profitability analysis requires detailed information about the financing of the project, as well as prices and costs over time. This includes data on raw materials, chemicals, utilities and final products to calculate variable operating costs, along with costs to calculate the fixed operating costs and capital investment. Therefore, collecting accurate data is a complex but crucial step, and relying on estimates and industry averages can make results less reliable. When evaluating costs across the entire product value chain, several decisions must be made, like which cost categories to include, how to aggregate or allocate them.

Indicators of economic performance are needed for the economic and profitability evaluation of a project on its conceptual and design stage. These are usually derived from Discounted Cash Flow models (DCF) and CAPEX & OPEX classifications, and include the Net Present Value (NPV), Internal Rate of Return (IRR), Payback Time, Discount rate and the Return on Investment (ROI) of the project.

Discounted cash flow analysis

The discounted cash flow is a valuation method for the value of an investment, based on the projections of how much money that investment will generate in the future. This analysis is an important aspect of financial management because it reveals the cash available to cover expenses, pay debts and reinvest in growth, providing a more accurate representation of the liquidity. Thus, it goes beyond accounting only profits, which can be affected by non-cash items, like depreciation expenses.

This method considers the present value of the cash flows that will be received in the future from the sales of the product, together with the present value of the capital and operational expenses (CAPEX and OPEX). These cash flows are discounted using a cost of capital factor, usually obtained from public industry statistics.

An investment is usually characterised by negative cash flows at the beginning of the project (the investment) and positive cash flows generated by selling the products during the operating time of the plant. For these calculations, an expected lifetime of the project must be set, with the typical project lifetime being between 15-25 years.

CAPEX & OPEX

The total investment required for a project, known as Capital Expenditures (CAPEX), represents the one-time cost of starting up everything on the project. This includes all construction costs, processing and handling equipment, site preparation, and non-process structures. CAPEX can be roughly divided into the sum of the fixed capital investment (FCI), which is the total cost of the plant for start-up (including the cost of design, construction, equipment, etc.) and working capital investment (WCI), which is the additional operating investment needed when starting up, so the costs for the labour, services and materials required to start the operation of the plant.

Operational Expenditures (OPEX) are the ongoing expenses incurred during the day-to-day functioning of a project. These costs include items such as salaries, utilities, rent, maintenance, raw materials, and other operational costs. Annual OPEX can be grouped into direct manufacturing costs (DMC), fixed manufacturing costs (FMC) and general expenses (GE), although not all the cost categories have to be provided (Turton et al., 2012).

Discount rate

The discount rate is the interest rate used to determine the present value of the future cash flows. You can calculate the discount rate if you know the future and present values and the total number of years of the project. The discount rate reduces future cash flows, so the higher the discount rate, the lower the present value of the future cash flows (meaning that money in the future will have less purchasing power).

The discount rate can be calculated with the following equation:

Equation 1. Calculation for the Discount Rate.

$$DR = \left(\frac{Future\ value\ of\ cash\ flow}{Present\ value}\right)^{1/n} - 1$$

Where n is the number of years until the Future Value of the cash flow. However, it is easier to rely on an industry-average discount rate rather than calculating it from scratch. For example, the discount rate of the Environmental and Waste Services Industry is around 6.88% (Damodaran, 2025).

Damodaran (2025) and Aguilar et al. (2017) assumed a discount rate of 4.89%, when analysing economically a plant in Ecuador for biogas production using anaerobic co-digestion of food waste and primary sludge. Wiranarongkorn et al. (2023) assumed a higher discount rate of 9.4%, for an integrated biorefinery treating furfural residue to produce biochemicals and energy. Choosing a higher discount rate reflects a higher risk of the project.

When assessing the viability of a potential project, the weighted average cost of capital (WACC) can also be used as the discount rate. The WACC is the average cost that the company pays for the capital coming from borrowing or selling equity.

Net Present Value (NPV)

The NPV measures the time value of money of the project's profitability. It is the difference between the present value of the cash coming in and the present value of the cash going out over a period of time. The NPV should be at least zero, as a positive NPV indicates that the project is expected to generate more cash than the initial investment, making it economically viable. It calculated with the following equation:

Equation 2. Calculation of the Net Present Value.

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

Where R_t is the net cash inflow-outflows during a single period, *i* is the discount rate or and t the number of periods.

In waste recovery projects, a small positive NPV can be usually achieved if discount rates are low, there are supportive policies in place (which help in the economic viability of the project), and the project can be scaled to reduce unit costs over time. This is especially important given that revenue streams from biobased products might be limited, as outlined in this report.

Internal Rate of Return (IRR)

The IRR measures the expected profitability of the project by quantifying the annual rate of growth that an investment is expected to generate. It is defined as the discount rate at which the NPV is just equal to zero, so it relies on the same formula as the NPV and gives the result as a percentage. It could be considered as the break-even interest rate of the investment, in way.

Equation 3. Calculation of the Internal Rate of Return.

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0$$

Where C_t is the net cash inflow during the period t, which can be negative or positive depending on the estimates for the project, and C_0 the total initial investment costs, which will always be negative because it is an outflow of cash.

A project is profitable when the IRR is higher than the discount rate. The higher the IRR, the more favourable the project, because it means the project can still break even (NPV = 0) even if future cash flows are discounted more heavily. So, when comparing investments, the one with the highest IRR would be considered the best.

Return on Investment (ROI)

The ROI shows how profitable an investment is by comparing the return to its cost. A higher ROI means a better return, while a negative ROI means a loss. It’s useful for comparing projects, but ROI doesn’t account for the passing of time, so it can be misleading as some investments can take longer to generate a profit than others and some costs might increase over time, such as inflation or tax rates.

The ROI is calculated by dividing the return of an investment by the cost of the investment, with the result being expressed as a percentage:

Equation 4. Calculation of the Return on Investment.

$$ROI = \frac{(Current\ value\ of\ investment - Cost\ of\ investment)}{Cost\ of\ investment}$$

The current value of an investment comes from the sale of the investment, so it includes factors like the cash flow over the investment's lifetime and any maintenance costs incurred. The average ROI of an industry changes due to competition, technology, and consumer preferences. What determines a "good" ROI depends on the specific financial objectives of the project (wealth accumulation, income generation, stability…).

The ROI of waste recovery projects could be promising due to the growing interest in organic practices, the savings in cost in raw materials and support from regulation.

Other economic factors

It is important to also consider the various taxes and insurance costs associated with running a plant. These can include local and regional taxes, property taxes, licensing fees, or even payments for environmental protection. These costs tend to be periodic and relatively stable, unless significant changes are made to the plant's infrastructure or insured assets. For biobased projects, there may be opportunities for tax deductions or incentives due to the biobased nature of the final products or the innovative technologies employed, as highlighted in this report.

8.b Environmental, social and governance indicators

In the transition to the circular economy, measuring and reporting on the progress becomes a key driver. This means going beyond mandatory requirements, as new frameworks emerge, including voluntary reporting frameworks, sector standards, methodologies to set goals, sector guidance, and regulated frameworks for sustainability disclosure (Ellen MacArthur Foundation, 2024).

