European Climate, Infrastructure and Environment Executive Agency - CINEA

Work Package 2

Regulatory barriers, sustainable good practices, and recommendations on future paths for using viable recycled media in microalgae fertilising products for organic farming

Annex to the Final Report

European Maritime, Aquaculture and Fisheries Fund (EMFAF)

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Acronyms

Abbreviation	Definition
ABP	Animal byproduct
AD	Anaerobic Digestion
CAGR	Compound Annual Growth Rate
CCU	Carbon Capture and Utilisation
CO2	Carbon Dioxide
COD	Chemical Oxygen Demand
DAC	Direct Air Capture
DIC	Dissolved Inorganic Carbon
EC	European Commission
EU	European Union
EU ETS	EU Emissions Trading System
FPR	Fertilising Products Regulation
GAECs	Good Agricultural and Environmental Conditions
HRAP	High-Rate Algal Ponds
K	Potassium
MS	Member State
MSFD	EU Marine Strategy Framework Directive
N	Nitrogen
P	Phosphorus
PBR	Photobioreactor
PoM	Programmes of Measures
SMRs	Statutory Management Requirements
WFD	Water Framework Directive

Executive summary

The Farm to Fork Strategy aims to have at least 25% of the EU's agricultural land under organic farming by 2030. New, innovative, and efficient primary production methods that are compatible with organic production are being adopted. Biobased fertiliser (organic carbon-based) are increasingly being used worldwide as a complement to traditional mineral fertilisers, helping to enhance soil health and reduce reliance on synthetic inputs. At the same time, plant biostimulant are gaining traction in agriculture to strengthen crop resilience and improve resource-use efficiency in intensive production systems.

A new generation of innovative microalgae-based biostimulants can promise to boost organic food production; however, this comes at a premium cost. As farmers are already under pressure from further obligations without support, this would only aggravate the current situation ([1]). New biostimulant products are subject to efficacy and safety evaluations to substantiate their claims, such as enhancing nutrient use efficiency or improving plant tolerance to abiotic stress. These products are typically applied in combination with fertilisers to support crop performance and more efficient nutrient management. **Currently, most biostimulants on the European market are imported. Furthermore, very few biostimulants carry an organic label.**

This report first scrutinises the European regulatory framework for organic production rules (especially Regulations (EU) 2018/848 and 2021/1165) concerning microalgae production provisions for biostimulant and fertiliser applications. The scope includes permitted nutrient inputs for **organic microalgae production intended for fertilising product applications** (fertilisers and plant biostimulants). The analysis shows that the rules are complex, fragmented, and unfair to microalgae, with definitions and provisions inadequately described, creating many barriers to industry uptake.

Based on the regulatory findings, **the report analyses viable alternative agro-industrial sources of effluents containing macronutrients and carbon dioxide in Europe** suitable for organic microalgae production, by considering technical/value chain, economic, and environmental factors. The analysis concludes by suggesting three promising, scalable scenarios of nutrient sources for microalgae production:

Plant-based Anaerobic Digestion Effluents:

These effluents are rich in ammonium, ortho-phosphate, and other nutrients essential for microalgae growth, making them an effective, sustainable feedstock. Integrating microalgae cultivation with biogas plants can recover nutrients from digestate, reduce biomass production costs, increase treatment efficiency, and

([1]) ESPP ScopeNewsletter151.pdf. (n.d.). Available here.

use waste CO_2 and heat, all contributing to technical and economic feasibility at large scales.

Treated Winery and Brewery Effluents:

Pre-treated effluents from wineries and breweries contain substantial levels of nitrogen, phosphorus, and organic carbon, which support robust microalgae cultivation. Treatment beforehand reduces inhibitory compounds, ensuring stable and scalable algal growth while achieving effective wastewater remediation and bioresource recovery. This circular approach aligns with environmental policies and can be economically viable due to reduced treatment costs and added value products.

Untreated Winery/Brewery Effluents:

Direct use of untreated effluents leverages high organic and nutrient loads for rapid microalgae production, minimizing the need for additional growth media and lowering operational expenses. Although this may require careful species selection or adaptation to cope with variability and potential inhibitors, using these waste streams at scale turns significant pollution sources into valuable resources, supporting both cost-effective wastewater management and sustainable biomass production.

These scenarios were then used to develop recommendations for regulators at both the European and Member State (MS) levels on how to support this nascent niche market.

This report comes at a good time. A new European Commission (EC) College was formed last year, and the regulatory framework has been re-evaluated. The EC has promised that the expected **Circular Economy Act** will support sustainability and circularity in the economy, especially concerning critical raw materials such as phosphorus.

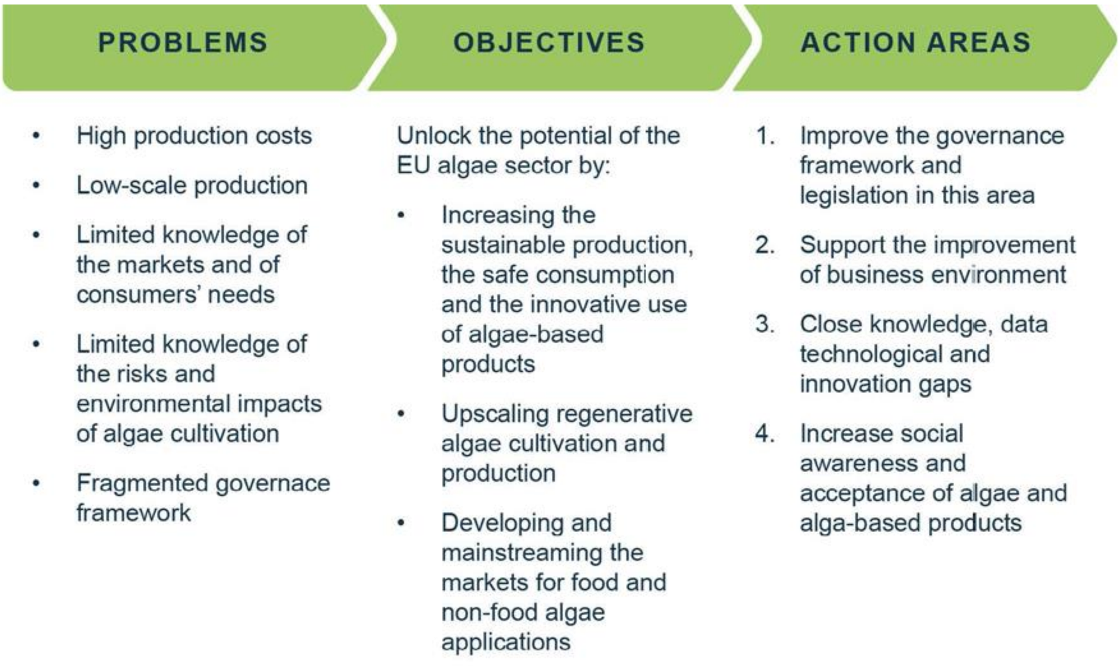
Based on the situational analysis and examination of existing legal frameworks and governance, priority recommendations are proposed in Section 6. Key recommendations for DG AGRI, DG GROW, Member States, industry, and researchers focus on regulatory harmonization, circular economy incentives, capacity building, and innovation support. Detailed recommendations are provided in Section 6.

1. Introduction

1.1. About the EU Algae Initiative

The EU Algae Initiative was announced on 15 November 2022 in a Communication from the Commission: *Towards a Strong and Sustainable EU Algae Sector,* and sets out 23 specific policy actions to accelerate the development of the European algae sector. The EU Algae Initiative aims to improve the sustainable production and consumption of algae across Europe. This initiative acknowledges the potential of algae-based products, including their application in fertilisers, to reduce dependence on traditional fertilisers and support sustainable agricultural practices.

Figure 1 - EU Algae Initiative: Unlocking the potential of the EU algae sector



Source: EU4Algae

Out of these 23 strategic actions, for this report, the following action has been identified as being most relevant to this report:

Action 8A – to work with the algae industry and Member States to identify valid and safe alternatives for sourcing nutrients and CO_2 for microalgae cultivation and organic certification. This includes the use of secondary nutrients (from wastewater) or excess nutrients from eutrophic surface waters for the cultivation of microalgae and cyanobacteria in closed cycles.

1.2 Objectives of the report

This report aimed to showcase viable and scalable alternative nutrients and carbon dioxide for producing microalgae and cyanobacteria for applications in organic production, as regulated under Regulation 2018/848.

Specific objectives are to:

1. Assess the state of play regarding the use of alternative sources of carbon and nutrients for organic microalgae cultivation for fertiliser market applications, with an emphasis on analysing the legal framework and the application of EU laws by Member States; and

2. Develop a set of industry-validated recommendations for viable alternative sources of carbon and nutrients, considering economic, legal, and environmental dimensions.

The target audience for this report is primarily the European Commission services – e.g. DG MARE, DG AGRI, DG GROW, DG RTD, DG ENV, and JRC – as well as the research community, industry, and the public.

1.3 Definitions & scope of the report

1.3.1 Definitions

Algae are a highly diverse group of organisms found almost everywhere on the planet. *Algae* is an informal term referring to a large and varied collection of photosynthetic eukaryotic and prokaryotic organisms that are not evolutionarily related and therefore come from different taxonomic backgrounds. The term is used in a general sense, much like how people refer to “trees”, “bushes”, or “herbs”.

Algae include organisms ranging from unicellular microalgae and cyanobacteria to multicellular forms such as giant kelp, a large brown alga that can grow up to 60 metres in length. Most algae are photoautotrophic in nature, performing oxygenic photosynthesis and fixing CO_2 using sunlight. However, there are exceptions: some heterotrophic algae can grow in the dark using simple organic compounds, while others lack photosynthetic organelles entirely and are unable to perform photosynthesis. Estimates suggest that algae encompass anywhere from 30,000 to over one million species.

Algae can be grouped into:

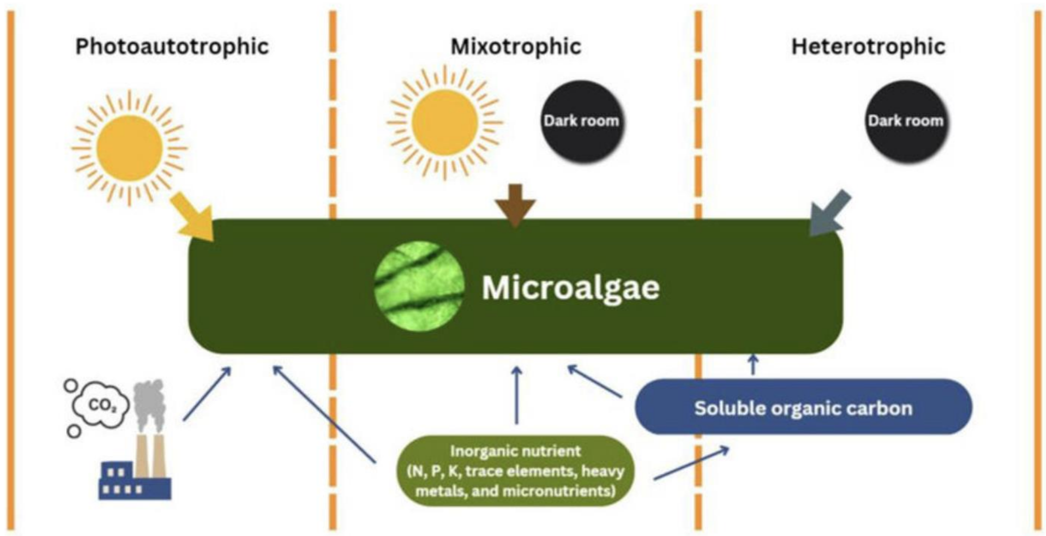
- macroscopic multicellular species;

- microscopic and mostly unicellular (although they can also be filamentous or colonial) species called microalgae.

Microalgae are microscopic eukaryotic organisms composed of single differentiated cells which can obtain energy using chromophores. They lack complex structural differentiation like flowers or spores for proliferation, and multiply by means of single celled gametes or by vegetative cell division.

Cyanobacteria are prokaryotic organisms that can grow under photoautotrophic, mixotrophic or heterotrophic. In this report, cyanobacteria species are treated as a sub-category of microalgae species, unless mentioned separately.

Figure 2 - Different trophic conditions utilised by microalgae



Source: Adapted from Sundaram, T. et al. (2)

Aquaculture means the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants, such as algae.

Fertiliser (as defined under Regulation (EU) 2019/1009) is a natural or artificial substance, mixture, microorganism, or other material that contains essential plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K), and is applied or intended to be applied to plants, their rhizosphere, mushrooms, or their mycosphere—either alone or in combination with other materials—for the purpose of providing nutrients or improving nutrient use efficiency, thereby enhancing plant growth and productivity. Fertilisers can be classified as **mineral**, **organic**, or **organo-mineral**, depending on the origin of their

(2) Sundaram, T., Rajendran, S., Gnanasekaran, L., et al. (2023). Bioengineering strategies of microalgae biomass for biofuel production: Recent advancement and insight. *Bioengineered*, *14*(1), 2252228. https://doi.org/10.1080/21655979.2023.2252228

components, and are sometimes referred to as **plant nutrients** or **enrichment products**.

Plant biostimulant (as defined under Regulation (EU) 2019/1009) means a product that stimulates plant nutrition processes independently of its nutrient content, with the sole aim of improving one or more of the following characteristics of the plant or its rhizosphere: (a) nutrient use efficiency; (b) tolerance to abiotic stress; (c) quality traits; or (d) availability of confined nutrients in soil or rhizosphere. Biostimulants typically contain bioactive substances or extracts and are applied in small quantities to the plant or soil. Under the FPR, plant biostimulants must not provide nutrients themselves; however, a fertilising product blend (e.g. plant biostimulant + fertiliser) may deliver both functions in a single formulation.

Biogenic Carbon Dioxide (CO_2) is defined as CO_2 released because of organic (biological) matter decomposition or combustion.

1.3.2 Scope

This report focused on industry-relevant alternative sources of carbon dioxide gas and soluble macronutrients for producing microalgae on land, which can produce agronomic products, such as fertiliser and biostimulants, relevant for organic production rules.

Algae-based agronomic products that cannot be certified or labelled for organic production are out of the scope of this report, as these are scoped in another report delivered under this report ([3]). Also, **only microalgae and cyanobacteria species** are covered in this report. In contrast, heterotrophic microalgae are out of scope.

Finally, the report focused on alternative, i.e., secondary and tertiary process side streams and effluents available on land as sources rich in carbon dioxide, dissolved nitrogen, phosphorus, and potassium. Thus, virgin sources, such as mineral sources of nitrogen, phosphorus, and potassium, direct air capture (DAC), and natural water bioremediation schemes, are out of scope.

A complementary report on “Advancing algae-based alternatives in EU aquafeeds: pathways to reducing fish-based ingredients” (Work Package 1) addresses heterotrophic algae for aqua feed applications.

Furthermore, there is a second complementary report of the Algae Industry report called on “Algae potential for (waste)water treatment and fertiliser/plant biostimulants production” (Work Package 3) which investigated:

([3]) Sustainable Algae Industry Study WP3 “Algae potential for (waste)water treatment and fertiliser/plant biostimulants production”

- Algae-fertilisers for conventional agriculture;
- Algae that remediate natural, marine or fresh waters from nutrients and used as fertiliser;
- Algae used for urban wastewater treatment;
- Strategies for recycling nutrients from (industrial) side streams to grow algae, e.g. regional industrial symbiosis.

Regarding the assessment methods used, a state-of-the-art regulatory analysis – drawing from European and national regulations – was conducted to establish compliance requirements. In addition, interviews with key stakeholders, including European Commission regulators, experts, and industry representatives, were carried out to identify and validate regulatory barriers and industry trends, and to inform the design of recommendations for next steps.

- **Chapter 1** presents the task description, the objectives of this report, the scope, and the rationale.
- **Chapter 2** defines the challenge and strategic environment, introduces the main vocabulary used, and outlines the state of play in organic agriculture and aquaculture.
- **Chapter 3** analyses the European policy framework, including the Green Deal, the Farm to Fork Strategy, the Action Plan on organic production, nutrient management, fertilisers, the European organic regulatory framework, and relevant industry standards.
- **Chapter 4** maps the available and relevant industrial effluent streams in Europe that are suitable as alternative sources of macronutrients and CO_2 for growing microalgae.
- **Chapter 5** develops scenarios for Northern and Southern European climates based on the most promising effluent sources. It also includes three fact sheets that assess the legal, environmental, and economic dimensions of these scenarios.
- **Chapter 6** provides priority recommendations for next steps, directed at EU policymakers, Member State authorities, industry, and research stakeholders.

2. Challenge & strategic environment

2.1. Defining organic fertilisers

2.1.1. Vocabulary: Organic vs. …Organic!

A shared language is currently lacking for organic fertilisers.

According to **EU Fertilising Product Regulation, Regulation (EC) No 2019/1009** laying down rules on the making available on the market of EU fertilising products:

Organic fertiliser contains organic carbon (C org) and nutrients of solely biological origin. An organic fertiliser may include peat, leonhardite, and lignite, but no other material that is fossilised or embedded in geological formations. Also, according to EEA ([4]), organic fertilisers are materials of animal origin used to maintain or improve plant nutrition and the physical, chemical, and biological properties of soils, either separately or in combination. These may include manure, digestive tract content, compost, and digestion residues.

The EU adopted new rules for **organic and waste derived fertilising** in 2019, . Thus, **the definition of EU regulation for organic fertiliser consistently differs from the subject of this report, which focuses on fertilisers used in organic production systems.**

Confusion sometimes arises due to the dual meaning of the word *organic* in English-speaking countries. Unlike in Italy, France, Germany, or Denmark – where organic farming is referred to as *biologic*, *BIO*, or *ØKO* (ecological) – the English term *organic* can refer either to a method of agriculture or to a chemical classification based on carbon content.

To avoid ambiguity, this report uses the term *organic* – as in *organic algae* or *organic products* – **exclusively to refer to organic production**, i.e. biologic agriculture.

2.1.2. State of play of organic agriculture and aquaculture

The European regulatory framework is increasingly restricting the use of chemical inputs in organic farming in response to growing demand for organic food and

([4]) European Environment Agency (n.d.). Organic fertiliser. Available here.

rising environmental awareness ([5]). The organic sectors have been highly dynamic in the EU-27 over the past decade. The **organic agriculture sector** has shown significant growth in cultivated surface area and production volume. According to Eurostat data, the organic surface area in the EU-27 reached **14.7 million hectares** in 2020 – an increase of **55.6%** from 2012 to 2020 ([6]). France, Spain, Italy, and Germany are the most important organic areas. At the EU-27 level, organic land represented **9.1%** of the total utilised agricultural area in 2022.

In the aquaculture sector, global production reached **87 million tonnes** in 2020. China remains the largest producer, accounting for **57%** of total global output, followed by India, which accounts for **10%** of global organic aquaculture production. The EU-27 ranked **10th globally**, contributing **1.3%** to global aquaculture production, with **1.1 million tonnes** produced. This production is primarily composed of mussels, oysters, and fish, with lower volumes for clams. According to EU and national sources, total organic aquaculture production in the EU-27 was estimated at **74,032 tonnes** in 2020, representing **6.4%** of total EU aquaculture production. For comparison, in 2015 the organic aquaculture production was estimated at **46,341 tonnes** in the EU-27 (and **49,723 tonnes** in the EU-28), accounting for approximately **4%** of the sector (EUMOFA report).

Organic microalgae production is in a nascent stage, mainly comprising the cultivation of cyanobacteria (*Spirulina/Arthrospira),* and microalgae grown on land. Given the small volumes, organic algae products are sold locally. They may be marketed in bulk in business-to-business (B2B) contexts for further processing or sold via retail in specialised organic stores. Country-level data on microalgae and cyanobacteria (mainly Spirulina) are presented below from a CIRCALGAE project report; however, it should be noted that these figures may already be outdated due to the rapidly growing market in Europe. The data may be considered indicative of the EU organic market ([7]).

([5]) Brunelle, T., Chakir, R., Carpentier, A., et al. (2024b). Reducing chemical inputs in agriculture requires a system change. Communications Earth & Environment, 5(1). https://doi.org/10.1038/s43247-024-01533-1
([6]) European Union. (2022). ORGANIC AQUACULTURE IN THE EU. In Maritime Affairs and Fisheries. Publications Office of the European Union. Available here.
([7]) EABA communication (20 May 2025).

Table 1 - Organic microalgae aquaculture production statistics by country

Country	Tonnes (dry weight)	Year
Europe - All	Spirulina: 347 Microalgae: 182	2019
Iceland	Microalgae: 50	2020
France	Spirulina: 222 Microalgae: 4.6	2019 2022
Austria	Microalgae: 15	2021
Italy	Spirulina & microalgae: 27.5	2023
Spain	Spirulina & microalgae: 2.59	2021
Germany	Microalgae: 150*	2019
Sweden	Microalgae:40	2022
UK	Spirulina & microalgae: 1-5	2013

Note: * - may not be directly comparable with other data In European production, due to differences in reporting methods, production types, or measurement (e.g., dry vs. wet weight).

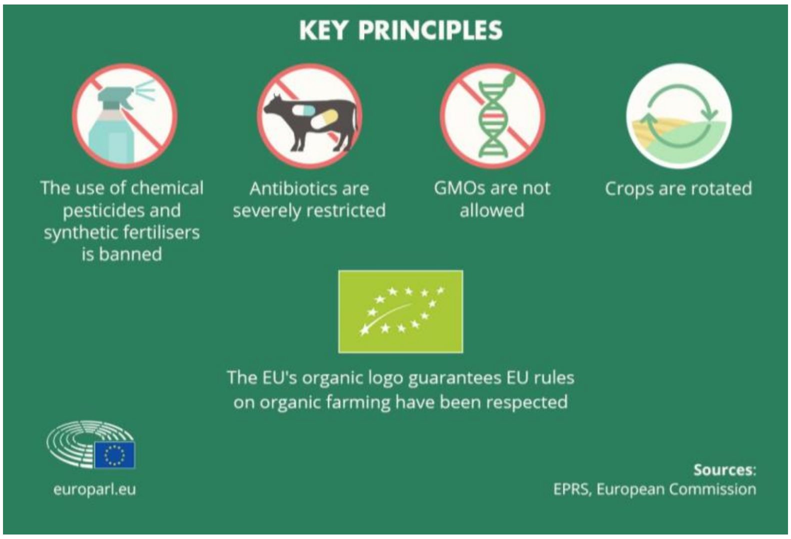
2.1.3. Where organic production meets circular economy

Producing organically in Europe means adhering to the rules on organic farming. These rules are designed based on general and specific principles to **promote environmental protection, maintain the biodiversity of Europe, and build consumer trust in organic products.**

These regulations govern **all areas of organic production** and are based on several **principles,** such as:

- **responsible use of energy and natural resources;**
- **sustainability of soil, water, air, plants, and animals,** and preservation of natural landscape and heritage;
- **limiting the use of artificial** fertilisers, herbicides, and pesticides;
- excluding the use of GMOs and other veterinary medicines.

Figure 3 - EU's organic food market: Facts and Rules



Source: European Parliamentary Research Service (EPRS), European Commission. "Key principles of organic farming in the EU." European Parliament, europarl.europa.eu ([8]).

This means that organic producers must adopt different approaches to **maintaining soil fertility** and ensuring animal and plant health, including the following:

- **prohibition of the use of mineral nitrogen fertilisers;**
- **cultivation of nitrogen-fixing plants and other green manure crops** to restore the fertility of the soil, including algae.

But how do organic value chain principles align with circular economy principles?

Algae, whether in whole or processed form, can be used as macro-nutrient fertilisers and crop biostimulants when applied to land, enhancing plant growth. However, as photosynthetic organisms, algae themselves also require macronutrients (and carbon dioxide) to grow. For example, in land-based algae production systems, nutrient-containing growth media and dissolved inorganic carbon dioxide (DIC, supplied as CO_2 gas) are commonly added as inputs to support algae growth. However, fertilisers and nutrient inputs used in aquaculture or algae production are **not covered under the EU Fertilising Products Regulation (EU) 2019/1009**, which applies only to fertilising products placed on the market for use on agricultural and horticultural land.

The **circular economy** is a system in which materials never become waste and nature is allowed to regenerate. In a circular economy, products and materials are kept in circulation through maintenance, reuse, refurbishment, remanufacturing, recycling, and composting. This model addresses climate

([8]) The EU's organic food market: facts and rules (infographic) | Topics | European Parliament. (2018, October 4). Topics | European Parliament. Available here.

change and other global challenges – such as biodiversity loss, waste, and pollution – by decoupling economic activity from the consumption of finite resources ([9];[10]).

The circular economy is based on three principles, driven by design:

- Eliminate waste and pollution;
- Circulate products and materials (at their highest value);
- Regenerate nature; by slowing down extraction of virgin resources, we leave space for natural systems to recover and regenerate.

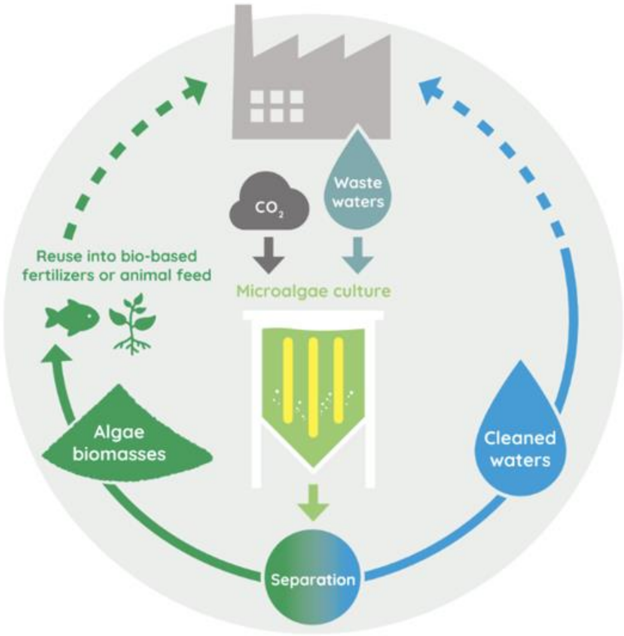
Circular materials or inputs (including biobased ones) are non-virgin and/or regeneratively grown products. In contrast, circular processes refer to interventions – such as reusing, remanufacturing, and recycling – that keep products and materials in circulation.

In this context, microalgae cultivation using alternative nutrient sources serves as a strong example of circular economy principles that can also comply with organic production standards. The circular economy framework for microalgae centres on maximising resource efficiency, minimising waste, preventing pollution, and regenerating natural systems through closed-loop processes conducted on land. Microalgae production can repurpose nutrient-rich effluents and carbon dioxide-rich gases that would otherwise be released or lost. By reusing and recycling these locally on land, the process can significantly reduce pollution and environmental impacts at the regional level (e.g. nutrient inflow to seas and reservoirs), while also contributing to the mitigation of global ecological challenges such as climate change. Finally, the reuse of circular resources has the potential to offset the demand for virgin resources.

In summary, recycling nutrients and carbon sources to produce microalgae-based agricultural products offers a viable pathway that aligns with the principles of organic production and advances environmental sustainability through circularity.

([9]) Ellen MacArthur Foundation (n.d.). Circular economy introduction. Available here.
([10]) Ellen MacArthur Foundation (2024) Supply chains and the circular economy. Available here.

Figure 4 - (Organic) microalgae and circular economy



Source: Zeni ([11])

2.1.4. Algae fertilisers for organic production

Microalgae, for example when used in macronutrient fertilisers, have been explored less extensively than seaweed in agricultural applications. Traditionally, cyanobacteria (blue-green algae) are recognised for their nitrogen-fixing capacity – estimated at approximately 20–30 kg of nitrogen per hectare – particularly in paddy fields and have demonstrated benefits for a variety of other crops. The soil application of harvested microalgal biomass is known to function as a slow-release fertiliser and soil conditioner ([12]).

([11]) Ze-ni. (2024, April 10). ZENI - Industrial wastewater treatment with microalgae. https://ze-ni.com/en/

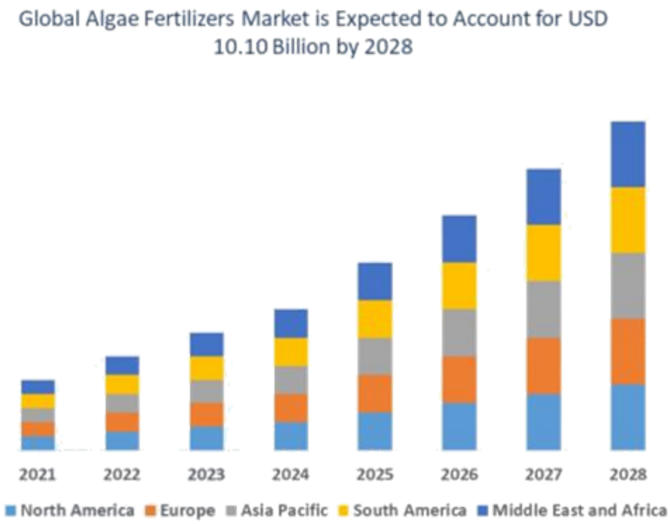
([12]) Kapoore, R. V., Wood, E. E., & Llewellyn, C. A. (2021). Algae biostimulants: A critical look at microalgal biostimulants for sustainable agricultural practices. Biotechnology Advances, 49, 107754. https://doi.org/10.1016/j.biotechadv.2021.107754

Figure 5 – Terralgea - an Organic biostimulant by Allmicroalgae

Source: Allmicroalgae

The algae fertiliser market is expected to grow 6.30% in the forecast period of 2021 to 2028 and reach €9 billion (USD 10.10 billion) by 2028. The Asia-Pacific region, home to countries with large agricultural industries like China, India, and Japan, holds a significant portion of the market share, followed closely by North America and Europe. **The demand for algae fertilisers is expected to surge in regions with a rising focus on organic farming practices and sustainable agriculture.** As farmers across the globe seek to reduce their reliance on chemical fertilisers, algae-based alternatives are likely to play a more prominent role in meeting the nutritional needs of crops ([13]).

Figure 6 - Global algae fertilisers market



Source: Data Bridge ([14])

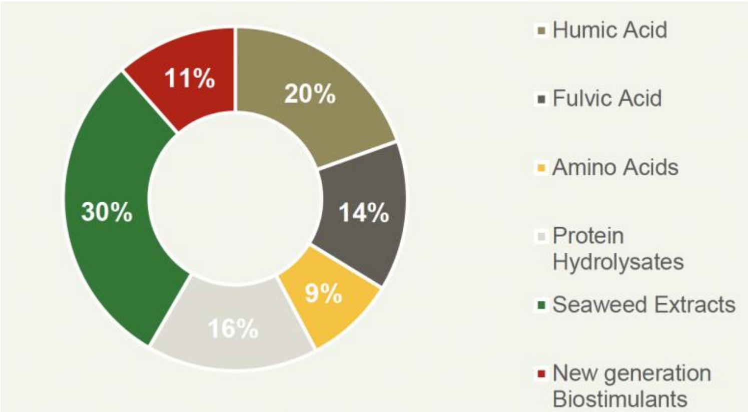
([13]) Data Bridge (2021, November 30). Global Algae Fertilizers Market Report - Product page. Data Bridge Market Research. Available here.
([14]) Global Algae Fertilizers Market Report - Product page. (2021c, November 30). Data Bridge Market Research. Available here.

2.1.5. Biostimulants for organic production

A biostimulant product is defined more by its mode of action than by the nature of its constituents, which may be of various origins and can be used alone or in combination. Traditional biostimulants currently account for nearly 90% of the market. Macroalgae have been exploited for their biostimulant potential since the early 1980s and now represent a key category within the organic plant biostimulants market ([15]).

New generation biostimulants, such as those derived from microalgae, account for approximately 11% of market share by revenue. These newer biostimulants are characterised by targeted action and claims, and they typically perform better in environmental terms – exhibiting a lower environmental footprint and greater soil stability.

Figure 7 - Biostimulant Market Share by Revenue (%), active ingredients



Source: Global (2019) ([16])

Most market analysts report that the European biostimulants market accounts for roughly half of the global market. Estimates of the value of the European market ranged around USD 1.5-2 billion in 2022 ([17]). It is projected to grow from USD 3.46 billion in 2024 to USD 3.82 billion in 2025, at a compound annual growth rate (CAGR) of 10.3%. Growth during the historical period can be attributed to several factors: the increasing need for sustainable agriculture, rising demand for organic products, advancements in research, government initiatives, and regulatory support ([18]).