With the rise in awareness towards sustainability, economic performance and investment decisions are becoming increasingly tied to environmental, social and governance (ESG) performance, to include these aspects in the daily operations of a company. These types of indicators can inform investment decisions and accelerate capital flows too, as well as guide decisions and provide a broader rationale. These indicators highlight trade-offs and synergies with financial performance, but it must be noted that they are not directed at economic profitability, but rather at disclosing information and showing compromise to social and environmental targets. Currently, there are barriers and concerns about data availability, and the comparability or reliability of the ESG assessment, and it is still a challenge to effectively report and measure these initiatives, as there is not a single, uniform method or indicator for such impacts (Gebhardt et al., 2023; Zarzycka & Krasodomska, 2021).

For example, adopting environmentally friendly practices can require a higher initial investment, but can yield long-term cost savings, resilience, and market reputation, which are not usually accounted in traditional economic profitability indicators. On the other hand, a profitable model might cause social harm, threatening future regulatory compliance. Therefore, an integrated framework for assessing business models and projects is needed.

Environmental metrics should assess how a business model interacts with and impacts natural ecosystems, addressing resource efficiency, carbon and other greenhouse gas emissions, biodiversity impact, waste reduction, pollution control, and nutrient recycling. Regarding social performance, indicators should address job creation and quality (including the creation of green jobs), health and safety standards, community engagement or access to benefits. Governance measures the structures, policies, and accountability mechanisms of a business model, such as transparency and reporting practices or stakeholder participation in decision-making.

This holistic framework is also explored in the concepts of the “Triple Bottom line” (TBL) or “Corporate Social Responsibility” (CSR), which also aim at integrating environmental and social concerns in the business operations of a company. The European Commission has promoted these concepts as a way to build trust between businesses and society and drive inclusive growth. For example, European law now requires large companies to publish regular reports on the social and environmental risks they face, and how their activities impact people and the environment, under the Corporate Sustainability Reporting Directive (CSRD) (Directorate-General for Financial Stability European Commission, n.d.).

Some other existing voluntary and mandatory reporting frameworks and mechanisms are:

- Environmental Footprint methods like the Product Environmental Footprint (PEF) and Organisational Environmental Footprint (OEF), which provide guidelines for modelling, calculating and reporting the environmental impacts through the life cycle analysis of specific products or an organization (Directorate-General for the Environment European Commission, n.d.-b).

- Global Reporting Initiative (GRI) Standards, which allow any organization to understand and report their impacts on the economy, environment and people in a comparable and reliable way. They are regularly reviewed to reflect best practices for sustainability reporting (Global Reporting Initiative, n.d.).

- The EU Eco-Management and Audit Scheme (EMAS) is a tool established by the EC to evaluate, report and improve the environmental performance of an organisation, with more than 4000 organizations registered as per 2025 (Directorate-General for the Environment European Commission, n.d.-a).

- Science-based Targets for Nature (SBTN): developed by the Science Based Targets Network, these describe how companies should evaluate, set targets, monitor, and report their environmental impacts. They provide a credible and prescriptive approach to achieve these goals (Science Based Targets Network, n.d.).

- The Taskforce on Nature-related Financial Disclosures (TNFD) has developed disclosure recommendations and guidelines so that businesses can assess, report and act on their dependencies, impacts, risks and opportunities related to nature, integrating these aspects in their decision making (Taskforce on Nature-related Financial Disclosures (TNFD), n.d.).

8.c Pricing strategies and green premiums

There are different approaches to determine the pricing of biobased fertilizers; the most used ones are the engineering-based and the value-based ones. The engineering approach sets the price based on the value of the nutrients contained in the fertilizer, referencing the prices in the mineral fertilizer market. While this method is straightforward and objective, it ignores other important factors such as the form, concentration and quality of nutrients, or the demand side of the market, particularly the willingness-to-pay of farmers for new products.

A value-based pricing strategy is based on the consumers' perception of value and is more recommended for setting prices and market strategies. Different studies have explored the willingness-to-pay and price sensitivity of farmers and agricultural stakeholders across the EU, highlighting the factors that influence purchasing decisions.

For instance, Moshkin et al. (2023) concluded that there are multiple potential pricing points for biobased fertilizers. However, in all cases fertilizer producers must be prepared to give up some revenue to increase market penetration of the products, accepting lower profit margins. In the agricultural sector, profit margins tend to be already low due to weather uncertainty, high inventory levels, operational costs, the need for farming and storage space, and the overall resource-intensive nature of agricultural activities.

Green premiums

Green Premiums are the extra price that consumers might be willing to pay for a product just because it is green or, in this case, biobased. Understanding where Green Premiums exist and where they will emerge over the short or medium term can help capture economic benefits and expand market penetration, determining market potential. The rising preference for organic food reflects an increasing consumer willingness to pay for sustainable agricultural practices, including the use of biobased fertilizers. This indicates the possibility for green premium in the prices of organic food.

However, the cost of organic fertilizers tends to be absorbed by farmers rather than reflected in final product prices, as evidenced in Table 2 in section 2, which shows that the cost difference between organic and inorganic fertilizers decreases when considering the total cost of food production instead of only the cost of the fertilizer (Šatvar Vrbančić et al., 2025).

As a result, the green premium opportunity for biofertilizers must target farmers as key consumers. Manufacturers need to consider product quality, production costs and the environmental awareness of farmers. In the mentioned study targeting Croatian farmers done by Šatvar Vrbančić et al. (2025), it was found that 47.78% of farmers would be willing to pay a premium if the quality of the fertilizer is shown to be better than their current options, but 36.45% of farmers were not willing to pay more, suggesting that cost is a major barrier.

Hong et al. (2018) found that the consumers' level of environmental awareness also affects directly green premiums: when awareness is low, manufacturers should price biofertilizers below conventional alternatives to secure market share. Conversely, when awareness is high, they can justify premium pricing for eco-friendly products (Hong et al., 2018). As mentioned in section 5, low awareness in farmers regarding environmental impacts of agricultural practices is a risk, so biofertilizers should be under-priced for the time being to reach market penetration.

This is further supported by (2023) who analysed farmers' willingness to pay for biobased and mineral fertilizers. Results showed that to maximize market penetration the price for biobased fertilizers should be around 30% to 45% lower than their mineral counterparts (Moshkin et al., 2023). According to Šatvar Vrbančić et al. (2025), the optimal selling price for biobased fertilizers in Europe is estimated to be 76.6% of the price of equivalent mineral fertilizers with similar nutrient content and properties.

Deliverable 4.3 also concludes that demand for mineral fertilizers is quite inelastic, meaning that changes in price have a limited effect on their consumption. As a result, only using price-based instruments (like taxes or subsidies) may not be enough to shift farmer behaviour. Additional measures (such as regulation and education programs) must be implemented to increase demand for organic fertilizers, instead of putting high taxes on mineral fertilizers.

9.Conclusions

The transition from linear to circular business models in the agricultural sector offers significant opportunities to address sustainability, economic resilience, and resource efficiency. The current system regarding the production of fertilizers imposes high environmental costs to the planet, and, economically, makes actors highly dependent on external sources and price volatility.

This deliverable has analysed the technical, economic, and social factors required for this shift, with a focus on nutrient recovery from waste streams. By redefining waste as a resource, circular strategies can reduce environmental burdens while creating new revenue opportunities, particularly in rural economies. Increasing nutrient use efficiency by recycling and recovering them from waste streams can help in achieving a partial replacement of mineral fertilizers with biobased fertilizers.