([15]) Kapoore, R. V., Wood, E. E., & Llewellyn, C. A. (2021). Algae biostimulants: A critical look at microalgal biostimulants for sustainable agricultural practices. Biotechnology Advances, 49, 107754. https://doi.org/10.1016/j.biotechadv.2021.107754
([16]) Vaniperen. (2022). Layman's report Plants for Plants. Available here.
([17]) Market overview - EBIC. (2024, November 3). EBIC. Available here.
([18]) The Business Research Company. (2025). Sustainable Agriculture Global Market Report 2025. Available here.

2.1.6. Sustainable intensification of production & nutrient management

Fertilisers play a significant role in food security, and the EU heavily depends on imports ([19]). Intensification of farming increases the use of capital, labour and resources (materials), including fertilisers and pesticides, relative to land area, to increase agricultural production per hectare. Intensification increases the pressure on the environment due to increased use of inputs, e.g. nitrogen and phosphorus fertilisers. Higher use of fertilisers and pesticides increases the risk of nutrients and pesticides running off into surface and groundwaters ([20]).

Organic farming, as a premium food market sector, supports sustainable agriculture ([21]). Algae are hereby presented as a solution that can increase the sustainability (environmental performance) of organic agriculture by "upcycling" discharges (nutrient and carbon side streams and wastes) into functional added-value products for agriculture. This approach can enhance circular economy practices, promote zero waste, prevent pollution of runoff waters, and contribute to regional nutrient management.

2.2. Acceptance of algae and algae products as ingredients for fertilisers suitable for organic farming

The market analysis for organic algae fertilisers and biostimulants is presented in Chapters 2.1.4 to 2.1.5.

It is well known that farmers and agribusinesses are actively seeking eco-friendly alternatives to conventional fertilisers. Organic algae fertilisers align with sustainable farming practices and help reduce reliance on chemical inputs that can harm ecosystems ([22;23]). The main factors driving the growth of the algae fertilisers market are:

- **Government support and regulations**: EU Green Deal, and Farm to Fork;

([19]) Ensuring availability and affordability of fertilisers. (2025, May 22). Agriculture and Rural Development. Available here.
([20]) Arvaniti, et al. (2025). Developing a monitoring framework to assess bioremediation offered by algae in Europe. EU4Algae. Available here.
([21]) Organics at a glance. (2025, February 11). Agriculture and Rural Development. Available here.
([22]) Microalgae Fertilizers Market Size & Forecast 2025 to 2035. (2025, March 21). Available here.
([23]) Ltd, R. a. M. (n.d.). Algae Fertilizer Market Size, Competitors & Forecast to 2030. Research and Markets Ltd 2025. Available here.

- **Rising demand for sustainable agricultural practices**: algae-based fertilisers are a natural and renewable resource, making them a popular choice for farmers seeking to reduce their environmental footprint ([24]);
- **Health and safety concerns**: algae fertilisers offer a non-toxic, biodegradable option that does not contribute to harmful chemical residues in food crops ([25]);
- **Enhanced soil health**: algae fertilisers not only provide essential nutrients to plants but also improve soil structure and microbial activity ([26];[27]);
- **Climate change and drought resistance**: algae fertilisers have been shown to help plants better withstand environmental stresses, including droughts ([28]).

Therefore, providing that organic algae fertilisers perform well in environmental and safety metrics, fertiliser markets are expected to favour them. The question is, how do **algae fertilisers perform with regards to environmental and economic factors, especially when algae are produced with alternative nutrients?** This is studied in Chapter 4.

([24]) Ammar, E. E., Aioub, A. A., Elesawy, A. E., Karkour, A. M., Mouhamed, M. S., Amer, A. A., & El-Shershaby, N. A. (2022). Algae as Bio-fertilizers: Between current situation and future prospective. Saudi Journal of Biological Sciences, 29(5), https://doi.org/10.1016/j.sjbs.2022.03.020
([25]) Gonçalves, J., Freitas, J., Fernandes, I., & Silva, P. (2023). Microalgae as Biofertilizers: A sustainable way to improve soil fertility and plant growth. Sustainability, 15(16), 12413. https://doi.org/10.3390/su151612413
([26]) Ammar, E. E., Aioub, A. A., Elesawy, A. E., Karkour, A. M., Mouhamed, M. S., Amer, A. A., & El-Shershaby, N. A. (2022). Algae as Bio-fertilizers: Between current situation and future prospective. Saudi Journal of Biological Sciences, 29(5), 3083-3096. https://doi.org/10.1016/j.sjbs.2022.03.020
([27]) Gonçalves, J., Freitas, J., Fernandes, I., & Silva, P. (2023b). Microalgae as Biofertilizers: A sustainable way to improve soil fertility and plant growth. Sustainability, 15(16), 12413. https://doi.org/10.3390/su151612413
([28]) Li, C., Liang, Y., Miao, Q., Ji, X., Duan, P., & Quan, D. (2024). The influence of microalgae fertilizer on soil water conservation and soil improvement: Yield and quality of potted tomatoes. Agronomy, 14(9), 2102. https://doi.org/10.3390/agronomy14092102

3. Regulatory framework

The European Union has established a comprehensive regulatory framework to support the use of algae as a sustainable ingredient in organic fertilisers. This framework encompasses EU laws, communication strategies and technical standards, all of which are designed to ensure safety, environmental sustainability and alignment with organic certification principles.

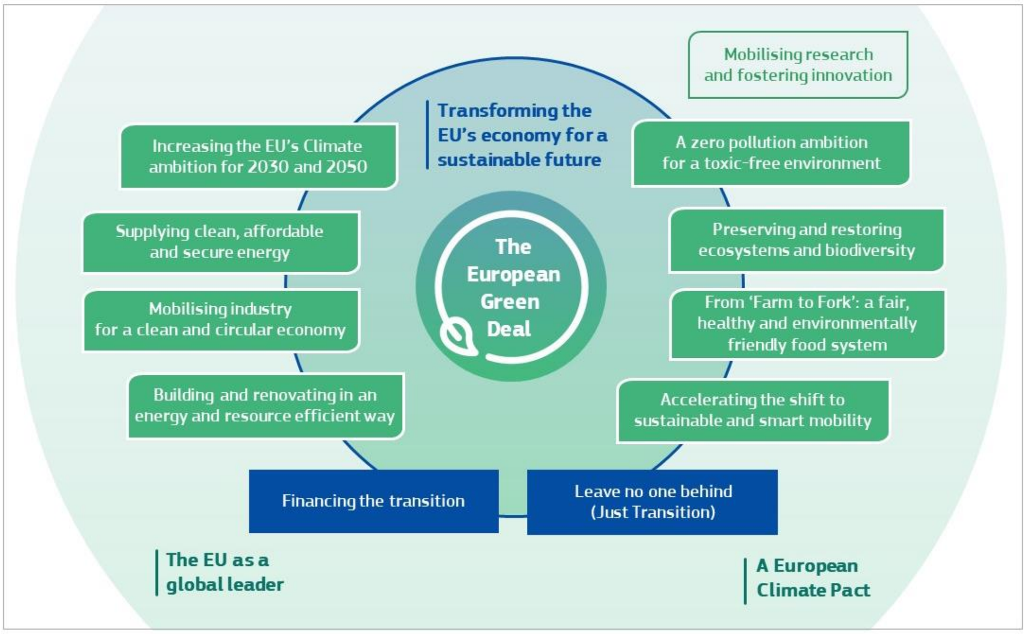
EU laws provide the legal basis for using algae in fertilisers, addressing safety, traceability and sustainability. Communication strategies at both EU and national levels promote the integration of algae into agricultural practices, fostering innovation and collaboration. Additionally, EU standards set technical guidelines for ensuring the quality, safety, and efficacy of algae-based fertilisers.

Together, these elements form a cohesive approach that enables the adoption of algae as a key input in organic farming, thereby supporting the EU's broader goals for sustainable agriculture and environmental protection.

3.1. Define circular algae products for organic production

3.1.1. European Green Deal

Figure 8 - The EU Green Deal



The **European Green Deal** is the largest environmental framework with ambitious targets to turn Europe into the **first climate-neutral region in the world**. The EU Green Deal provides an action plan to: (1) boost the efficient use of resources by moving to a clean and circular economy; (2) cut pollution and pressures on ecosystems by decoupling economic growth from resource use; and (3) restore biodiversity by sustainably managing and preserving resources and ecosystems. The Green Deal builds on a series of sectors and policy strategies that will support a just and inclusive ecological and climate transition, including the **Farm-to-Fork Strategy**, Climate Neutrality by 2050, a Zero Pollution Action Plan, and the **Bioeconomy Strategy,** among others. Also, organic fertilisers and circular bioeconomy are key in the EU Algae Initiative, and the upcoming Circular Economy Act.

The Farm to Fork Strategy, as one of the key initiatives of the European Green Deal, aims to create a fair, healthy, and environmentally friendly food system ([29];[30]). The Farm to Fork strategy sets the following relevant targets to be achieved by 2030:

Table 2 - How this report relates to Farm to Fork Strategy

Farm to Fork Strategy	Relevance to this report
Reduce nutrient losses by at least 50%	WP2 aimed to recycle nutrients from viable sources for organic microalgae production.
Reduce the use of fertilisers by at least 20%	WP2 aimed to produce plant biostimulants formulations that can reduce the need for other macronutrient fertilisers.
Develop an integrated nutrient management action plan to address nutrient pollution at source and recycle organic waste into renewable fertilisers (no specific target)	WP2 developed scenarios and research gaps for recycling nutrient-rich effluents for enriching microalgae cultivation.
Convert 25% of the EU's agricultural land to organic farming. It emphasises the development of sustainable agricultural inputs, including fertilisers, to support organic production ([31]).	WP2 aimed to produce microalgae fertilising products suitable for organic farming
Reduce Greenhouse Gas emissions from agriculture (no specific target)	WP2 investigated environmental performance of recycling nutrients for microalgae production.
Significantly increase organic aquaculture (no specific target).	WP2 investigated economic performance of organic microalgae fertilising products to scale up production.

The Farm to Fork Strategy specifically acknowledges that the legal framework supports the shift to organic production, but states that "more needs to be done, and similar regulatory shifts need to take place in the oceans and inland waters". As such, the further development of organic aquaculture is recognised as an important priority alongside organic agriculture.

The Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture for the Period 2021 to 2030 promote the development of organic aquaculture and other forms of aquaculture with lower environmental impact. These include energy-efficient recirculating aquaculture systems, integrated multi-trophic aquaculture (IMTA), and the diversification towards lower-trophic species such as algae.

The EU Bioeconomy Strategy highlights the importance of biological resources, including algae, as renewable inputs for sustainable agricultural solutions. Algae cultivation is recognised as a promising sector for producing biofertilisers and soil

([29]) Farm to fork strategy. (n.d.). Food Safety. Available here.
([30]) Coste, M., Yael Pantzer, Marta Messa, et al. (2021). What do the new EU Farm to Fork and Biodiversity Strategies mean for Slow Food? Available here.
([31]) Organic action plan. (2025, February 11). Agriculture and Rural Development. Available here.

amendments. The strategy encourages research and innovation to create value-added products like algae-based fertilisers for organic farming ([32]).

The CAP Strategic Plans under the Common Agricultural Policy (CAP) provide a framework that promotes practices that reduce environmental impacts, such as the use of organic algae-based fertilisers. Each EU Member State can include specific measures in its national plans to incentivise the use of more sustainable fertilisers in line with CAP's goals for nutrient management, environmental protection, and climate action ([33]). Use of recycled nutrients by farmers or on-farm nutrient recovery is included in the 5th Specific Objective of the CAP on "Sustainable Development, reduce chemical dependency, foster efficient natural resources management" ([34]).

A relevant EC initiative on the Integrated Nutrient Management Action Plan (INMAP) has been planned since 2022, but is experiencing delays ([35]). Finally, the new European Commission (starting 1 December 2024) announced a new Circular Economy Act, which aims to develop a single waste and secondary materials market, focusing on phosphorus resources ([36],[37],[38]).

More recently, the President of the European Commission, Ursula von der Leyen, announced an EU Circular Economy Act to follow the second Circular Economy Action Plan (March 2020). Her mission letter to the new Commissioner for Environment, Water Resilience and a Competitive Circular Economy, Jessika Roswall, specified that the new Circular Economy Act should **include measures to create market demand for secondary materials and a single market for waste, especially for critical raw materials**. This is relevant because phosphate rock, used in phosphorus mineral fertilisers, is on the EU Critical Raw Materials list since 2014, confirmed in the EU Critical Raw Materials Act 2024.

3.1.2. EU Mission: A Soil Deal for Europe

The main goal of the Mission 'A Soil Deal for Europe' is to establish 100 living labs and lighthouses to lead the transition towards healthy soils by 2030. In doing so, Mission Soil is also promoting healthy and environmentally friendly food systems by enhancing food safety, promoting agroecological practices and other

([32]) Bioeconomy Strategy. (n.d.). Environment. Available here.
([33]) Approved 28 CAP Strategic Plans (2023-2027). Available here.
([34]) Veronica. (n.d.). ESPP position papers on Nutrient Recycling Policy open for comments. Available here.
([35]) European Environmental Bureau letter to EU COM (2023): Available here.
([36]) Ursula von der Leyen calls for a more circular and resilient economy. (2024, July 21). European Circular Economy Stakeholder Platform. Available here.
([37]) ESPP. (2024). ESPP input to the European Commission on Circular Economy perspectives for EU water policy and for the Sewage Sludge Directive (pp. 1–6). Available here.
([38]) ESPP. (2024). ESPP input to the European Commission on Circular Economy perspectives for EU water policy and for the Sewage Sludge Directive (pp. 1–6). Available here.

soil-friendly practices (e.g. regenerative, organic agriculture, nature-based solutions) across food value chains and in consumption.

Table 3 - Restore Soil objectives, concrete targets for 2030 relevant to this report

Objectives	Mission Target by 2030
Reduce soil pollution and enhance restoration	Reducing fertiliser use by at least 20%; Reduce nutrient losses by at least 50%; 25% of land under organic farming.

3.1.3. EU Mission: Restore our Ocean and Waters

With a 2030 target, the **EU Mission "Restore our Ocean and Waters"** aims to protect and restore the health of our ocean and waters through research and innovation, citizen engagement and blue investments. The Mission's new approach addresses the ocean and waters as one and plays a key role in achieving climate neutrality and eliminating pollution. The goals of the Mission Ocean, although not directly citing "organic", overlap with organic farming benefits, such as improving soil health and reducing nutrient leaching ([39]).

Table 4 - Mission: Restore our oceans and waters objectives, concrete targets for 2030 relevant to this report

Mission Ocean objectives	Targets
Prevent and eliminate pollution	≥50% less nutrient losses
Make the EU's blue economy carbon-neutral and circular	Circular, low-carbon multi-purpose use of marine and water space.

3.1.4. Macro-regional focus: the Baltic Sea Action Plan

The Baltic Sea Action Plan aligns with broader goals of nutrient recycling, reducing eutrophication, promoting sustainable innovations, and achieving **Good Environmental Status** of the EU Water Framework Directive. Algae-based fertilisers, particularly those derived from excess nutrient-rich algae, can significantly support these objectives within a circular economy framework. Sustainable management and environmental safeguards would be crucial to ensure their use does not negatively affect marine ecosystems ([40]). ([41]).

([39]) Publications Office of the European Union. (2023). Baseline study for the implementation of lighthouses of the Mission 'Restore our ocean and waters by 2030': Atlantic, Arctic, Danube and Mediterranean lighthouses. Publications Office of the EU. Available here.
([40]) Helcom Baltic Sea Action Plan Update (2021). Available here.
([41]) European Compost Network ECN e.V. (2018). Quality manual. Available here

3.2. European Industry Standards for fertilising products and effluents

Standards ensure interoperability and safety, reduce costs, and facilitate companies' integration in the value chain and trade. European Standards are the responsibility of the European Standardisation Organisations (CEN, CENELEC, ETSI) and can support EU legislation and policies (see Chapter 3.1). **Several European standards are available for algae and fertiliser market applications**; they are relevant both for conventional and even more for organic farming. A comprehensive yet not exhaustive list of European Standards for algae and algae products, fertilisers, and biostimulants is included in Annex 1 and Annex 2. The term “organic” reflects the “biobased” nature of the fertiliser material and does not refer to fertilisers suitable for organic production.