This transition requires a holistic approach, involving policy leadership, regulatory frameworks, and the active participation of businesses and consumers. The process also requires challenging social norms and adapting business models while ensuring fairness and equity.

A key finding of this work is the need to consider both supply and demand forces to ensure the scalability and adoption of biobased innovations, with farmers emerging as critical stakeholders on the demand side of the market. Their acceptance and participation are vital for the viability of biobased fertilizers. However, adoption can be hindered by price competitiveness, regulatory complexity, and limited awareness or trust in circular solutions. To bridge this gap, circular business models must be deeply aware of the local realities of their context, supported by appropriate infrastructure, and aligned with end-user needs.

The transition also relies on collaborative governance structures established across regions, as explored in Deliverable D2.3, which demonstrated the importance of engaging diverse stakeholders through Community of Members (CoM) frameworks to co-design governance solutions and support circular value chains.

Public policy from regional and local governments and institutions is key to support this emerging market in a fair way and ensure that economic benefits benefit all actors involved in the value chain and to level the playing field in terms of prices. The commitment of the EC is well established, as shown by their support for the bioeconomy. Financial options must be carefully analysed to ensure long-term viability, including targeted subsidies, eco-labels, and public-private partnerships. Furthermore, governance models that encourage stakeholder collaboration, decentralised implementation, and regional adaptation, such as those promoted by the Regional Innovation Valleys, will play a decisive role in ensuring long-term success.

It has also been identified that many of the environmental and social benefits associated with circular business models, such as reduced greenhouse gas emissions, improved soil health, job creation, and regional resilience are difficult to reflect in conventional economic assessments. Hence, these externalities are central to the long-term sustainability and societal value of nutrient recovery systems and must be accounted somehow in circular business practices. Methodologies and policy tools must advance towards the internalization of these positive externalities, through mechanisms such as life cycle assessments, impact valuations, or incentive structures.

Building on all the findings and previous deliverables, this deliverable proposes a methodology to support the development of viable, inclusive, and regionally adapted business models for the valorisation of nutrient-rich waste streams. The methodology follows a structured, sequential approach that includes key dimensions of implementation: the regulatory framework, identification of stakeholders, mapping of the value chain and market, the design of the business model, assessment of risks and barriers, economic and financial evaluation, and integration with relevant governance models.

In conclusion, making the circular business models to be applied at the identified waste streams of the NENUPHAR project requires a systemic and collaborative approach, while trying to keep it as local as possible. It's not only about the right technologies, but also about making sure these solutions are covering actual needs, are widely accepted and supported by policy. If the right conditions are in place, turning waste into valuable resources can play a key role in building a greener, fairer future for Europe's green transition.

10. Deviations

Two additional expert interviews were planned, in collaboration with AKI, to gather more insights into the transition to circular business models. However, the responses were not received in time to be incorporated into this deliverable.

11. References

[1] Aguilar, Marcelo Calispa, Wang, Yao Dong, Roskilly, Tony, Pathare, Pankaj B., & Lamidi, Rasaq O. (2017). Biogas from anaerobic co-digestion of food waste and primary sludge for cogeneration of power and heat. Energy Procedia, 142, 70–76. https://doi.org/10.1016/j.egypro.2017.12.012

[2] Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. In Journal of Cleaner Production (Vol. 65, pp. 42–56). https://doi.org/10.1016/j.jclepro.2013.11.039

[3] Castro, Camila Gonçalves, Trevisan, Adriana Hofmann, Pigosso, Daniela C. A., & Mascarenhas, Janaina. (2022). The rebound effect of circular economy: Definitions, mechanisms and a research agenda. In Journal of Cleaner Production (Vol. 345). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2022.131136

[4] Chojnacka, Katarzyna, Moustakas, Konstantinos, & Witek-Krowiak, Anna. (2020). Bio-based fertilizers: A practical approach towards circular economy. In Bioresource Technology (Vol. 295). https://doi.org/10.1016/j.biortech.2019.122223

[5] Coppens, Joeri, Grunert, Oliver, Van Den Hende, Sofie, Vanhoutte, Ilse, Boon, Nico, Haesaert, Geert, & De Gelder, Leen. (2016). The use of microalgae as a high-value organic slow-release fertilizer results in tomatoes with increased carotenoid and sugar levels. Journal of Applied Phycology, 28(4), 2367–2377. https://doi.org/10.1007/s10811-015-0775-2

[6] Damodaran, Aswath. (2025, January 5). European WACC data. NYU Stern School of Business. https://pages.stern.nyu.edu/~adamodar/pc/datasets/waccEurope.xls

[7] Daramola, Damilola A., & Hatzell, Marta C. (2023). Energy Demand of Nitrogen and Phosphorus Based Fertilizers and Approaches to Circularity. In ACS Energy Letters (Vol. 8, Issue 3). https://doi.org/10.1021/acsenergylett.2c02627

[8] Donner, Mechthild, Gohier, Romane, & de Vries, Hugo. (2020). A new circular business model typology for creating value from agro-waste. Science of the Total Environment, 716. https://doi.org/10.1016/j.scitotenv.2020.137065

[9] Donner, Mechthild, Verniquet, Anne, Broeze, Jan, Kayser, Katrin, & De Vries, Hugo. (2021). Critical success and risk factors for circular business models valorising agricultural waste and by-products. Resources, Conservation and Recycling, 165. https://doi.org/10.1016/j.resconrec.2020.105236

[10] EEA. (2024). Accelerating the circular economy in Europe: state and outlook 2024. Publications Office of the European Union.

[11] Elias, Andrew, Favaro, Camila, Bettiol, Wagner, Ribeiro, Caue, & Farinas, Cristiane. (2022). Economic Aspects on the Production of Biofertilizers as Granular Composites. ACS Sustainable Chemistry & Engineering, 10(31), 10426–10438. https://doi.org/https://doi.org/10.1021/acssuschemeng.2c04021

[12] Ellen MacArthur Foundation. (2015). Towards a circular economy - Business rationale for an accelerated transition. https://www.ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition

[13] Ellen Macarthur Foundation. (2021, November 23). Press Release: Circular Business Models. Ellen Macarthur Foundation. https://www.ellenmacarthurfoundation.org/press-release-circular-business-models

[14] Ellen MacArthur Foundation. (2024, March 4). Measurement and reporting for the circular economy. Ellen Macarthur Foundation. https://www.ellenmacarthurfoundation.org/topics/measurement/overview

[15] European Commission. (2020, March). Circular economy action plan. Environment.Ec.Europa.Eu. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

[16] European Commission. (2025). Call for evidence and public consultation: Towards a Circular, Regenerative and Competitive Bioeconomy. European Commission. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/14555-Towards-a-circular-regenerative-and-competitive-bioeconomy/feedback_en?p_id=47923705

[17] European Commission, Directorate General for Environment. (2025, March 31). Commission launches public consultation on upcoming EU Bioeconomy Strategy. Environment – European Commission. https://environment.ec.europa.eu/news/commission-launches-consultation-eu-bioeconomy-strategy-2025-03-31_en