As explained in the next Chapter, fertilisers aimed for organic agriculture are “standardised” by EU regulation.

Regarding standardisation of effluent quality, this is an important market development tool, with much support from the industry. The first AD digestate standard was tested in the UK in 2012 (PAS110), and since then, many European countries have developed national standards on digestate, e.g. Germany and Ireland.

The ECN-QAS is a pan-European private quality assurance scheme for compost and AD digestate. It sets harmonised requirements for production processes, input materials, product quality (including nutrient content and contaminants), sampling, testing, certification, and labelling. Digestate plants can obtain the ECN-QAS conformity label ([42]), recognised by quality assurance organisations in many EU countries.

3.3. EU laws regulating algae fertilisers for organic farming

The EU organic regulation has a significant impact on organic farmers, processors, traders, retailers, certifiers, researchers, and consumers. The development of EU legislation has resulted in a comprehensive framework governing the safe and sustainable use of fertilisers and algae in organic farming.

([42]) European Compost Network ECN e.V. (2018). Quality manual. Available here.

So far, 22 secondary regulations have been adopted and published: 15 Delegated Regulations and 7 Implementing Regulations ([43]).

Regulation (EU) 854/2004 emphasises official animal-origin product controls to ensure food and feed chain safety. It established procedures for animal by-products (ABP), which later became critical fertiliser inputs. **Regulation (EU) 1069/2009** sets health rules for the handling, processing, and using animal by-products in fertilisers to ensure safety and environmental protection. It formed the foundation for incorporating ABP into organic fertilisers (meaning of biological origin) and is directly linked to subsequent fertiliser **Regulation (EU) 1009/2019.**

([43]) IFOAM Organics Europe. (2025, April 4). Organic regulations, rules for organic products - IFOAM Organics Europe. Available here.

The **EU Fertiliser Product Regulation (FPR), Regulation (EC) 2019/1009,** sets new rules on marketing EU fertilising products, including organic fertilisers (meaning of biological origin). It amended **Regulation (EU) 1069/2009** for ABP use by expanding permissible inputs to include algae and bridging organic certification rules. **Regulation (EU) 834/2007** and **Regulation (EU) 889/2008**, are now replaced by **Regulation 2018/848,** with technical safety and performance standards.

The FPR is the main pathway for authorising a new fertiliser, obtaining a CE mark and placing the product in the EU's internal market. Still, the old (transitional) national regulatory pathway for marketing fertilisers continues to exist. In the latter case, each MS has its own rules and process for authorising fertiliser products to be marketed within national borders.

According to FPR, **a new fertilising product marketed in Europe must comply with two main requirements. It must**

- fall under one of the Product Function Categories (PFC), e.g. organic (meaning of biological origin) fertiliser or soil improver, or non-microbial plant biostimulant, as defined in this Regulation, each subject to specific safety and quality requirements;
- meet the requirements set out by the FPR for at least one relevant Component Material Category (CMC).

According to the definition of CMC 2 of the FPR, "an EU fertilising product may contain plants, plant parts or plant extracts having undergone no other processing than cutting, grinding, milling, sieving, sifting, centrifugation, pressing, drying, frost treatment, freeze-drying or extraction with water or supercritical CO_2 extraction. For the purpose of this point, plants include mushrooms and algae and exclude blue-green algae (cyanobacteria)".

Therefore, with the exception of cyanobacteria, fresh and dried algae are explicitly included in FPR CMC 2 (Plants, plant parts, or plant extracts). Furthermore, CMC 2 does not differentiate between algae cultivated in synthetic media, grown using alternative nutrient sources, or harvested from natural environments.

Additionally, it should be clarified that the authorisation of a new fertiliser product under the FPR is a prerequisite before the product can be considered suitable for use in organic farming (see below).

Historically, Regulation (EC) **2007/834** outlined principles for organic farming, focusing on sustainability and natural inputs, including fertilisers like algae-based products. Also, **Regulation (EC) 2008/889,** implementing Regulation (EC) 834, specified permissible fertilisers and soil improvers suitable for organic farming.

More recently, Regulation (EC) 2007/834 was replaced by Regulation (EU) **2018/848,** updating organic farming rules. It strengthens traceability and sustainability, emphasising the use of natural and recycled inputs, including algae-based products, to enhance eco-friendly practices in organic systems.

Implementing Regulation (EU) **2021/1165** provides details under art. 24 of Reg 848, authorising certain products and substances for use in organic production and establishing their lists.

In the next chapter, we will dive into Regulations (EU) **2018/848** and **2021/1165,** which characterise conditions for using recycled inputs in algae production targeting fertilising product applications.

3.4. Lessons learnt and applications of Regulation 2021/1165 and Regulation 2018/848 by EU member states stakeholders

This chapter is intended primarily for Member States and EU policymakers. It presents findings from the analysis of European Regulations 2018/848 and Implementing Regulation 2021/1165 and compares these with relevant national rules from Member States to highlight good practices for effectively promoting the use of recycled media in organic microalgae products. Figure 9 provides an infographic summarising the key findings on organic rules for microalgae production using alternative nutrient and carbon dioxide sources.

Figure 9 - Infographic presenting that nutrients and carbon sources are allowed and not allowed in algae-based fertilising products, based on organic production rules.

3.4.1. Regulation (EU) 2018/848 on organic production and labelling of organic products

Regulation (EU) 2018/848 sets out the principles and rules for organic production of food, feed, and agricultural products, related certification and use of organic indications, and rules on controls. Article 15 of the regulation states that operators producing organic microalgae (called phytoplankton) shall comply with the detailed production rules in Part III of Annex II.

The Regulation (EU) 2018/848 set **general and specific organic principles**:

- sustainability of use of resources soil, water, and air, plants and animals, and preservation of natural landscape and heritage;
- responsible use of energy and natural resources;
- ensure the integrity of organic production;
- exclude the use of GMOs, products produced from or by GMOs, with some specific exceptions only for veterinary medicinal products where no alternatives are available.

Specifically for authorising microalgae as fertlisers in **organic agricultural products**, the following production conditions apply:

- Use of external fertilisers and nutrients in microalgae cultivation is allowed **only in indoor production units**, such as photobioreactors or enclosed ponds in accordance with Annex II, Part III of Regulation (EU) 2018/848.
- Organic production facilities must be **strictly separated from non-organic production** operations.
    - The organic conversion period for a production unit is six months.
- **Only authorised external nutrients of plant or mineral origin (Article 24) may be used in algae cultivation.**
    -
    - **Plant-based nutrients**, including processed plant-based nutrients, e.g., **plant-based digestate**, can enrich microalgae cultivation, as microorganism preparations are allowed.
        - Using effluents from animal byproducts, such as **animal manure and fish discharges, is prohibited**.
        - Using processed animal byproducts, such as manure-containing anaerobic digestate, is also prohibited.
    - When external nutrient sources are used, the **nutrient levels in the effluent water** shall be verifiably the same or lower than those in the inflowing water.

According to the Fertiliser Product Regulation (FPR, (EC) 2019/1009), EU wide end-of waste criteria are defined for certain waste derived materials and only these may be used in EU fertilising products. If algae grow on effluents with waste status, they may inherit the waste classification ([44]), which would significantly restrict their potential use and require the inclusion of relevant EU wide end-of-waste criteria in order to be included in fertilisers under the FPR. Under Regulation **2018/848, only non-waste effluents**, as described above, are allowed.

Outlook for Regulation (EU) 2018/848

Regulation (EU) 2018/848 is not straightforward when it comes to algae, as it was evidently drafted with seaweed in mind. Microalgae are only indirectly addressed through the phrase: *"Those rules shall apply mutatis mutandis to the production of phytoplankton"*. The regulation establishes the principles of organic production and sets out the rules governing organic practices. It includes provisions for the use of algae in organic food, animal feed, and fertiliser products.

Algae are not defined in Article 3 under definitions. This follows merely the generic approach of European policy that algae are treated as a family, being part of plants rather than animals. Indeed, algae are aquatic organisms that grow and need nutrition just like terrestrial or aquatic plants. Still, **the rule separates plant production rules for terrestrial plants and aquatic algae** (see Annex II Part I of Regulation 2018/848). The main section regarding fertilising terrestrial plants does not apply to algae, and authorised nutrients to fertilise algae are addressed separately. The rule **mentions algae and aquaculture animals together** (see Article 15 of Regulation 2018/848), as both are aquatic, and the EU Common Market Organisation policy on fishery and aquaculture (CMO, Regulation 2013/1379/EU) covers both fishery and other aquatic organisms, such as algae. **Standardisation for algae and algae products helps here, having already given terms and definitions for the sector, which are recognised in the EU Algae Initiative**. However, not all European standards are compliant with the FPR rules. As noted in Chapter 3.3, whole cyanobacteria are currently not permitted under CMC 2 of the FPR for use in fertilising products, although cyanobacterial extracts may be allowed under CMC 1. Regulatory developments may expand their future eligibility.

Finally, where an MS considers that a product or substance should be granted **a specific authorisation for use in an outermost region of the Union** due to the conditions set out in Article 45(2), it may request the EC to carry out an assessment.

([44]) Waste Framework Directive. (n.d.). Environment: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

3.4.2. The implementing Regulation 2021/1165 on authorising certain products and substances for use in organic production and establishing their lists

The implementation of Regulation 2018/848 Article 24 is the **Regulation (EU) 2021/1165**, which authorises and establishes lists of certain products and substances that may be used in organic production as fertilisers, soil conditioners and nutrients also for enriching algae cultivation (Annex II).

The Annex II includes **algae material (biomass) and algae fertilising products, provided they are obtained according to the rules:**

- physical processes, including: (i) dehydration, freezing and grinding; (ii) extraction with water or aqueous acid and/or alkaline solution; and (iii) fermentation;
- Only from organic or collected in a sustainable way in accordance with point 2.4 of Part III of Annex II to Regulation (EU) 2018/848.

On mineral nutrients for algae enrichment, Annex II of the 2021/1165, specifically lists fertilisers soils conditioners and nutrients which can be used in organic production:

- **Recovered struvite** is a material of precipitated phosphate salts derived from processing animal byproducts.
    - Struvite sourced from manure must respect restrictions on origin, including exclusion of intensive or factory farming where applicable.
    - Some waste-derived materials, including recovered struvite, are allowed under Regulation (EU) 2021/1165 and its subsequent amendments, provided they meet the specific requirements and are listed in Annex II.
    - Annex II is regularly updated via delegated regulations to add or modify permitted substances based on scientific evidence and policy developments; users should always consult the most current version for the latest authorised materials.
    - For example, recovered struvite may be permitted if it complies with origin and processing criteria specified in Annex II
- Not all waste-classified materials are excluded from use as fertilisers under the FPR; eligibility depends on compliance with the relevant Component Material Category (CMC) criteria in Regulation (EU) 2019/1009.
- These provisions apply generally and may not be explicitly mentioned for algae cultivation but still govern inputs used in fertilisers for organic production.

UPDATE: Carbon dioxide is listed in Annex II of 2021/1165. In a recent act adopted by Regulation (EU) 2025/973 of 23 May 2025 that will amend the Implementing Regulation (EU) 2021/1165:

- Use of food-grade-quality carbon dioxide for the enrichment of water for algae cultivation only in closed systems on land;
- Preferably, the carbon dioxide should be a process by-product or from renewable sources.

Outlook for Regulation (EU) 2021/1165

Annex II of Regulation 2021/1165 specifies the list of nutrients of plant or mineral origin suitable for organic algae cultivation. It has noted that "Products and by-products of plant origin for fertilisers, e.g. oilseed cake meal, cocoa husks, malt culms" are not subject to the restriction to be organic, and **this discriminates against algae in favour of plants,** which was not present in former regulation 2008/889/EC, so, in this regard, the situation for algae has become worse.

Indeed, in Annex II of Regulation 2021/1165, **20 out of 44 materials listed are mineral sources**, including struvite and sodium nitrate which were added as a mineral nutrient input for algae to Annex II thanks to application from the European Algae Biomass Association. Struvite must not be derived from animal manure of factory farming origin. The regulations specify that recovered struvite is excluded if sourced from manure or other animal by-products from intensive (factory farming) livestock operations. However, there is **no official EU definition of "factory farming," so national authorities may interpret this provision.** Otherwise, national and international organic standards increasingly recognise struvite for fertiliser applications, especially when it is plant- or livestock-derived and not contaminated with prohibited substances.

Lesson learnt: Apart from marketing in the EU through harmonising rules, there is the national pathway where each MS has set its own rules for authorising new fertilising products. However, for fertilisers to be used in organic farming, only substances listed in Annex II of Regulation (EU) 2021/1165 are allowed. For example, in the Netherlands, recovered struvite is used in organic farming fertilisers ([45]). The Netherlands was one of the front-running MS considering struvite a suitable source for organic farming ([46];[47]).

([45]) De Jong, A. L. & Reststoffenunie. (2016). Summary of regulatory requirements for recovered phosphates in the Dutch Fertiliser Regulation [Report]. Available here.
([46]) CE Delft. (2021, April 15). The potential of struvite in Dutch agriculture - CE Delft - EN. CE Delft – EN. Available here.
([47]) Lucarelli, E. (n.d.). Recovered struvite authorised in EU Certified Organic Farming. Available here.

Good practice: Currently, in closed greenhouses with organic crop production in Europe (not algae), burning fossil fuels in winter for heating and in summer for enrichment with CO_2 is a widespread practice ([48]).

3.4.3. Experiences and good practices in interpreting the EU organic rules

During our research, we identified a few examples that shed light on stakeholders' experiences of applying the European rules.

In 2024, the European Sustainable Phosphorus Platform (ESPP) published **a comprehensive report with a legal opinion after analysing the EU regulation framework and national court proceedings.** The report examined algae appearing in waste (WFD) ([49]), animal by-product (ABP) ([50]) rules, including using digestate to enrich algae cultivation. Unfortunately, the report did not include the organic production rules (2018/848), so the findings are not so relevant here. The report was presented in an ESPP workshop in November 2024, and the findings are elaborated in the Sustainable Algae Industry Study WP3 report ([51]).

The most relevant aspect of the **ESPP report** for this report is its methodology. By analysing **national court proceedings**, **the report examined in depth how MS interpret European rules**. Such national proceedings may be used as evidence in the EU Court of Justice or in other national courts to support the interpretation of EU law. However, **access to national MS court proceedings is often limited for non-experts, creating a barrier to innovation, and slowing progress towards a just transition and greater cohesion across Member States.**

In the EU, organic production rules organic production rules have existed since 1991, with successive regulatory updates, the most recent being Regulation (EU) 2018/848, which became fully applicable in January 2022. National authorities have been applying and enforcing EU organic rules for decades, including for

([48]) Vergote, N. and Marien, H. (2011) Use of a gas absorption heat pump in combination with Borehole Thermal Energy Storage in organic protected horticulture, Acta Hort. 915, ISHS: 55-60. Available here.
([49]) Waste Framework Directive. (n.d.). Environment: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en
([50]) Animal by-products. (n.d.). Food Safety. https://food.ec.europa.eu/food-safety/animal-products_en
([51]) Sustainable Algae Industry Study WP3 "Algae potential for (waste)water treatment and fertiliser/plant biostimulants production"

products such as algae, which were already addressed under previous regulations (e.g. Reg. 889/2008). Interviews with a fertiliser producer revealed an incident in Portugal, where the **authorisation process was delayed because authorities struggled to interpret the new EU regulation**. Instead, they referred to repealed national organic rules, which were more familiar. As a result, the producer was subject to "double standards", being required to comply with both the outdated national rules and the current EU regulation when seeking authorisation for a fertiliser product intended for organic farming.

Outside the EU, in Switzerland, there is no explicit prohibition against using **manure digestate as a nutrient source for algae cultivation**, provided that the resulting algae fertiliser complies with Swiss organic farming rules regarding the origin of inputs and the absence of contaminants ([52]). This regulatory approach allows small cattle farms in Switzerland to use nutrient-rich effluents to produce organic microalgae. A similar approach could be considered within the EU, whereby manure digestate from non-factory farming may be accepted for use in organic farming.

([52]) Fedlex. (n.d.). 910.181. EAER Ordinance of 22 September 1997 on Organic Farming. Available here.

4. Alternative sources of nutrients & carbon dioxide for microalgae fertilisers compliant for organic agriculture

In this Chapter, we will analyse available compliant sources of nutrients and carbon for microalgae production, looking at alternative streams from large industrial sectors in Europe.

4.1. Viable solutions for the scenarios

The circular bioeconomy approach shifts away from using virgin resources in traditional linear value chains followed by end-of-pipe remediation, towards promoting circular models that prioritise resource valorisation at all steps. In this way, the concept of waste is eliminated, and cradle-to-cradle solutions are activated.

The EU4Algae WG5, Algae 4 Eco ([53]), developed several applied bioremediation and valorisation solutions using algae to clean effluents by removing excess nutrients or CO_2 while simultaneously producing algal biomass. These solutions were intentionally presented as modular building blocks, which can be combined and tailored according to specific needs – for example, integrating a solution that recycles macronutrients with one that recycles CO_2 to maximise circular performance in algae production.

After aligning with the scope of this report and verifying their regulatory compliance for organic production, three algae-based solutions were pre-selected:

1. A system that takes up circular macronutrients;
2. A system that takes up circular macronutrients and organic sugars;
3. A system that takes up circular carbon dioxide,

These pre-selected solutions will be further analysed in the regional scenario work presented in Chapter 5 of this report.

In the following paragraphs of Chapter 4, we analyse the availability of nutrient sources in Europe, aiming to investigate feasibility and scalability.

([53]) adapted from Annex 2 of Arvaniti, et al. (2025). Developing a monitoring framework to assess bioremediation offered by algae in Europe. EU4Algae. Available here.

Table 5 - Solution adapted from EU4Algae report on recycling macronutrient effluents

Production of microalgae on land with recycled nutrient side-streams		**TRL 7-8**
This solution on land uptakes dissolved nutrients, mainly Nitrogen (N) and Phosphorus (P), from compatible nutrient-rich agro-industrial effluents and assimilates them in organic microalgae biomass to support growth, while removing excess nutrients from the water medium. The solution replaces the use of conventional synthetic fertilisers for algae, by using N and P from secondary sources. The solution could potentially be applied as a secondary water bioremediation technology, e.g. denitrification. A variation of the solution is with algae being produced in **mixotrophic conditions**, where they can also take up sugars from secondary effluents, in addition to CO_2, and in this case algae can replace bacterial water treatment step to remove organic load (COD) in addition to denitrification. The solution can be used on land and more specifically with tanks, photobioreactors, or raceway ponds, depending on the climate and location. There is a variety of side streams that can be used in this solution from food and non-food supply chains, e.g. food & beverage processing, horticulture, aquaculture, pulp & paper effluents, and biogas digestate, which also affects product applications downstream. The quality of the stream used will dictate whether a pre-treatment or dilution step is necessary to make it suitable for algae cultivation. The algae species used should have high nutrient removal capacity, preferably combining high nutrient uptake with high biomass yields. The match of algae type with the industrial set-up will mostly depend on the availability of fresh or saline water and conditions like temperature. The solution can be combined with a CO_2 recycling solution. The solution can be part of an industrial symbiosis.		
This solution is suitable for: • Use of both raceway ponds and closed photobioreactors; • Algae producers with access to industrial land and water near a relevant nutrient side-stream source.	**The solution is NOT suitable for:** • Side-streams containing organic carbon load; • Variable inflow nutrient, because the algae system is sensitive, so nutrient inflow should be stable.	
Relevant EU projects:	AlgaeNauts, REDWINE, Alg-AD, LOCALITY, REALM, AlgaeProBANOS, CIRCALGAE, SEMPRE-BIO, AlgaeBrew, IDEA, INTEGRATE, MULTI-Str3am, SCALE, MULTIPLY, ALLIANCE (due to start in September 2025), INGREEN, ZEST, Grass2Algae, Water2Return, LIFEBIOBEST.	
Relevant industry practitioners:	Necton/Allmocroalgae (PT), Biorizon Biotech (SP), A4F (PT), AlgaEnergy (SP), NeoAlgae (SP), Algiecel (DK), MiAlgae (UK), Swedish Algae Factory (SE), Heirbaut aLgriculture (BE), Microphyt (FR), Algen (SL), Aqualia (SP)	

Source: Adapted from Annex 2 ([54])

([54]) Arvaniti, et al. (2025). Developing a monitoring framework to assess bioremediation offered by algae in Europe. EU4Algae. Available here.

Table 6 - Solution adapted from EU4Algae report on recycling CO_2 side-streams

Microalgae produced on land with recycled CO_2 side-streams	**TRL: 7**
The biological carbon capture system takes place on land, especially in closed photobioreactors, where compatible industrial CO_2 is fed to the reactor as a carbon source for algae to grow. The carbon can be sourced from relevant plant-based CO_2 sources, such as food, and perhaps biogas, and paper mills. To claim carbon storage or carbon farming in algae products requires compliance with the EU ￼(￼). Such products can be soil amendments, such as biochar, and such scenarios are elaborated in another [55]EU4Algae report￼ ￼. Carbon credit verification standards and Certifications are still under development.([56]). Carbon credit verification standards and Certifications are still under development. The solution can be combined with the macronutrient recycling solution.	
This solution is suitable for: • Closed Photobioreactors (PBR) or enclosed raceway ponds inside a greenhouse; • Regions with access to land and water, e.g. industrial symbiosis settings, and with access to CO_2 point emissions, from compatible food-grade sources (plant-based food and beverage and potentially also AD digestate).	**The solution is NOT suitable for:** • Open raceway ponds; • Regions without accessible CO_2 point sources, such as remote or rural areas without industrial activity.
Relevant EU projects:	Alg-AD, SEMPRE-BIO, COSEC, AlgaeBrew, REDWINE, LIFEBIOBEST.
Industry practitioners:	CarbonWorks (FR), Algiecel (DK), A4F (PT), Power Algae (EE), AlgaEnergy (ES)

Source: Adapted from Annex 2 ([57])

4.2. Compliant alternative nutrients and CO_2

Regarding technical feasibility, alternative nutrient sources must meet minimum technical specification standards for indoor microalgae cultivation. These standards are not specific to organic production but are essential to ensure viable growth conditions.

Technical specifications of alternative microalgae nutrients (not organic-specific):

- **Nutrients must be dissolved in aquatic solutions;** solid substrates or non-aqueous solutions are not suitable.

([55]) Carbon removals and carbon farming. (n.d.). Climate Action. Available here.
([56]) Publications Office of the European Union. (2025). #EU4Algae: business case and project recommendations on the development of regenerative ocean farming as a bioremediation measure in Europe. Publications Office of the EU. Available here.
([57]) Arvaniti, et al. (2025). Developing a monitoring framework to assess bioremediation offered by algae in Europe. EU4Algae. Available here.

- **Solutions should have low levels of suspended solids** and exhibit low colour, opacity, and turbidity, to ensure adequate light penetration for photosynthesis and cell growth ([58]).
- **The media must contain compatible macronutrient forms,** such as carbon dioxide (e.g. dissolved inorganic carbon), nitrogen (e.g. nitrates or urea), and phosphorus (e.g. dissolved phosphate salts). High concentrations of ammonia, often found in digestate, are not ideal.
- **The concentration and ratio of macronutrients must be tailored to the target species.** Excessive concentrations can be toxic depending on the species and environmental conditions. For instance, an N:P ratio of approximately 8:1 is ideal for *Chlorella vulgaris* ([59]) Unlike digestate, which typically requires dilution, most other nutrient sources do not need dilution.
- The sugar content of the media is also an important factor. Some microalgae and cyanobacteria, such as Spirulina, are strictly autotrophic, while others can grow under mixotrophic or heterotrophic conditions, enabling them to assimilate sugars.
- The media (formulations?) should contain a low level of contaminants, in accordance with the FPR. No additional contaminant thresholds are specified under the organic production rules ([60]).

4.3. Main relevant nutrient sources in Europe

Following the above legal and technical specifications, **relevant industries that can provide macronutrients and CO_2 are:**

- Fermentation co-/by-products from wine, beer or bread production;
- Other bioethanol plants;
- Plant-based digestate and CO_2 from biomethanation plants (of AD biogas);
- Crop residues and processing side-streams from potatoes, corn, sugar-beet, onion, olive, etc.;
- Struvite.

([58]) Chakraborty, B., Gayen, K., & Bhowmick, T. K. (2023). Transition from synthetic to alternative media for microalgae cultivation: A critical review. The Science of the Total Environment, 897, 165412. https://doi.org/10.1016/j.scitotenv.2023.165412
([59]) Silva, N., Gonçalves, A., Moreira, F., et al. (2015). Towards sustainable microalgal biomass production by phycoremediation of a synthetic wastewater: A kinetic study. Algal Research, 11, 350–358. https://doi.org/10.1016/j.algal.2015.07.014
([60]) For more information on contaminants in fertilisers, check the Sustainable Algae Industry Study WP3 “Algae potential for (waste)water treatment and fertiliser/plant biostimulants production”

Below we present the important side-stream categories based on availability (abundance in Europe) and relevance (under legal, technical terms) for this report.

4.3.1. Food-grade CO_2 is a commodity

Food-grade E 290 (carbon dioxide) is a food additive used as a propellant and acidity regulator in the food industry. The European food-grade CO_2 market was valued at €250.31 million, with a projected 7.9% CAGR. However, high-quality/purity biogenic CO_2 sources are not always readily available, as CO_2 is often recycled within the primary manufacturing process (e.g. wine and breweries) or sold to third parties for specific and restrictive applications that require stringent quality standards (e.g. food packaging or greenhouse cultivation) ([61]). For instance, greenhouse CO_2 demand alone in the EU was estimated at 5,000 thousand tonnes in 2017 ([62]), illustrating the growing competition for food-grade CO_2 across industries.

In 2022, shortages of food-grade CO_2 disrupted several key industries in Northern Europe, including in Germany, Poland, and France ([63]). As a result, the price surged to €1,000 per tonne, though it stabilised between €300 and €600 per tonne during 2023–2024, following the resolution of the immediate supply crisis ([64]).

Various sources of food-grade CO_2 are present across Europe, such as sugar fermentation and bioethanol production. In addition, food-grade CO_2 derived from anaerobic digestion (AD) biogas is becoming increasingly available, with production capacity and facility numbers rising rapidly as carbon capture and utilisation (CCU) technologies continue to mature.

Below, we analyse large European sectors producing plant-based side-streams rich in macronutrients and food-grade CO_2.

([61]) Lorenzo, M., Díaz, M., Marta Ramos, et al. (2022). PRELIMINARY EU CO2 SOURCES. In CO2SMOS [Document, Report]. Available here.
([62]) European Biogas Association. (2022). Biogenic CO_2 from the Biogas Industry. Available here.
([63]) Reuters (2022). Food industry in parts of Europe under pressure as CO2 runs short. Available here.
([64]) Ricardo (2025). Why the food industry needs CO_2 - and how to make it sustainable. Available here.

4.3.2. Wineries and breweries

Table 7 - Performance analysis of winery and brewery effluents as a source of nutrients and/or CO_2 for microalgae production.

CO_2 source	Macronutrients
Abundance: Regulatory relevance: Technical specs:	Abundance: Regulatory relevance: Technical specs:

Macronutrients from winery and brewery effluents

- **Ethanol fermentation processes of sugars in food and beverage industry,** including breweries and wineries, generate high-purity food-grade CO_2 gas and liquid effluents rich in nitrogen and phosphorus macronutrients and COD organic load.
- **Winery and beer production effluents, especially in wineries, have a high COD organic content.** First, the effluent is typically treated with a biological water treatment process train to remove the organic load by bacteria, and then by a denitrification-nitrification step to remove organic nitrogen. The nitrogen removal efficiency is low, at its highest at 20% ([65]).

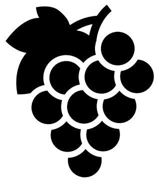
Two scenarios are suggested to use winery and brewery effluents for the enrichment of microalgae cultivation:

- **A first alternative scenario is to grow algae in autotrophic conditions to replace the bacterial nitrification step and efficiently produce beneficial algae biomass.**
- **A second scenario is to grow algae in mixotrophic conditions that can consume sugars, thereby reducing COD** and eliminating water treatment (aerobic or AD). For example, *Scenedesmus* was tested in a hybrid system with brewery wastewater containing COD and added CO_2 gas. The algae removed ammonia nitrogen, total nitrogen, total phosphorus, and COD by 90%, 76%, 96%, and 74%, respectively ([66]).

([65]) Bolzonella, D., Zanette, M., Battistoni, P., & Cecchi, F. (2007). Treatment of winery wastewater in a conventional municipal activated sludge process: five years of experience. Water Science & Technology, 56(2), 79–87. https://doi.org/10.2166/wst.2007.475
([66]) Song, C., Hu, X., Liu, Z., Li, S., & Kitamura, Y. (2020). Combination of brewery wastewater purification and CO2 fixation with potential value-added ingredients production via different microalgae strains cultivation. Journal of Cleaner Production, 268, 122332. https://doi.org/10.1016/j.jclepro.2020.122332

CO_2 from winery and brewery off-gases

The sugar fermentation process emits CO_2 as a by-product (at a ratio of 950 kg of CO_2 per tonne of bioethanol) along with other products. Within this sector, the production of beer and wine and the processes that involve acid fermentation (for instance, citric acid) are worth mentioning as the main industrial processes.



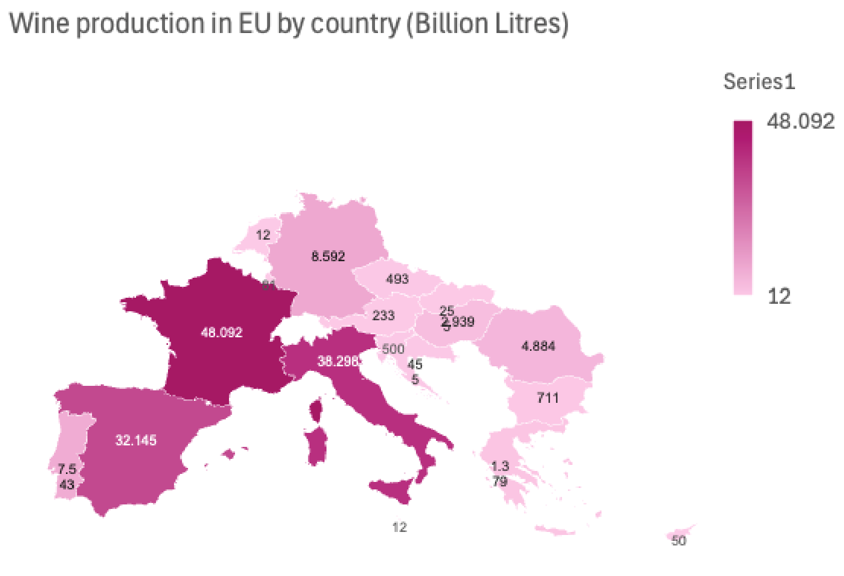
Wine industry facilities have the following characteristics:

- Average size: small to medium-sized facilities (like the beer industry);
- A high-quality food-grade CO_2 stream is produced (food quality degree), but it is reused as a protective gas in the filling system.;
- Winery liquid effluents are rich in COD, typically 6,800-7,100 mg O_2/litre total COD, which is approximately eight times higher than brewery effluents;
- The organic nitrogen is approximately 22-30 mg/litre, and organic phosphorus ranges from 6-8 mg/litre of effluent;
- Availability/Seasonality: in the case of wine fermentation, it is important to note that the annual CO_2 production is concentrated within a three-month period, due to the seasonal nature of winemaking.