[18] European Commission, Directorate General for Financial Stability. (n.d.). Corporate sustainability reporting. European Commission. Retrieved July 24, 2025, from https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

[19] European Commission: Directorate-General for Research and Innovation. (2018). A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment - Updated Bioeconomy Strategy. Publications Office. https://doi.org/10.2777/478385

[20] European Commission: Directorate-General for Research and Innovation. (2023). Regional innovation valleys for bioeconomy and food systems. https://doi.org/https://data.europa.eu/doi/10.2777/93434

[21] European Commission, Directorate General for the Environment. (n.d.-a). Eco Management and Audit Scheme (EMAS). Retrieved July 25, 2025, from https://green-forum.ec.europa.eu/green-business/emas_en

[22] European Commission, Directorate General for the Environment. (n.d.-b). Environmental Footprint Methods. European Commission. Retrieved July 25, 2025, from https://green-forum.ec.europa.eu/green-business/environmental-footprint-methods_en

[23] European Environment Agency. (2022, October 6). Progress and prospects for decarbonisation in the agriculture sector and beyond. European Environment Agency. https://www.eea.europa.eu/publications/Progress-and-prospects-for-decarbonisation

[24] European Environment Agency. (2024). Accelerating the circular economy in Europe : state and outlook 2024. Publications Office of the European Union.

[25] FAO. (2024). Inorganic fertilizers – 2002–2022. FAOSTAT Analytical Briefs, No. 90. https://doi.org/https://doi.org/10.4060/cd1485en

[26] Febrer, C. & Boy M. (2025) Deliverable D2.3 Outline of NENUPHAR Regional CoM. NENUPHAR – New governance models to enhance nutrient pollution handling and nutrients recycling (Grant Agreement No. 101082169).

[27] Febrer, C. & Boy M. (2025) Deliverable D2.4 Best practices for the implementation of governance models. NENUPHAR – New governance models to enhance nutrient pollution handling and nutrients recycling (Grant Agreement No. 101082169).

[28] Febrer, C. & Boy M. (2024) Deliverable D4.1 UE Policies and regulations baseline analysis. NENUPHAR – New governance models to enhance nutrient pollution handling and nutrients recycling (Grant Agreement No. 101082169).

[29] Fertilizers Europe. (2023). Forecast of food farming and fertilizer use in the European Union 2024-2034. https://www.fertilizerseurope.com/wp-content/uploads/2024/12/Forecast-2024-34-web.pdf

[30] Future Market Insights. (2024, October 2). Organic Fertilizer Market Projected to Reach USD 15,994.2 Million with a CAGR of 6.2% from 2024 to 2034: Sustainable Farming Trends and Key Growth Opportunities. GlobeNewswire. https://www.globenewswire.com/news-release/2024/10/02/2956952/0/en/Organic-Fertilizer-Market-Projected-to-Reach-USD-15-994-2-Million-with-a-CAGR-of-6-2-from-2024-to-2034-Sustainable-Farming-Trends-and-Key-Growth-Opportunities-FMI.html

[31] Gaffey, James, McMahon, Helena, Marsh, Emily, & Vos, John. (2021). Switching to Biobased Products - The Brand Owner Perspective. In Industrial Biotechnology (Vol. 17, Issue 3, pp. 109–116). Mary Ann Liebert Inc. https://doi.org/10.1089/ind.2021.29246.jga

[32] Gatto, Fabiana, & Re, Ilaria. (2021). Circular bioeconomy business models to overcome the valley of death. A systematic statistical analysis of studies and projects in emerging bio-based technologies and trends linked to the sme instrument support. Sustainability (Switzerland), 13(4), 1–37. https://doi.org/10.3390/su13041899

[33] Gebhardt, Maria, Thun, Toni W., Seefloth, Marcel, & Zülch, Henning. (2023). Managing sustainability—Does the integration of environmental, social and governance key performance indicators in the internal management systems contribute to companies' environmental, social and

governance performance? Business Strategy and the Environment, 32(4), 2175–2192. https://doi.org/10.1002/bse.3242

[34] Global Reporting Initiative. (n.d.). Global Reporting Initiative Standards. Standards. Retrieved July 25, 2025, from https://www.globalreporting.org/standards/

[35] Godinot, Olivier, Jouan, Julia, Nesme, Thomas, & Carof, Matthieu. (2024a). Evidence of a rebound effect in agriculture: Crop-livestock reconnection beyond the farm gate does not always lead to more sustainable nitrogen management. Agricultural Systems, 221. https://doi.org/10.1016/j.agsy.2024.104137

[36] Godinot, Olivier, Jouan, Julia, Nesme, Thomas, & Carof, Matthieu. (2024b). Evidence of a rebound effect in agriculture: Crop-livestock reconnection beyond the farm gate does not always lead to more sustainable nitrogen management. Agricultural Systems, 221. https://doi.org/10.1016/j.agsy.2024.104137ï

[37] Grizzetti, B., Vigiak, O., Aguilera, E., Aloe, A., Biganzoli, F., Billen, G., Caldeira, C., De Meij, A., Egle, L., Einarsson, R., Garnier, J., Gingrich, S., Hristov, J., Huygens, D., Koeble, R., Lassaletta, L., Le Noë, J., Liakos, L., Lugato, E., … Zanni, M. (2023). Knowledge for Integrated Nutrient Management Action Plan (INMAP), EUR 31487 EN. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/692320

[38] Haarich, Silke., Kirchmayr-Novak, Stephanie., Sanchez Lopez, Javier., Borzacchiello, Maria Teresa., & Avraamides, Marios. (2022). Bioeconomy strategy development in EU regions. Publications Office of the European Union.

[39] Hjorth, M., Christensen, K. V., Christensen, M. L., & Sommer, S. G. (2010). Solid-liquid separation of animal slurry in theory and practice. A review. In Agronomy for Sustainable Development (Vol. 30, Issue 1, pp. 153–180). https://doi.org/10.1051/agro/2009010

[40] Hong, Zhaofu, Wang, Hao, & Yu, Yugang. (2018). Green product pricing with non-green product reference. Transportation Research Part E: Logistics and Transportation Review, 115. https://doi.org/10.1016/j.tre.2018.03.013

[41] Joint Research Centre. (2022, October 13). Bioeconomy strategies in EU regions. Where are we? The Joint Research Centre: EU Science Hub. https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/bioeconomy-strategies-eu-regions-where-are-we-2022-10-13_en

[42] Kong, Wei, Kum, Hyun, Bae, Sang Hoon, Shim, Jaewoo, Kim, Hyunseok, Kong, Lingping, Meng, Yuan, Wang, Kejia, Kim, Chansoo, & Kim, Jeehwan. (2019). Path towards graphene commercialization from lab to market. In Nature Nanotechnology (Vol. 14, Issue 10). https://doi.org/10.1038/s41565-019-0555-2

[43] Kurniawati, Ari, Stankovics, Petra, Hilmi, Yahya Shafiyuddin, Toth, Gergely, Smol, Marzena, & Toth, Zoltan. (2023). Understanding the future of bio-based fertilizers: The EU's policy and

implementation. Sustainable Chemistry for Climate Action, 3. https://doi.org/10.1016/j.scca.2023.100033

[44] Laborda E. & Cebrián, M. (2024) Deliverable D4.2 Definition of current regulatory instruments and competencies of each demo case. NENUPHAR – New governance models to enhance nutrient pollution handling and nutrients recycling (Grant Agreement No. 101082169).