Some Italian winery liquid effluents are:

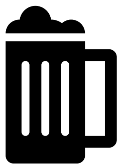
- COD 6,800-7,100 mg O_2 per litre
- Nitrogen content: 22-30 mg per litre effluent
- Phosphorus content: 6-8 mg per litre effluent

Figure 10 - Wine production EU by country in 2023/2024



Source: Adapted from ([67])

Beer industry facilities have the following characteristics:



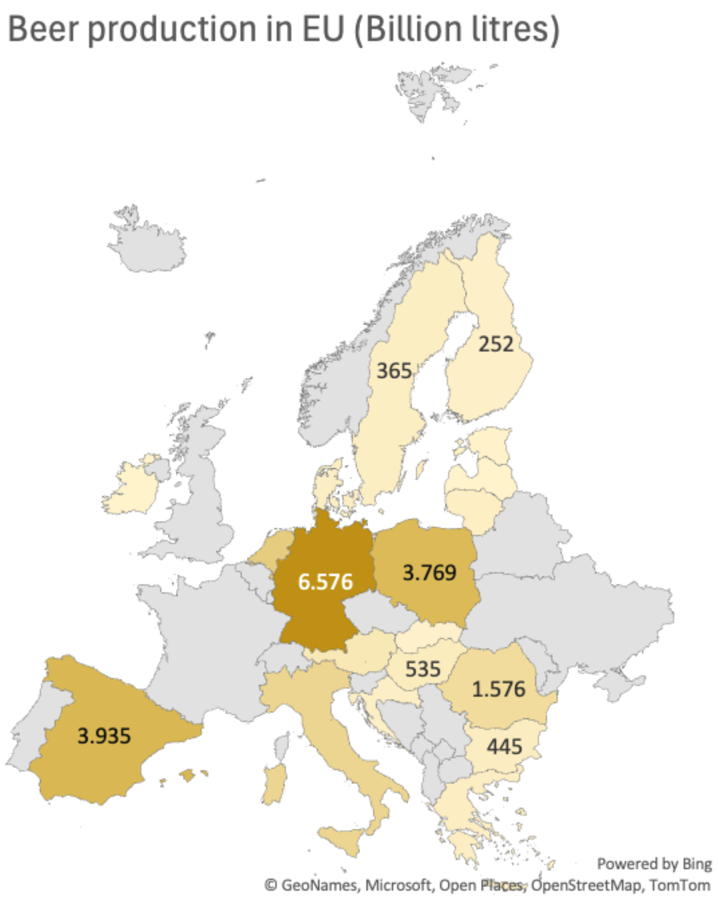
- Average size: small to medium-sized facilities. In Europe, two out three breweries ([68]) are small producers or microbreweries; therefore, emission sources are small and with a high degree of dispersion.
- The UK brewing industry uses an estimated 34 million m3/year of water – often the volume of water used is more than 3.4 times that of beer brewed. Most breweries discharge most of the supplied water as trade effluent, and, in many cases, trade effluent costs are higher than water supply costs ([69;70]).
- A high-quality food-grade CO_2 stream is produced (food quality degree), but it is reused as a protective gas in the filling system.

([67]) Wine production estimates EU 2024/2025. Available here.
([68]) Leferman, J. & The Brewers of Europe. (2024). THE CONTRIBUTION MADE BY BEER TO THE EUROPEAN ECONOMY. Available here.
([69]) Accepta. (2022, November 10). Brewing industry – reducing water & effluent treatment costs. Accepta Ltd. Available here.
([70]) Tuset, S. (2024, July 23). Treatment of effluents in the brewing industry and valorization of its liquid waste | Condorchem Enviro Solutions. Available here.

Brewery liquid effluents availability and composition:

- Availability is high in Western/Central, and Southern Europe
- Local discharge high: 3.5 - 8 litres per litre of beer produced
- Low COD: 1,100 mg O_2 per litre
- Low total phosphorus: ca. 30 – 50 mg per litre of wastewater
- Low total nitrogen: 50 - 100 mg per litre

Figure 11 - Beer production in EU by country 2023



Source: adapted from ([71])

([71]) Eurostat. (2024). 34.3 bn litres of beer produced in the EU in 2023. Available here.

4.3.3. Bioethanol plants

Table 8 - Performance analysis of bioethanol plant effluents as a source of nutrients and/or CO_2 for microalgae production.

CO_2 source	Macronutrients source
Abundance: Regulatory relevance: Technical specs:	Abundance: Regulatory relevance: Technical specs:

As discussed in the section on wineries and breweries, sugar fermentation can produce **bioethanol and CO_2**. The bioethanol produced in bioethanol plants is used as a transport fuel.

Bioethanol production also generates high-purity CO_2 as a by-product during fermentation processes. Due to its high concentration and low level of impurities, CO_2 from bioethanol production **can be refined to food-grade standards with minimal processing.**

Like other ethanol fermentation sectors, the liquid effluents from bioethanol production are rich in macronutrients and exhibit a high COD, showing many similarities to food-grade ethanol effluents.

The primary feedstocks for first-generation bioethanol plants are wheat, maize (corn), and sugar beet. There are approximately 58 first-generation bioethanol fermentation plants operating in Europe ([72]), with the majority located in **France (17 plants)**, followed by **Germany (8 plants)** and the **United Kingdom (5 plants)**. According to ePURE members' production data from 2020, 79.2% of renewable ethanol production was allocated to fuel applications, while 15.2% went to industrial uses and 5.6% to the food and beverage market. ePURE members represent approximately 85% of renewable ethanol production in Europe ([73]).

([72]) USDA GAIN Report. (2019). EU Biofuels Annual 2019. Available here.
([73]) Home - ePURE. (2025, May 15). ePURE. https://www.epure.org/

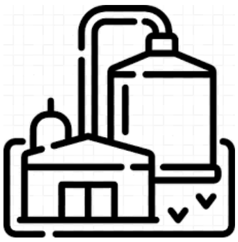
4.3.4. Effluents from plant-based Anaerobic Digestion

Table 9 - Performance analysis of plant-based anaerobic AD effluents as a source of nutrients and/or CO_2 for microalgae production.

CO_2 source	Macronutrients source
Abundance: ●●●●● Regulatory relevance: ●●●○○ Technical specs: ●●●●○	Abundance: ●●●●● Regulatory relevance: ●●●○○ Technical specs: ●●●●●

Anaerobic Digestion (AD) technology cannot remove nitrogen and phosphorus effectively, so it is often coupled with secondary nitrogen and phosphorus removal technologies, such as denitrification-nitrification.

Feedstocks for plant-based AD:



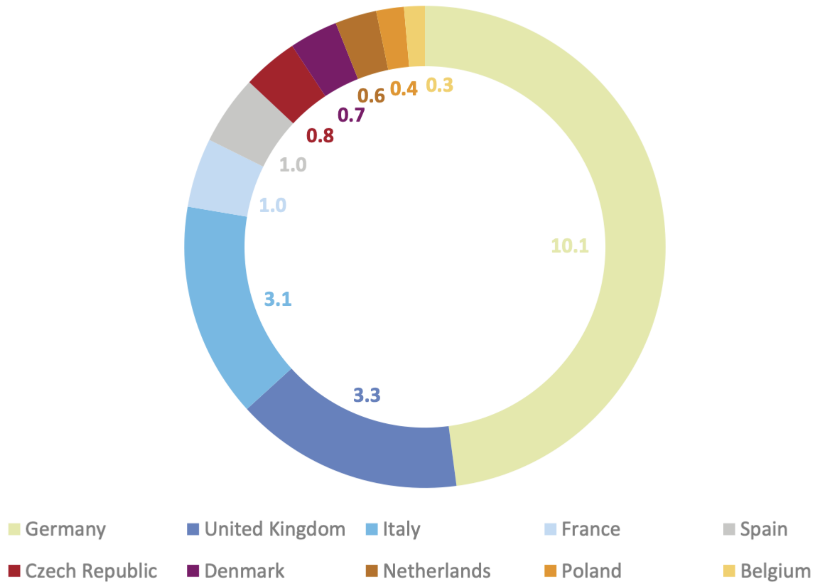
- **Crop Residues and Silage**: digestates derived from monocultures (e.g., corn) or mixed cultures (e.g., corn with legumes like broad beans or white sweet clover) are common. These digestates are rich in nitrogen, phosphorus, and organic matter, making them effective soil amendments ([74]);
- **Dedicated Energy Crops**: crops grown specifically for anaerobic digestion, such as corn or grass silage, and contribute to plant-based digestate production ([75]);
- **Industrial Food Processing Residues**: by-products from food industries, such as fruit and vegetable peels or pulp, are also digested to produce nutrient-rich plant-based digestate.

Food-grade CO_2 from AD biomethanation

The captured CO_2 from biogas upgrading is highly concentrated (99%). Even though a few pollutants (sulphur or organic compounds) must be removed, it is relatively easy to handle and to process. Biogas upgrading is a mature technology.

([74]) Hammerschmiedt, T., Kintl, A., Holatko, J., et al. (2022). Assessment of digestates prepared from maize, legumes, and their mixed culture as soil amendments: Effects on plant biomass and soil properties. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1017191
([75]) Hammerschmiedt, T., Kintl, A., Holatko, J., et al. (2022). Assessment of digestates prepared from maize, legumes, and their mixed culture as soil amendments: Effects on plant biomass and soil properties. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1017191

Figure 12 - Biogenic CO2 production potential per country (Mton/year) from AD plants, if they were upgraded to biomethane plants; data based on the actual combined biogas and biomethane production in 2020



Source: European Biogas ([76])

AD liquid digestate

AD digestate is widely abundant in Europe and can be an excellent mixed medium for microalgae production. In EU legislation, digestate can be a restricted nutrient source for organic algae production (see regulatory analysis in Chapters 3.3 and 5.3). Only **plant-based digestate can be a nutrient source for algae production** ([77]).

Digestate produced from processing non-animal effluents, often called **plant-based digestate**, is made through the anaerobic digestion of plant-based feedstocks ([78]) such as crop residues, silage, food side streams, and other organic plant materials. This digestate was not produced with manure, which is an animal byproduct.

It is estimated that, in 2021, Europe produced a total of between **222–258 Mt fresh matter digestate from agricultural residues (mixed plant-based and**

([76]) European Biogas Association. (2022). Biogenic CO_2 from the Biogas Industry. Available here.
([77]) Regarding algae fertiliser products for conventional agriculture and the use of manure digestate, check the Sustainable Algae Industry Study WP3 “Algae potential for (waste)water treatment and fertiliser/plant biostimulants production”, as these topics are out of scope of this report.
([78]) Kreloff, S. (2023, December 19). Understanding Digestate: The Bounty from Anaerobic Digestion. Sustainable Brands. Available here.

manure). More than 95% of this digestate is used directly in the agricultural sector as liquid fertiliser, while the solid fraction may be composted ([79]).

There are an estimated **2,000 anaerobic digestion plants** in Europe processing bio-waste, with a growing trend toward separate collection and treatment of plant-based waste streams ([80;81]).

Plant-based AD liquid digestate composition:

- Total phosphorus: 0.5–1.5 g/L
- Total nitrogen: 2–6 g/L, with ammonia (NH_4^+-N) constituting a significant portion (up to 43% of total N)

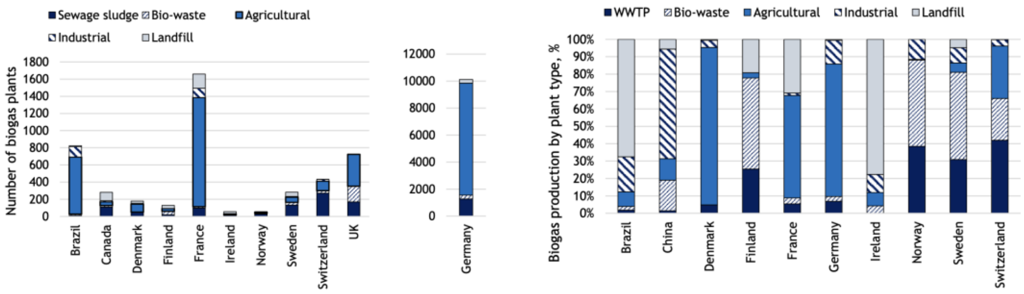
Country examples in Europe:

- **Germany** produces approximately **36.5 million tonnes** of digestate annually, of which 94% i**s liquid digestate** used directly on agricultural land;
- **The UK** produced **124 million tonnes of digestate** in 2009;
- **In Belgium (Flanders)**,**150 thousand tonnes of digestate** were produced in 2009.

AD (biogas) plants are typically organised based on their input biomass. In the IEA Bioenergy's report in Figure 5, most plants handle industrial, agricultural, and municipal biowastes, however, the number of plants treating only plant-based residues is unclear.

([79]) Stoyanov, G. (2016). Compost and digestate application in Europe – quality assurance & standards. Global Methane Forum 30 March 2016. Available here.
([80]) Gilbert, J., & Sibert, S. (2022). ECN Data Report 2022. Compost and digestate for a circular economy. Available here.
([81]) Walk, S., Gambini, R., & LIFE BIOBEST. (2024). LIFE BIOBEST D3.3 - Guideline on quality compost and digestate. Available here.

Figure 13 - LEFT: Number of biogas plants in operation in selected IEA Bioenergy Task 37 member countries; RIGHT: Production of biogas by type of plant.



Source: IEA Bioenergy ([82])

https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en The EU Circular Economy Act comes in good times, as the **REPowerEU plan** ([83]), adopted by the European Commission, sets a clear target to increase biomethane production to **35 billion cubic metres per year by 2030** – more than a tenfold increase on current levels. Achieving this target will require the construction of approximately **5,000 new biomethane plants** across the EU. An average biogas plant produces approximately **1,500 m³ of digestate per day**. Under the REPowerEU plan, the European Union aims to produce **2.7 billion cubic metres of biogas per year by 2030**. A significant portion of the resulting nutrient-rich digestate is expected to be in liquid form, making it potentially suitable for enriching microalgae cultivation. However, the origin of the digestate is generally not well-documented and is suspected to be a mixture of manure- and plant-based feedstocks.

4.3.5. Other agro-industrial residues and side-streams

Agricultural farms grow and process food crops, generating multiple side streams, including process water, vegetable and fruit juices, and other residues from crops such as potatoes, maize (corn), sugar beet, onions, olives, and grass. These side streams are excellent sources of macronutrients and can be used directly for microalgae cultivation without the need for AD.

For example, projects like the CBE-JU funded projects, ZEST ([84]) and INGREEN ([85]), demonstrate the use of low-cost agricultural side-streams and wastes (such as **fruit and vegetable processing side-streams** and paper mill

([82]) IEA (2024). A perspective on the state of the biogas industry from selected member countries. In IEA Bioenergy Task 37: Vol. 2024:2 [Report]. Available here.
([83]) REPowerEU. (2022, May 18). European Commission. Available here.
([84]) Zest Project. (2025, April 25). Home - Zest Project. Available here.
([85]) INGREEN | Circular Bio-based Europe Joint Undertaking (CBE JU). (2023, August 23). Available here.

wastewater) as feedstock for fermentation processes, including algae cultivation. This is because such side-streams are rich in accessible nitrogen and phosphorus nutrients. The INGREEN project operated a pilot plant that ferments paper mill wastewater, recovering nutrients, and producing bioplastics ([86]).

Additionally, the Grass2Algae operational group evaluates using grass juice to grow microalgae as an additional revenue source for farmers.

Moreover, the food fermentation of plant-derived biomasses (e.g. bakery, fruit pulp) can generate nutrient-rich effluents, mainly when controlled and optimised for microbial protein or organic acid production (precision fermentation).

4.3.6. Mineral nutrients: Struvite

Table 10 - Performance analysis of struvite as a source of nutrients for microalgae production.

Macronutrients source
Abundance: 
Regulatory relevance: 
Technical specs: 

The updated EU Organic Farming Regulations ([87]) recently authorised "recovered struvite and precipitated phosphate salts" as fertilising materials in organic production https://eur-lex.europa.eu/eli/reg_impl/2021/1165/oj/eng(amended **Regulation (EU) 2021/1165**).

Production Volume: As of 2020, between 990 and 1,250 tonnes of phosphorus were recovered as struvite annually in the EU, sourced from about 24 to 39 European production plants. These represent roughly 30–50% of the world's struvite installations.

Production sites: around 39 struvite plants have been identified in the EU, with installations using different precipitation processes. Most are located at municipal wastewater treatment plants, but some are linked to agro-industrial waste streams, such as potato processing and dairy wastewater.

([86]) Pilot plant for fermentation of PHA operational – INGREEN. (n.d.). Available here.
([87]) Commission Implementing Regulation (EU) 2023/121 of 17 January 2023 amending and correcting Implementing Regulation (EU) 2021/1165 authorising certain products and substances for use in organic production and establishing their lists. Available here.

Struvite can be a phosphate source but using it will require an additional nitrogen source.