[45] Lewandowski, Mateusz. (2016). Designing the business models for circular economy-towards the conceptual framework. In Sustainability (Switzerland) (Vol. 8, Issue 1). MDPI. https://doi.org/10.3390/su8010043

[46] Miskó, K., Zita, E., Bálint, C., Hámori, J. (2025) Deliverable D4.3 Assessment tool and new proposals on economic instruments and financial schemes. NENUPHAR – New governance models to enhance nutrient pollution handling and nutrients recycling (Grant Agreement No. 101082169).

[47] Moshkin, Egor, Garmendia Lemus, Sergio, Bamelis, Lies, & Buysse, Jeroen. (2023). Assessment of willingness-to-pay for bio-based fertilizers among farmers and agricultural advisors in the EU. Journal of Cleaner Production, 414. https://doi.org/10.1016/j.jclepro.2023.137548

[48] Precedence Research. (2024, October 7). Fertilizer Market Size, Share, and Trends 2024 to 2034. Precedence Research. https://www.precedenceresearch.com/fertilizer-market

[49] Ramirez, Jerome, McCabe, Bernadette, Jensen, Paul D., Speight, Robert, Harrison, Mark, Van Den Berg, Lisa, & O'Hara, Ian. (2021). Wastes to profit: A circular economy approach to value-Addition in livestock industries. Animal Production Science, 61(6), 541–550. https://doi.org/10.1071/AN20400

[50] Reim, Wiebke, Parida, Vinit, & Sjödin, David R. (2019). Circular business models for the bio-economy: A review and new directions for future research. Sustainability (Switzerland), 11(9). https://doi.org/10.3390/su11092558

[51] Research and Markets. (2025, March 21). Fertilizers Market Global Forecast Report 2025-2030, with Profiles of ICL, Yara, K+S, Nutrien, Mosaic, CF Industries, Syngenta, EuroChem and more. GlobeNewswire. https://www.globenewswire.com/news-release/2025/03/21/3046959/0/en/Fertilizers-Market-Global-Forecast-Report-2025-2030-with-Profiles-of-ICL-Yara-K-S-Nutrien-Mosaic-CF-Industries-Syngenta-EuroChem-and-more.html

[52] Šatvar Vrbančić, Mihaela, Čoga, Lepomir, Špicnagel, Ana Marija, Vugrin, Natalija, Meers, Erik, & Čop, Tajana. (2025). Farmers' Preferences and Practices Regarding Bio-Based Fertilizers: A Croatian Perspective. Sustainability (Switzerland), 17(8). https://doi.org/10.3390/su17083367

[53] Science Based Targets Network. (n.d.). Science Based Targets Network. Retrieved July 25, 2025, from https://sciencebasedtargetsnetwork.org/

[54] Spherical Insights. (2022, October). Global Fertilizer Market Size, Share, and COVID-19 Impact Analysis, By Type (Organic and Inorganic), By Form (Dry and Liquid), Application (Horticulture, Agriculture, Gardening, and Others), and By Region (North America, Europe, Asia-Pacific, Latin

America, Middle East, and Africa), Analysis and Forecast 2021 – 2030. Spherical Insights. https://www.sphericalinsights.com/reports/fertilizer-market

[55] Sporchia, Fabio, & Caro, Dario. (2023). Exploring the potential of circular solutions to replace inorganic fertilizers in the European Union. Science of the Total Environment, 892. https://doi.org/10.1016/j.scitotenv.2023.164636

[56] Taskforce on Nature-related Financial Disclosures (TNFD). (n.d.). Taskforce on Nature-related Financial Disclosures. Retrieved July 25, 2025, from https://tnfd.global/

[57] Tierney, John. (2023, July 4). Fertilizer prices in 2023: why are they falling? How do they affect food markets? https://macrohive.com/hive-explainers/fertilizer-prices-in-2023-why-are-they-falling-how-do-they-affect-food-markets/

[58] Turton, R., Bailie, R. C., Whiting, W. B., & Shaeiwitz, J. A. (2012). Analysis, Synthesis, and Design of Chemical Process (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

[59] Vermunt, D. A., Negro, S. O., Verweij, P. A., Kuppens, D. V., & Hekkert, M. P. (2019). Exploring barriers to implementing different circular business models. Journal of Cleaner Production, 222, 891–902. https://doi.org/10.1016/j.jclepro.2019.03.052

[60] Will, Daya, & Aernouts, Jef. (2024, January 8). Updated standard fertilizer costs for 2023-2024 season. Farmdesk. https://www.farmdesk.eu/en/publication/update-standard-fertilizer-costs-2023-2024/

[61] Wiranarongkorn, K., Im-orb, K., Patcharavorachot, Y., Maréchal, F., & Arpornwichanop, A. (2023). Comparative techno-economic and energy analyses of integrated biorefinery processes of furfural and 5-hydroxymethylfurfural from biomass residue. Renewable and Sustainable Energy Reviews, 175. https://doi.org/10.1016/j.rser.2023.113146

[62] Zarzycka, Ewelina, & Krasodomska, Joanna. (2021). Environmental key performance indicators: the role of regulations and stakeholder influence. Environment Systems and Decisions, 41(4), 651–666. https://doi.org/10.1007/s10669-021-09825-z

Annexes

ANNEX 1 Interviews to experts

With the cooperation of AKI, one of the NENUPHAR partners, UVIC-UCC has interviewed different experts in order to gather insights regarding demand and production of biobased fertilizers.

1st expert

Stakeholder interviewed: the AKI financial department was not available to answer, so the question was re-directed from AKI's department to a senior manager of Climate Change and Sustainability Services in Ernst and Young; with experience as analyst and in the OTP Bank Green Program Directorate.

Question: *In the context of circular business models focused on producing biobased fertilizers by recovering nutrients from agricultural wastes such as pig slurry, are farmers reaping the benefits of said transition and strategy? How are the generated revenues distributed across the value chain (waste treaters, manufacturers, farmers, end consumers…)?*

Answer: At present, the situation is often asymmetrical in terms of the level of information and understanding that individual players have, and the benefits they can derive from this. For example, Lidl already has to disclose its carbon footprint because it has an impact on its financing and can already obtain green loans. It is already enforcing this on its suppliers. However, its suppliers (e.g., small and medium-sized companies) do not yet understand how this works.

Answer: SMEs are unable to issue green bonds—there is a minimum size for green bond issuance, and it does not work on a small scale (e.g., transaction costs are higher). To simplify, for the time being, the larger the player and the greater the concentration along the product chain, the better green financing works. In the case of the agricultural and food industry, for example, the two ends of the chain are fertilizer manufacturers and retailers are the largest. The question arises as to whether some kind of cooperation could work to bring together the more fragmented players in the chain.

ANNEX 2 Interviews to partners

The following questionnaire was sent to all NENUPHAR partners. Answers were received from CIRCE, AKI, LUKA and ZSA partners.

Questionnaire

Dear partner,

In order to collect feedback for Deliverable 4.4, led by UVIC-UCC, regarding the implementation of circular business models in each region, we kindly ask you to answer the following questions with as much information as you have, trying to be concise.

1. *Are there any existing practices or recent initiatives that can be a strong foundation or work together with the NENUPHAR project for moving toward a more circular model? Which stakeholders have been involved in them? Can the factors that have help in creating these initiatives be replicated?*

Answer – AKI

Carbon farming systems: offering carbon sequestration, soil health improvements, and new income streams for farmers. Here are notable initiatives and practices that align and can be synergized.

1. Voluntary Soil Carbon Credit Markets (e.g., Agreena, Soil Capital)

- Practices: No-till, cover cropping, reduced fertilizer use, long-term rotations.
- Stakeholders: Agritech startups (Agreena, Soil Capital), farmers, verifiers like Verra, buyers in corporate supply chains.
- Factors to replicate: Reliable MRV (measurement-reporting-verification), alignment with international standards, and financial incentives.

2. Regenerative Farming Networks & Platforms

- Examples:
  - Regrow uses satellite data and ML to monitor field-level practices and support corporate/regulator engagement
  - Farms4Climate's "AperiCarbon" and Murcia conference: participatory events with farmers, researchers, banks, regulators
- Stakeholders: Farmers, universities, financial institutions, policy bodies.
- Replicable factors: Peer-to-peer learning, co-designed protocols, inclusion of financial and technical actors.

3. EU-Funded Carbon-Farming Projects

- Carbon Farming CE (Interreg Central Europe): Tests 6 techniques in 9 countries; develops business models and MRV roadmaps with farmers, NGOs, policymakers

- EIT Climate-KIC / Irish Summit: Government–Climate-KIC partnership developing Ireland's national framework (including livestock emissions), piloting through 2027
- Bioeast HUB: Bioeast HUB is the network of national bioeconomy hubs across 11 Central and Eastern European (CEE) countries (including Hungary, Czechia, Bulgaria, Slovakia, Romania, etc.), established under the BIOEAST Initiative and empowered by the Horizon Europe BOOST4BIOEAST project. Its mission: foster regional collaboration to develop knowledge-based, circular bioeconomy strategies.
- National Hubs: Each country hosts its own HUB, coordinated by universities, ministries, research institutes, and NGOs—e.g., Hungary's hub launched Sept 2024 by BME, ÖMKi and AKI with support from the Ministry of Agriculture.
- Thematic Working Groups (TWGs): Support regional collaboration in Agroecology, Bio-based Materials, Freshwater, Education, etc. The Czech hub leads TWGs for Education and Clean Water, while the BIOEAST UniNet network connects universities across seven CEE countries.
- National hubs bring together:
- Public authorities: Ministries of Agriculture, Research & Education
- Academia & research institutes: Universities, Agricultural Academies, ÖMKi, BME, AKI, and AgriAcademy in Bulgaria
- Industry & agribusiness: Primary producers, biobased industry, agritech SMEs
- Civil society: NGOs, knowledge brokers, innovation clusters
- International experts: Western European partners integrating cross-regional expertise
- Key Activities & Success Enablers
- Strategic planning: Co-creating national bioeconomy action plans validated by public bodies
- Capacity building: Workshops, training, networking events (e.g., Annual Bioeconomy Conferences in Budapest); BIOEAST UniNet for universities
- Knowledge exchange platforms: Online knowledge portal, concept papers, best-practice info sheets, policy recommendations
- Cross-sector & policy linkages: Direct connection with policymaking, bridging sectoral gaps, supporting CAP and Green Deal alignment
- Regional coordination: Macro-regional alignment via the 11-state initiative, enabling shared SRIA updates by TWGs
- Replicable Factors
- Inclusive governance model – strong multi-stakeholder collaboration, connecting farmers, academia, government, business, and NGOs
- Alignment with EU frameworks – developing national plans within EU bioeconomy and Green Deal processes
- Capacity-building across levels – hands-on workshops plus strategic policy integration
- Shared innovation platforms – virtual toolboxes and university networks like UniNet
- Macro-regional coherence – common vision across the CEE region with joint SRIA and HUB-to-HUB learning

Circular Hungary (https://circularhungary.hu/)

- Mission: Accelerate Hungary's transition to a circular economy and position the country and local companies as global leaders in circular technologies.
- Structure: A voluntary cross-sector platform that connects businesses, academia, civil society, and government to develop and implement circular models, supported by working groups and coordinated via the MOL-PE Circular Economy Science Park.

Stakeholders Involved

- Government & Agencies: NRDI Office, various ministries, national waste authority
- Industry & Business: Over 180 companies (incl. SMEs, chemical, agri, construction, water), coordinated through BCSDH's Platform launched 2018 in partnership with Ministry and Dutch Embassy
- Academia & Research: 20+ universities, including University of Pannonia launching circular economy courses
- International Partners: Holland Circular Hotspot, Dutch development support, WBCSD/KPMG providing metrics frameworks MWBSD

Enabling Success Factors

- Broad, voluntary multi-stakeholder structure: Unifies government, academia, business, NGOs.
- Sector-specific working groups: Cover value chains from agri and construction to water and textiles.
- Institutional backing: Coordination by MOL-PE Science Park, hosted within NRDI framework.
- Capacity building: Workshops, training (Circular Economy Academy), conferences.
- Policy influence: Provides inputs to national strategy and regulations.
- Aligned with funding streams: Promotes EU and domestic R&D initiatives, supports access to grants.
- Adoption of circular metrics: CTI and similar tools for data-driven tracking by companies

Answer – CIRCE

Initiatives

- REDOL (Zaragoza, Regional Hub for Circularity): EU-funded project transforming Zaragoza into a climate-neutral and circular city and focused on redesigning urban-industrial waste chains: plastics, organics, textiles, e-waste.
- Aragon Circular Strategy and Aragon Circular Seal: Regional strategy launched in 2020 by the Government of Aragon. Promotes transition to a circular economy through 10 strategic commitments. The Seal recognizes organizations with strong circular practices.
- Operational Groups and Rural Innovation Projects (FEADER-Funded): These projects are part of Aragon's Rural Development Program, co-financed by EU FEADER funds and the regional government, fostering innovation in agriculture, livestock, and waste management.

“VALIQPORK” Focuses on the valorisation of pig slurry to produce biofertilizers and reduces environmental impact from livestock farming.

“OPTIDIGEST” Improves anaerobic digestion of agri-food waste as digestate and enhances biogas efficiency and nutrient recovery.

“COWCOMPOST” Promotes composting of cattle manure to create high-quality agricultural compost and encourages circular solutions in extensive livestock systems.

“FERTCAFÉ” Develops organic fertilizers from coffee waste from restaurants and industry and closes the urban-rural nutrient loop through composting and field trials.

“AGROCIRCULAR 2030” Aims to valorise agricultural and agri-food by-products (e.g., manure, rice husks). Results: biodegradable packaging, organic fertilizers.