4.4. Summary outlook

Below are the main findings from the analysis of availability, regulatory relevance, and technical specifications of various identified industrial effluent streams as sources of macronutrients and CO_2. With the **upcoming EU Circular Economy Act,** announced in December 2024, the EC plans to create measures to **stimulate demand for secondary materials** and wastes, revise waste regulations, and set stricter recycling targets, especially for critical raw materials such as phosphorus fertilisers.

Table 11 - Summary of findings from performance analysis of several nutrient sources and CO_2 for microalgae production.

Side-streams	Macronutrients	CO_2
Wineries & breweries	Abundance: ●●●●○ Regulatory relevance: ●●●●○ Technical specs: ●●●○○	Abundance: ●●●●○ Regulatory relevance: ●●●●○ Technical specs: ●●●●●
1G Bioethanol plants	Abundance: ●●●○○ Regulatory relevance: ●●●●○ Technical specs: ●●●○○	Abundance: ●●●○○ Regulatory relevance: ●●●●○ Technical specs: ●●●●●
Plant-based AD	Abundance: ●●●●● Regulatory relevance: ●●●○○ Technical specs: ●●●●○	Abundance: ●●●●● Regulatory relevance: ●●●○○ Technical specs: ●●●●●
Struvite (phosphate)	Abundance: ●●●●○ Regulatory relevance: ●●○○○ Technical specs: ●●○○○	

For the scenario work in the next Chapter, we will focus on ethanol fermentation and AD flows.

We will not elaborate further on the struvite stream as it contains only phosphorus nutrients, not nitrogen. Therefore, to use it, it needs to be combined with other nitrogen-rich effluents, such as digestate.

5. Hypothetical scenarios for Northern European cold climates and Southern European warm climates

Below we present three factsheets with recommendations for economically, environmentally and legally viable nutrients and CO_2 alternative sources for organic microalgae cultivation. The factsheets showcase regional scenarios for Northern and Southern European conditions.

5.1. Performance indicators

Below are performance indicators for analysing the presented scenarios. The work builds on the EU4Algae work and the AlgaeProBANOS project's sustainability performance indicators, which consider economic and environmental dimensions.

Table 12 - Performance indicators analysing economic, environmental and legal factors of presented scenarios.

Impact level	Economic	Environmental	Legal
Value chain	Production Costs: - Cost of sourcing alternative carbon and nutrient inputs - Cost of microalgae cultivation systems in cold and warm climates	Carbon Footprint: - Total carbon emissions in product LCA, incl. supply chain - Energy consumption during microalgae cultivation and processing - Biodiversity impact - Land use - Water Use	Compliance with EU Organic Regulation
Product off-setting	Market competitiveness: - Price comparison between algae-based products and organic fertilisers or biostimulants - Market demand for organic algae-based fertilisers/ biostimulants	Resource Efficiency: - competing nutrient use	National and Regional Regulations Food Safety and Contaminants
Technology	Infrastructure and Technology Investments: - For cultivation, processing, and drying systems	Waste Valorisation: - Potential for nutrient recovery from waste streams	Permitting and Licensing Standardisation
Sustainable innovation and finance	Economic Incentives: - Availability of subsidies or financial opportunities linked to EU funding programs or national initiatives - Scalability and viability	- Carbon and nutrient credits	EU Green Deal EU Algae Initiative EU Mission Ocean Circular Economy Alignment

5.2. Sketching regional scenarios

Based on regulatory analysis in Chapters 3.3 and 5.3, the available supply of nutrients and CO_2 in Chapter 4 and the analysis of best available solutions in Chapter 4, the following scenarios are outlined below.

Table 13 - Main descriptors of the North European and the South European cases.

Factor	Scenario 1: North European case	Scenario 2: South European case
Reactor type	Photobioreactor	Raceway pond enclosed in a greenhouse, photobioreactor
CO_2 sources	Winery, brewery, bioethanol, AD	Winery, brewery, bioethanol, AD
Dissolved macro-nutrient sources	Winery, brewery, bioethanol, AD	Winery, brewery, bioethanol, AD
Light	Artificial	Sunlight
Temperature control	Mainly for heating	Mainly for cooling
Microalgae species	No differentiation in scenario work; Mainly *Chlorella spp*. and *Scenedesmus spp.;* also, for agricultural applications other relevant species are: *Acutodesmus spp., Dunaliella spp., and Calothrix elenkini* ([88];[89]); and *Spirulina Plantensis (strictly autotrophic species*)	

([88]) Parmar, P., Kumar, R., Neha, Y., & Srivatsan, V. (2023). Microalgae as next generation plant growth additives: Functions, applications, challenges and circular bioeconomy-based solutions. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1073546

([89]) Çakirsoy, I., Miyamoto, T., & Ohtake, N. (2022). Physiology of microalgae and their application to sustainable agriculture: A mini-review. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1005991

5.3. Factsheet 1: Legal dimensions

Companies marketing organic products of microalgae fertiliser are few and small, as the sector is nascent. One of the key reasons is complex legislation, in addition to economic barriers, as analysed below.

5.3.1. How the scenarios support EU strategies on sustainable intensification of production and nutrient management

The EU Green Deal and Farm to Fork strategy, among others, foresee reducing nutrient losses by at least 50% and developing an integrated nutrient management action plan to address nutrient pollution at the source, increasing organic production by 25% by 2030. This report examines how the "North" and "South" scenarios can support these European strategies. Further, setting up specific targets at MS level and promoting local industrial symbiosis schemes at scale can derisk investments.

The **Circular Economy Act** has excellent support potential for developing markets for nutrients for organic algae production. Establishing harmonious definitions – such as those for algae and organic fertilisers – is urgently needed to provide clarity and strengthen market development.

If national laws and court proceedings are made more accessible, they can provide valuable guidance for policy makers and market operators.

Licensing, permits, and planning of new algae farms and larger industrial symbiosis projects are often complex due to fragmented processes governed by national laws. The level of development is at an early stage, and it can benefit from mapping and assessing national strategies and methods. EU4Algae ([90]) is developing a new algae farmers' toolkit, including a licensing toolkit to guide algae farmers.

5.3.2. Compliance with EU Organic legislation: available regulations and standards, good practices in the market, gap analysis

The EU has unified, legally binding **regulation for organic production**, Regulation (EU) 2018/848 and related acts. and related acts.

In Europe, there are harmonised principles and rules for the organic production of agricultural products and algae cultivation products. These rules include

([90]) EU4Algae. (n.d.). Maritime Forum. Available here.

production rules, provisions on certification and use of organic indications and controls (Regulation (EU) 2018/848 Article 15 and Part III of Annex II).

In the **main structure and definitions of 2018/848**:

- **Algae are not included** in the definitions section (Article 3);
- Algae are explicitly mentioned under Article 15 production rules for algae and aquaculture animals and detailed rules are set under Part III of Annex II
- Although algae need fertilisation to grow like terrestrial plants, **the rule separates plant production rules for terrestrial plants and aquatic algae** (see Annex II Part I), with the main provisions not applying to algae. Algae cultivation and relevant authorised nutrient inputs are addressed separately in Article 15. And Annex II Part III

On restricted nutrients for algae cultivation:

Only nutrients of plant and mineral origin can be authorised for use in organic production of algae. **Furthermore, their use is restricted to indoor algae production facilities, such as PBRs and enclosed raceway ponds, including greenhouses (Article 24)** ([91]). **Nutrients derived from animal by-products,** including manure digestate or non-factory farming effluents, are prohibited for use in organic algae production.

In industrial symbiosis settings, organic production must be clearly separated from non-organic output, for example through the separation of water flows and production locations.

Regarding the use of non-organic products and inputs in organic production – including in the cultivation of algae – **Regulation (EU) 2018/848** provides a defined framework whereby only authorised products and substances may be used. In accordance with Article 24, the European Commission may authorise certain non-organic substances for specific uses in organic production, such as fertilisers, feed materials, and processing aids, provided they meet strict criteria and are included in restrictive lists. This is not an exception, but a formal authorisation process based on necessity, origin, and alignment with organic principles. Member States may also submit requests for additions or changes to these lists, which are regularly reviewed by the Commission.

A MS considers that a product or substance should be granted **a specific authorisation for use in an outermost region of the Union**, it may request the EC to carry out an assessment and authorise such a product/substance (Article 45(2)). Such specific authorisations may be granted for a renewable period of two years. **On carbon dioxide use: CO_2 has recently been listed** as a nutrient for enriching water for algae cultivation in Annex II of a Regulation (EU)

([91]) in accordance with point 2.1.2. of Part III of Annex II

2021/1165 ([92]) amendment. Food-grade CO_2 has been listed as relevant for production in enclosed cultivation systems on land.

5.3.3. Findings and recommendations

Based on the analysis above, the findings are summarised in the table below:

Table 14 - Legal performance indicators and findings for the two regional scenarios.

Factor	Scenario 1: North European case	Scenario 2: South European case	EU Regulatory compliance
Reactor type	Photobioreactor	Raceway pond enclosed in a greenhouse	Enclosed algae cultivation facilities (Reg. (EU) 2018/848)
CO_2 sources	Winery, brewery, bioethanol, AD	Winery, brewery, bioethanol, AD	CO_2 is listed as a nutrient for algae in a 2021/1165 Annex II amendment.
Dissolved macro-nutrient sources	Winery, brewery, bioethanol, AD	Winery, brewery, bioethanol, AD	Only nutrients of plant and mineral origin (Regulation (EU) 2018/848); Algae produced with high environmental and health standards (Regulation (EU) 2018/848), so no waste inputs allowed.
Light	Artificial	Sunlight	N/A
Temperature control	Mainly for heating	Mainly for cooling	N/A
Microalgae species	Mainly *Chlorella spp., Scenedesmus spp.; also* relevant are *Acutodesmus spp., Dunaliella spp., and Calothrix elenkini* ([93;94]); *(Spirulina Plantensis*)		Non-GMO strains (Regulation (EU) 2018/848); No cyanobacteria strains, e.g. Spirulina (FPR Regulation (EC) 2019/1009, under CMC2), but allowed under CMC 1
Industrial Symbiosis examples	Kalundborg Symbiosis (DK), Sotenas symbiosis (SE), Fermentalg/ Carbonworks (FR)	A4F/Allmicroalgae (PT), Microphyt (FR), Aqualia (SP), Algen (SL)	In industrial symbiosis, organic production should be separated from non-organic output (Reg. (EU) 2018/848); also, only environmentally friendly processing is allowed (no organic solvents etc.)

([92]) Expert Group for Technical Advice on Organic Production EGTOP. (2023). FINAL REPORT On Plant Protection (VIII) And Fertilisers (VI). Available here.
([93]) Parmar, P., Kumar, R., Neha, Y., & Srivatsan, V. (2023c). Microalgae as next generation plant growth additives: Functions, applications, challenges and circular bioeconomy-based solutions. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1073546
([94]) Çakirsoy, I., Miyamoto, T., & Ohtake, N. (2022b). Physiology of microalgae and their application to sustainable agriculture: A mini-review. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1005991

Based on the analysis of the findings, the following recommendations are suggested:

For EU policymakers (DG AGRI, DG GROW):

- **Harmonise definitions in regulatory frameworks for terms such as *algae* and *organic*.** Promoting circular bio-based fertilisers is challenging when the legal framework and the wider community use different terminology to refer to the same product. For example, the term “organic” is strictly defined in Regulation (EU) 2018/848 for certified organic, BIO, food products, but it can also refer to carbon-based materials in a chemical or environmental context. This double meaning can cause confusion and lead stakeholders to perceive them as distinct product categories, even when they are functionally similar.
- **Clarify Regulations 2018/848 and 2021/1165 regarding the use of algae specifically for products placed on the market as fertilisers for organic farming** - which inputs are allowed, and which are prohibited. Most importantly, harmonise certain rules for algae and terrestrial plants, as both can serve as sources of fertilisers. It is inconsistent to impose strict organic requirements on algal biomass while exempting comparable plant-based products, resulting in an uneven playing field.
    - In Annex 2 - European standards relevant to algae biostimulants of Regulation (EU) 2021/1165, under Algae and algae products, the requirement ‘only from organic or collected in a sustainable way’ aims to ensure sustainable sourcing, particularly for wild-harvested seaweed used as fertilisers. This provision is important because seaweed collected from the wild is a significant input for fertilisers. However, Article 2.4 of Part III of Annex II to Regulation (EU) 2018/848 specifically addresses the sustainable collection of wild algae and should not be considered applicable to **microalgae and seaweed cultivated in controlled systems**. Therefore, the provision ‘’only from organic or collected in a sustainable way’’ should be removed.
- Engage in discussions for allowing **organically farmed manure digestate as input for algae** organic agriculture products (currently not allowed in Regulation 2018/848), taking the example from Switzerland (no factory farming, monitor contaminant levels);
- Connected to the above, DG AGRI is advised to consider establishing ambitious European Nutrient Recycling Targets ([95]) with MS-level recommendations.

([95]) EU stalls on strategy to curb nutrient losses. (2023). Euractiv. Available here.

For EU policymakers (DG AGRI, DG ENV, DG MARE):

- For the next Common Agricultural Policy (CAP) funding cycle, consider adding recommendations, under statutory management requirements (SMRs) or good agricultural and environmental conditions (GAECs), requiring farmers to produce or use circular fertilisers in the CAP 2023-2027 ([96];[97]);
- Consider integrating agriculture into the new Danish Farm CO as an example. The Danish tax plans to trade carbon and nutrients in the EU ETS ([98]);([99]);
- Promote algae as a measure in the Water Framework (WFD) and Marine Strategy Framework Directives (MSFD). EU MS are encouraged to include algae bioremediation as well as recycling of nutrients and carbon dioxide in Article 13 of MSFD Programmes of Measures (PoM) under the eutrophication descriptor, aiming to reduce the load and inflow of nutrients into marine waters and mitigate eutrophication ([100]).

For EU Member States:

- **Build capacity within Member State public administration bodies**, as harmonised EU rules may be perceived as **complex or even conflicting** when compared to existing national legislation. This can hinder regulatory interpretation and slow down product approval processes.
    - Identify MS contact points for “circular nutrients for organic products”.
    - Inform MS authorities via Q&A guides and ask them to create MS main contact points.

([96]) Conditionality. (2024, February 22). Agriculture and Rural Development. Available here.
([97]) European Commission. (2023). Approved 28 CAP strategic plans 2023–27. Directorate-General for Agriculture and Rural Development. Available here.
([98]) The Business Research Company. (2025b). Sustainable Agriculture Global Market Report 2025. In The Business Research Company. Available here.
([99]) Regeringen. (2024). Aftale om et grønt Danmark. Available here.
([100]) Arvaniti et al. (2025). “Verification of high potential Algae products and possible criteria, labels, tools (LCAs) to assess environmental footprint of algae products & services”; EU4Algae. Available here.

5.4. Factsheet 2: Economic dimensions

The following performance indicators and criteria were used in the economic analysis of the regional scenarios:

Table 15 - Economic performance indicators and criteria used in the analysing

Category	KPIs	Criteria
Market competitiveness	- Price comparison between algae-based products and other organic fertilisers or biostimulants - Market demand for organic algae-based fertilisers/ biostimulants	€/kg CAGR %
Production Costs	- Cost of sourcing alternative carbon and nutrient inputs - Cost of microalgae - Capital and operational costs of production	€/kg of inputs €/kg of product
Infrastructure and Technology Investments	- Investments for algae cultivation, processing, and drying systems	No. and size of companies producing relevant technologies and products.
Economic Incentives	- Availability of subsidies or financial opportunities linked to EU funding programs or national initiatives for industrial symbiosis and circular bioeconomy projects - Scalability and viability (risk)	No. of funded innovation projects, and total budget funded on the topic.

Each indicator is analysed separately below.

5.4.1. Market competitiveness

The value of the European plant biostimulants market is estimated around USD 1.5-2 billion in 2022 ([101]) with a compound annual growth rate of 10.3% ([102]). Standard biostimulants include humic acids, amino acids, seaweed extracts and microbial inoculants. **Biostimulant product categories** vary, offering targeted and/or widespread stimulating effects on crop growth and resilience. In contrast, algae whole cell biostimulant products and their biostimulant capacity can also provide macronutrients, thus substituting the use of fertilisers. However, few microalgae-based plant biostimulant products are produced in Europe, and even fewer are declared suitable for organic farming. Most of the microalgae biostimulants are imported from overseas at competitive prices ([103]).