The circular economy initiatives in Aragon have brought together a wide range of stakeholders, including:

- Public authorities: Government of Aragon, Zaragoza City Council.
- Research and technology centers: CIRCE, AITIIP, CITA, ITAINNOVA.
- Universities and academic institutions: University of Zaragoza, San Jorge University.
- Agri-food and environmental enterprises: cooperatives, livestock producers, waste management firms, composting companies, and local small and medium-sized enterprises took part in developing and piloting circular solutions.
- Industry and innovation platforms: actors from the bioenergy, fertilizer, and agri-tech sectors collaborated in Operational Groups to implement practical innovations on the ground.
- NGOs and sectoral associations: Involved in dissemination, training, and stakeholder engagement (particularly in rural innovation groups).

The key factors behind Aragon’s circular initiatives are highly replicable. Strong institutional support, especially through the Aragon Circular Strategy, provided clear direction and legitimacy. Access to EU and regional co-funding (e.g., FEADER) reduced financial risk and enabled innovation.

This combination of policy, funding, cooperation, and place-based design offers a strong, transferable framework for similar circular economy efforts elsewhere.

Answer – LUKA

On March 28, 2024, Latvia approved the Wastewater Sludge Management Plan for 2024–2027 (Cabinet of Ministers Order No. 237). This plan is based on a previously developed strategy that provides for sewage sludge management models at the regional level, and the most appropriate model for most regions is considered to be the composting of sewage sludge as part of the circular economy for use in agriculture. Water management companies, which are direct producers of excess sewage sludge, are actively involved in this process, as are the legislator, represented by the Ministry of Climate and Energy, and the State Environmental Service, as the supervisory authority. The NENUPHAR project promotes and continues this dialogue with practical results and examples so that the implementation of the sewage sludge management plan can move forward successfully. The NENUPHAR project also encourages the implementation of the water management plan, as farmers have already made their demand for an alternative to mineral fertilizers, which would be beneficial to all parties, heard loud and clear. It must be acknowledged that these factors are replicable, provided that there are clear criteria to follow – legislation and an understanding of the principles of the circular economy. The benefits are not always expressed in direct financial terms, but from a broader perspective of the environment and material circulation, the benefits are for society as a whole.

Answer – ZSA

We agree with the facts mentioned in the reply of LUKA. In Latvia, there are strong foundations for a new circular business model for the region – composted sewage sludge use in agriculture as a bio-based fertilizer. Wastewater Sludge Management Plan for 2024–2027 (Cabinet of Ministers Order No. 237) sets a course to make sewage sludge composting more popular in Latvia. However, there are still possible obstacles for implementation. For example, the process is not yet fully studied in Latvia. As the conditions in Latvia and Lithuania are specific, both in terms of wastewater and soil composition (e.g. both do not yet have too high concentrations of heavy metals, as there is no developed industry here, unlike in Western Europe), it can be said that the process of sewage sludge compost and its use in agriculture has not yet been fully explored. And therefore, there is not yet enough active demand for compost directly from farmers. However, an active interest is very much needed to motivate compost producers - sewage sludge processors (WWTPs) - to start producing quality compost and to introduce and promote this business model.

There are no other good examples of circular business models known to ZSA apart from NENUPHAR.

Additional to current NENUPHAR initiative, we see possible future opportunity to add onto this model by adding grain processing companies to the business model. Other possible stakeholders – grain pre-treatment processers. Such cooperation could be beneficial for all parties involved. Grain processing companies are often located quite close to the farmer, who is the final consumer in this business model. Using the grain residue from the grain processing plants as composting aggregates for sewage sludge composting process would reduce the costs of the supply chain and thus the costs of compost production (important for co-compost producers and end users). In turn, the waste processors may be interested in disposing of the organic waste - the grain residue

2. *Do you think there is an existing market for these secondary materials in your respective regions? Which one, if not, do you think that would be easy or more feasible to implement/support/motivate?*

Answer – AKI

There is a nascent but growing market for secondary materials in Hungary and Central Europe, particularly in the form of organic fertilizers, recovered phosphorus, digested sludge compost, and emerging waste-based biochar.

Organic fertilizers & recovered nutrients

- Numerous Hungarian companies (e.g. NUTRIMAN, 3R-BioPhosphate Ltd., Biofilter Zrt.) are producing organic fertilizers using recovered N and P from digestate or biomass (e.g., pelletized digestate, biochar with P).
- Academic research shows positive field results, such as sewage sludge compost being a viable phosphorus alternative in rye trials in Nyíregyháza.

Market viability: While the broader fertilizer market still heavily favors conventional mineral fertilizers (annual sales of 29,600 t N+P in 2023, down slightly) , demand for sustainable alternatives is rising, especially among organic farmers and green-oriented agritech providers like NUTRIMAN.

Phosphorus recovery from sludge/sludge ash

- In the Visegrád Group (incl. Hungary), there is recognized potential for P recovery from sewage sludge and sludge ash.
- Europe has around 75 full-scale P-recovery plants, including many struvite installations in wastewater treatment plants.

Market viability: While still nascent, legislation (e.g., EU Fertilizing Products Regulation) is pushing for mandatory P recovery, making struvite and ash-derived P increasingly marketable.

Emerging valorisation of biochar & digestate by-products

- Companies like 3R-BioPhosphate offer biochar-based products that act both as carbon-negative soil amendments and nutrient carriers.
- These materials have dual value—sequestering carbon and returning nutrients—appealing to regenerative farming models.

Which materials are easier to scale?

1. **Sewage-sludge compost / digestate-based fertilizers**
   • Benefit: Proven agronomic effectiveness, ongoing R&D, regulatory opening.
   • Easier adoption via organic farms and municipal reuse schemes.
2. Struvite recovery from wastewater
   • Benefit: Already built into EU regulations; good nutrient match for high-value crops.
   • Requires investment in treatment tech but benefits from over 75 EU installations.
3. Biochar + nutrient composites
   • Benefit: Strong carbon and nutrient narrative.
   • Adoption in early market phases via pilot projects and value-added pricing.

Enablers to scale secondary-material markets

- Regulation & Standards: The new EU Fertilizing Products Regulation boosts confidence and interoperability for recovered nutrient products.

- Financial Incentives: Subsidies for P-recovery systems, waste-to-product innovation (e.g., through Pillars of Circular Hungary or Széchenyi Plan Plus).
- Stakeholder Networks: Leveraging platforms like Circular Hungary or BCSDH's CE Platform to connect producers, agri-business, and policymakers.
- Proof-of-Concept Pilots: Expanding research plots (like Nyíregyháza's sludge compost trials) builds trust and market acceptance.
- MRV & Certification: Certified products (e.g., struvite under standards like EN 13432) assure farmers and buyers of quality and health compliance.

Answer – CIRCE

In Aragon, there is an emerging market for some secondary materials, particularly in areas related to the valorisation of livestock, agri-food, and organic waste. Products such as compost, treated digestate, and bio-based fertilizers (developed through projects like COWCOMPOST, OPTIDIGEST, and FERTCAFÉ) already have some local use, especially within cooperatives and farms committed to sustainable practices.

However, the market is not yet fully consolidated. Its development is limited by factors such as lack of standardization, low large-scale commercial demand, and limited awareness of the agronomic value of these alternatives compared to conventional fertilizers.

Among the different secondary materials, those that appear easiest to promote and scale up include:

- Manure- or organic-waste-based compost.
- Stabilized and treated digestate.
- Biofertilizers from agro-industrial by-products.

These materials are technically viable, aligned with the region's circular economy goals, and can build on previous pilot projects, quality labels, and public strategies such as the Aragon Circular Strategy.

Answer – LUKA

The market for wastewater sludge compost has already been calculated in the Wastewater Sludge Management Plan for 2024–2027. Essentially, there is much more agricultural land in Latvia where wastewater sludge compost can be used than there is wastewater sludge compost that can be produced.

Answer – ZSA

Again, we agree to the answers of LUKA – the potential market for composted sewage sludge is calculated and looks strong.

If the new approach - large-scale centralised production of sewage sludge compost - is successfully implemented, a significant amount of quality organic fertilizer will be obtained from circular economy stakeholders such as WWTPs, food processors and producers, including farmers with their food pretreatment. This will lead to a significant reduction of imported fertilizer, as initial analyses of the product - wastewater sewage sludge compost - show a good quality product.

The projected demand for the product is likely to be growing, due to the low animal density in the Baltic States compared to other EU countries and the lack of organic fertilizers. However, in order to stimulate this demand, the legislation on the use of sludge would need to be revised, which currently involves a disproportionate investment in the testing of various elements, which, according to our data, is unnecessary because the Baltics do not have a developed industry and are not heavy metals specific.

For farmers to be more vocal about their interest in this compost, we need evidence - that composted sewage sludge is of good quality and can make a good contribution to soil improvement and soil health, which is what NENUPHAR's activities will provide.

3. *Have you identified any necessities linked to the end-users of the biobased products (farmers) for the application of these products? Which are the main barriers for the implementation of these business models? What are the best mechanisms for social awareness and farmer education in your respective regions?*

Answer – AKI

Key farmer needs are:

1. Guaranteed agronomic performance
    a. Consistent nutrient content
    b. Predictable effects on yield and soil structure
    c. Compatibility with existing fertilization plans and machinery
2. Regulatory clarity and product safety certification
    a. Assurance against heavy metals, pathogens, microplastics in sludge-based products
    b. CE-marking (per EU Fertilizing Products Regulation) to avoid food-chain liabilities
3. Economic viability
    a. Competitive pricing versus conventional fertilizers
    b. Evidence of long-term soil health benefits (reducing need for other inputs)
    c. Access to subsidies/green schemes for using bio-based materials
4. Ease of use
    a. Suitable particle size, spreadability, storability
    b. Logistics and on-farm handling compatible with their scale
5. Trusted knowledge sources
    a. Recommendations from local agronomists, cooperatives, demonstration farmers
    b. Access to independent test results from regional universities or extension services

Main Barriers to Implementation of Circular Bio-Based Business Models. Hungary and CE region-specific obstacles include:

- Market immaturity & product unfamiliarity
  → Most farmers lack awareness or experience with digestate pellets, struvite, or biochar blends.
- Distrust in safety of waste-derived products
  → Concerns about pollutants, heavy metals, soil contamination.
- Fragmented logistics and processing infrastructure
  → Limited regional biorefineries or digestate upgrading facilities.
- Conservative purchasing behavior
  → Preference for tried-and-tested mineral fertilizers from trusted suppliers.
- Regulatory ambiguity (in certain product categories)
  → National rules sometimes lag behind EU standards for organic soil improvers or waste-based inputs.
- Lack of clear economic incentives
  → Few subsidies or premium payments tied to carbon farming or nutrient recycling use.

Best Mechanisms for Social Awareness & Farmer Education (CE Region)

1. On-farm demonstration plots and farmer-led trials
   → E.g., the Hungarian EIP-AGRI demo projects in Nyíregyháza and Szekszárd using sewage-sludge compost
   → Effective because farmers trust peer outcomes on local soils.
2. Professional agricultural extension services & advisers
   → In Hungary: NAK (National Chamber of Agriculture) field consultants, universities like SZIE (MATE) and University of Debrecen
   → Need to be equipped with up-to-date CE knowledge.
3. CE platforms integrating farmer networks
   → Circular Hungary or BCSDH CE Platform can host sector-specific events on agri-nutrient recycling.
4. Certification schemes and labels
   → CE-marking and carbon farming credits tied to bio-based fertilizer use
   → Increases farmer confidence and potential added income.
5. Rural community awareness campaigns via cooperatives
   → Informal but powerful — local cooperatives or machinery rings arranging CE-awareness days.
6. Digital knowledge-sharing platforms
   → Webinars, regional CE databases (like the Bioeast Hub knowledge platform being developed).

Answer – CIRCE

Their main requirements include:

- Reliability and agronomic effectiveness: farmers need guarantees about the quality, stability, and performance of these products compared to conventional fertilizers.
- Ease of use and compatibility with their current farming practices, especially in large-scale or livestock-based operations.
- Clear and accessible information regarding benefits, dosage, legal requirements, and mid-term effects on soil and crops.

The main barriers to the implementation of these circular business models are:

- Lack of trust or limited awareness about the actual effectiveness of biobased products.
- Insufficient standardization, labelling, and certification, which complicates commercialization.
- Logistical costs related to the transport and application of bulky organic materials.
- Limited coordination between waste producers, processors, and final users (farmers).

Regarding the most effective mechanisms for awareness and education, Aragon has shown success through:

- On-farm demonstrations and pilot trials, where farmers can directly observe the outcomes.
- Operational and cooperative groups, in which farmers participate actively in co-developing solutions.
- Technical workshops and field days organized by institutions, farmers' cooperatives, and professional associations.
- Awareness campaigns aligned with regional policies, such as the Aragon Circular Strategy or the Aragon Circular Seal.

In summary, a combination of technical training, practical support, and institutional backing is essential to encourage the real and sustained adoption of circular economy models in the agricultural sector.

Answer – LUKA

Yes, technical needs have been identified in terms of setting quality criteria and expressing quality indicator results, which could enable farmers to develop fertilization plans for their land much more quickly and accurately. The NENUPHAR project already sets all indicators in its pilot according to farmers' needs, which speeds up the process (proven in practice). The main obstacles to continuing this cooperation model at present are the adoption of the necessary legislative changes for mutual clarity. Practical events dedicated to agriculture (such as the current NENUPHAR project), exhibitions, and personal conversations, during which experiences can be shared without concern, are considered to be the best mechanisms for promoting public awareness and educating farmers.

Answer – ZSA

Local field testing of these bio-based fertilizers is needed, preferably on a long-term basis, as climatic conditions vary greatly from year to year and the availability of different nutrients to plants varies (e.g. when testing soil and runoff samples in the first season after organic fertilization, there may be cases where it is not known where phosphorus disappears - it may not initially show up in the soil where phosphorus disappears).

It is not possible to inform equally well farmers as end users and society as a whole using the same methods and forms as there are different specific requirements for these groups. The public, whose knowledge is very superficial and cursory. Additionally, the usual forms of information do not really work anymore, and other forms of cooperation have to be sought - local communities and specific target groups etc.

In addition, product promotion requires the creation of particularly good advertising materials. Usually, projects involve project specialists and field experts but not advertising specialists. While more commercial products are promoted using high-quality advertisements, in the use of which large resources of knowledge, time and money are invested, such initiatives often falter, using fewer resources for information and thus not gaining sufficient popularity.