([101]) Market overview - EBIC. (2024c, November 3). EBIC. Available here.
([102]) The Business Research Company. (2025b). Sustainable Agriculture Global Market Report 2025. In The Business Research Company. Available here.
([103]) Biorizon Biotech. (2024, February 10). Biorizon Biotech is the only company with four European certified biostimulants. Available here.

As elaborated in Factsheet 1 in Chapter 5.3, the industry considers the current European organic legislation for algae-based fertilisers and biostimulants "unfair." For example, in Regulation 2021/1165, there is a lack of level play for algae with non-algae fertilisers, meanwhile, in Regulation 2018/848, algae are discriminated against in comparison with terrestrial plants. The regulatory obstacles evidently discourage the industry from investing in organic algae ([104]), which can affect reaching organic production targets, considering that microalgae-based biostimulants are promising "next generation" products with better efficacy and environmental performance.

Biostimulant producers must first verify the product's bioactive claims in Europe. Gathering data and submitting the portfolio is a rather cost-intensive process. European projects like AlgaeProBANOS are developing such guiding dossiers for algae biostimulant producers.

Prices for microalgae extracts and whole cell biostimulants are estimated to range from approximately **€10,000 to €80,000 per tonne of dry weight** at small-scale retail pricing ([105]). At bulk scale, prices are expected to be up to ten times lower, with starting prices from around €1,000 per tonne.

The **European organic fertilisers market** prices are so low compared to algae production costs that **only a combined biostimulant/fertiliser product**, such as a whole-cell algae product ([106;107;108]) can achieve a competitive price.

The benchmark of **microalgae-based organic fertilisers** is mainly meal-based fertilisers (62% of EU market share), which are by-products of the meat processing industry, due to their rich nutrient content (nitrogen, phosphorus, potassium, calcium) ([109]). The second most competitive and upcoming organic fertiliser product for 2024-2029 is livestock manure-based fertilisers, the use of which is expected to grow in Europe (see JRC's RENURE proposal for safely using processed manure as a chemical fertiliser alternative) ([110]). **Bone meal organic fertiliser prices are found €5,800 per tonne at small-scale retail pricing** ([111]), and are expected to be 10 times lower, i.e. €580 per tonne, at a bulk price.

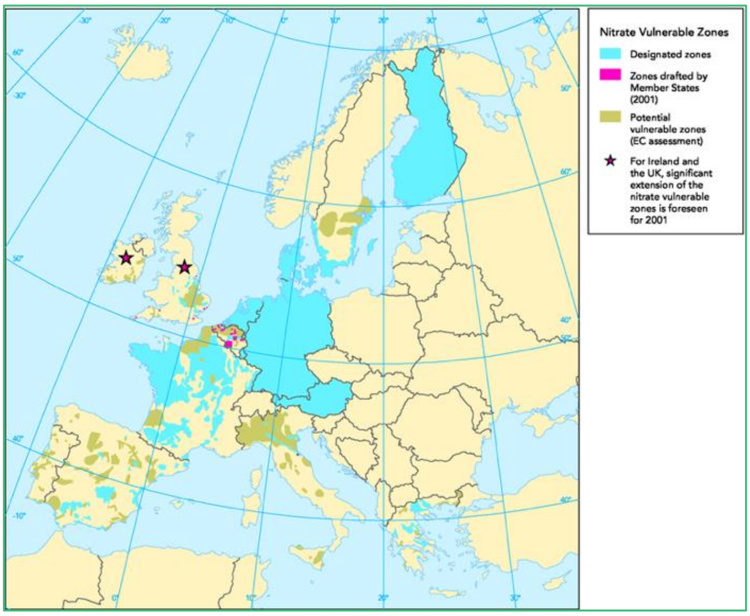
([104]) Personal communication.
([105]) Bärebring, L. (2016). Sustainability aspects of Swedish crop cultivation (Master's thesis, University of Gothenburg). DiVA Portal. Available here.
([106]) Water2Return. (n.d.). Microalgae cultivation as biostimulants in agriculture. Available here.
([107]) Renuka, N., Guldhe, A., Prasanna, R., Singh, P., & Bux, F. (2018). Microalgae as multi-functional options in modern agriculture: Current trends, prospects and challenges. Frontiers in Plant Science, 9, 1870. https://doi.org/10.3389/fpls.2018.01782
([108]) CINEA. (n.d.). ALGAENAUTS – Sustainable biopesticides based on microalgae. European Climate, Infrastructure and Environment Executive Agency. Available here.
([109]) Mordor Intelligence. (n.d.). Europe organic fertilizer market. Available here.
([110]) European Commission, Joint Research Centre. (2020). Assessment of nutrient flows and pressures on land and water in the EU: Integrated assessment of nutrient management in agriculture (JRC121636). Publications Office of the European Union. Available here.
([111]) Organic Way. (n.d.). Bone meal 25kg. The Seed Store. Available here.

5.4.2. Production costs

Liquid effluent prices

AD digestate: There is **no standardised, Europe-wide market price for plant-based AD liquid digestate** as prices are highly regional and depend on factors like nutrient content, processing, transport, and local supply-demand dynamics. For example, LIFEBIOBEST investigated the fact that compost prices may have a low value in the largest market segment (€ 4 per tonne in agriculture). Still, its premium value can increase in other segments with mean prices of € 75 per tonne in retail ([112]). This is a large difference in pricing depending on market demand, e.g. prices are low or even negative in nitrate vulnerable zones, where digestate cannot be directly applied on land ([113]).

Figure 14 - Nitrate Vulnerable Zones, where price of digestate can be even negative



Source: Nitrate vulnerable zones ([114])

Certified digestates, such as those with an ECN-QAS label, can achieve a higher price in the market.

>>> Good practice from outside EU: As mentioned in Chapter 3.2, the UK together with the industry, developed in 2017 an end-of-waste quality private

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([112]) Zero Waste Europe. (2024, June). LIFE BIOBEST WP3 D3.1 Guideline Bio-waste Separate Collection: Annex 1 – Best Practices. Available here.
([113]) Nitrate vulnerable zones, EU. (2009b, November 12). European Environment Agency’s Home Page. Available here.
([114]) Nitrate vulnerable zones, EU. (2009b, November 12). European Environment Agency’s Home Page. Available here.

standard protocol for AD digestates (PAS110), which has led to market development and commodification of side-streams in the last twelve years ([115]).

Table 16 - Estimate AD liquid digestate prices range across EU regions and depending on quality and standards.

EU Region	Raw Liquid Digestate	Processed/Certified Digestate
Central/Western Europe	€-10 ([116]) (negative price) – €5/t	€10–€30/t
Southern Europe	€-5 (negative price) – €15/t	€20–€40/t
Eastern Europe	€-5 (negative price) – €(negative price) 5/t	€ 10–€ 25/t

Winery & brewery effluents: There is **no established commercial market price for winery liquid effluents in Europe**. Winery liquid effluents, mainly the wastewater generated from wine production processes (such as tank washing, grape pressing, and fermentation), are typically considered as a **waste management cost** rather than a product with a sale price. Therefore, it has a negative price (discharge fee). European projects, like REDWINE, ALG-AD and CHEERS, develop industry-relevant solutions for valorisation of wine and beer effluents with microalgae.

>>> Good practice: in the UK, breweries can save up to **65% on water discharge costs** by investing in advanced onsite treatment of liquid effluents ([117]).

5.4.2.1. Comparing close raceway ponds vs. photobioreactor systems

Photobioreactors (PBRs) are a dominant system for microalgae production in the EU, accounting for 71% of all production units. Open raceway ponds and fermenters are used to a lesser extent, representing 19% and 10% of production units, respectively. For Spirulina, the most common cultivated algae species, most producers (83%) rely primarily on open pond systems ([118]).

While PBRs are the most used system across all microalgae-producing countries, some, such as **Spain, also significantly use open ponds**. The so-called HRAP (High-rate algal ponds) system, coupled with biofertiliser production, was

([115]) Environment Agency. (2014, March 17). Quality protocol: anaerobic digestate. GOV.UK. Available here.
([116]) Negative price, trade fee.
([117]) G R O U P, Little, M., & Nichols, C. (n.d.). St Austell Brewery set to save up to 65% on water discharge costs with innovative wastewater treatment technology. Case Study. Available here.
([118]) Coppens, J., Grunert, O., Van Den Hende, S., Vanhoutte, I., & Boon, N. (2021). From lab to market: An integrated approach to valorise microalgal biomass into biostimulants. Frontiers in Marine Science, 7, 626389. https://doi.org/10.3389/fmars.2020.626389

implemented in Andalucía (Almeria, Spain), where the mean temperature is 19.1°C and global solar radiation is 5.29 kWh/m^2 d ([119]).

Specifically, the **production costs of *Chlorella spp*. are estimated at € 32 per kilo when produced with tubular PBR and LED lights.** On average, CAPEX accounts for 44% of the price, and OPEX accounts for 56% of the cost price of microalgae production.

Some geographic and technical factors that can affect production prices are:

CAPEX-related factors:

- System configuration and bioreactor setup: For example, **light supply** through LED or electricity using **photovoltaic panels** requires additional investments;
- Biomass productivity: **Algae growth depends on location-dependent climate conditions** (temperature, light);
- Scale of facility: Large facilities benefit from economies of scale.

OPEX-related factors:

- Input requirements linked to system configuration and bioreactor setup: **LED-based photobioreactors**, **photobioreactors with photovoltaic panels** and photobioreactors relying on **geothermal energy** have different electricity requirements;
- Input prices: **energy prices** and **labour costs** vary across countries.

5.4.3. Infrastructure and technology investments

Biostimulant manufacturers reinvest 3-10% of turnover into research and development, but it takes up to ten years to bring new products to market. This is a significant investment considering how little protection exists to prevent copies or reverse engineering of biostimulant products ([120]).

The following companies are actively developing relevant products in combination with using circular regimes. Three European companies – AlgaEnergy, Biorizon Biotech, and NeoAlga, all based in Spain – were identified as having certified organic biostimulant products.

([119]) Rouphael, Y., & Colla, G. (2018). Synergistic biostimulatory action: Designing the next generation of plant biostimulants for sustainable agriculture. Science of The Total Environment, 644, 1316–1329. https://doi.org/10.1016/j.scitotenv.2018.06.356
([120]) European Biostimulants Industry Council. (2024d, November 3). Market overview. Available here.

Table 17 - Industry good practices that use circular systems and produce agricultural products; in bold companies that produce organic products

Scenario	Company name (country)	Recycling alternative sources of nutrients and carbon; algae products
Northern Europe	Algiecel (DK)	Uses CO_2 emissions from precision fermentation no organic products
	MiAlgae (UK)	Uses whiskey distillery effluents no organic products
	Swedish Algae Factory (SE)	Uses food side-steams no organic products
	CarbonWorks (FR)	Uses CO_2 emissions from a heterotrophic microalga no organic products
	Power Algae (EE)	Uses AD digestate No organic products
Southern Europe	AlgaEnergy (ES)	**Produces biostimulants for organic production**
	Necton/Allmocroalgae (PT)	Uses food-grade residual sugars and nutrients Produces fertilisers and biostimulants; no organic
	Biorizon Biotech (ES)	**Produces biostimulants for organic production**
	A4F (PT)	Not known
	NeoAlgae (ES)	**Produces biostimulants for organic production**

5.4.4. Economic incentives to drive innovation and investments

In March 2024, ESPP organised a one-day workshop at the 16th CRU Phosphates 2024 Conference & Exhibition in Warsaw, Poland, on possible policy tools to support market uptake of recovered nutrients, where Stephanos Kirkagaslis, European DG AGRI (CAP), was also present. The results were published by ESPP online.

Among the findings, it was highlighted that the **CAP can support innovation, notably in nutrient recycling, through EIP-Agri, CAP-Network, and LEADER, while further agricultural research opportunities are available through**

Horizon Europe ([121]). Specifically, nutrient recycling can be supported under both Pillars of the CAP:

- Pillar I: through farmer participation in Eco-Schemes and/or Sectoral Interventions;
- Pillar II: via agri-environment-climate commitments and green investments.

Such support is subject to conditionality provisions, including Statutory Management Requirements (SMRs) and Good Agricultural and Environmental Conditions (GAECs). These are valid and effective economic instruments that promote circularity, and are therefore included in the list of recommendations for DG AGRI**.**

Moreover, support can be available under rural development interventions. Eco-Schemes and agro-environment management commitments are agricultural practices for the voluntary (subsidised) participation of farmers, reflecting national needs. Member States are responsible for identifying priorities, such as nutrient recycling.

EU Funding programmes

After analysing the EU4Algae AirTable for microalgae funded projects, we identified:

- 13 projects on side-stream valorisation with budget €46 million.
- 16 projects funded since 2014 on biostimulants and pesticides with €22 million budget.
- 10 projects on bioremediation topics with €20 million.

([121]) Van Spingelen, R., Kirkagaslis, S., & European Sustainable Phosphorus Platform. (2024). European Sustainable Phosphorus Platform SCOPE Newsletter. European Sustainable Phosphorus Platform SCOPE Newsletter, n° 151, 1–3. https://www.phosphorusplatform.eu/images/scope/ScopeNewsletter151.pdf

5.4.5. Recommendations

The findings are summarised below:

Table 18 - Performance indicators and findings for the two regional scenarios

Factor	Scenario 1: North European case	Economic performance	Scenario 2: South European case	Economic performance
Reactor type	Photobioreactors (PBR)	PBR most common	Raceway pond enclosed in a greenhouse	Mix of types; open raceway most common for low/medium value products, e.g. Spirulina, due to associated costs, especially in Spain
CO_2 sources	AD plants	- Availability from AD: Highest in Germany, UK, Denmark, other EU countries are also option - Quality from AD or food production - 99% Quality; can clean to food-grade easily	AD plants	- Availability from AD: Highest in Italy, France, Spain, other EU countries are also option - Quality from AD or food production - 99% Quality; can clean to food-grade easily
	Winery, brewery, bioethanol plants	- Winery CO_2: Availability high in Central/East Europe; reused onsite; seasonal - 99% Quality - Price can vary based on demand	Winery, brewery, bioethanol plants	- Wine & Beer effluents: Availability high in Central/West, East and South Europe; reused onsite, winery seasonal - 99% Quality - Price can vary based on demand
Dissolved macro-nutrient sources	Winery, brewery, bioethanol, AD	- Low prices and high availability; Depending if a region is a NVZ, effluent prices can be even negative - Wine effluents: Availability high in Central/East Europe	Winery, brewery, bioethanol, AD	- Low prices and high availability; Depending if a region is a NVZ, effluent prices can be even negative - Wine & Beer effluents: Availability high in Central/West, East and South Europe
Light	Artificial	If solar panels or geothermal energy used, needs additional investment	Sunlight	-

Temperature control	Mainly for heating	If solar panels or geothermal energy used, needs additional investment	Mainly for cooling	If solar panels used, needs additional investment
Industrial Symbiosis producing algae		- Sotenas symbiosis (SE) recycling food effluents tested at pilot		- A4F/Allmicroalgae (PT) recycling food effluets Fermentalg/ Carbonworks (FR), recycling CO_2 Aqualia (SP) and Microphyt (FR) are recycling wastewater effluents

Note: Indicators: - High performance, -¯ Medium performance, ¯ Low performance.

Based on findings the following recommendations are suggested:

- **Use incentives, such as tax exemptions, to encourage industry to reduce or valorise waste streams and to support the use of side-streams instead of virgin inputs.** Examples include:
  - CAP funding support for farmers processing/standardising digestates.
  - Include nutrient recycling activities under the EU Taxonomy.
- **Develop European marketing strategies for sidestreams and residues**, and promote standardisation of effluents, including:
  - The development of a new European “organic” effluent standard.
- **Map European sidestreams relevant organic production** focusing on plant-based digestate and food-grade CO_2:
  - Include an “organic” typology, e.g. plant-based digestate and food-grade CO_2 within the scope of IEA Bioenergy Task 37.
- **Incentivise industry champions to invest in the development and marketing of circular organic products from algae,** for example through tax reductions:
  - Financing the marketing/certification step of a new algae biostimulant product needs efficacy testing, safety and quality testing, documentation, etc., which can be a complex and resource-intensive process for an SME. Further, applying for organic certification adds a new cost;
  - Algae biostimulants are premium products compared to conventional biostimulants, such as animal meal, while organic

algae biostimulants are considered high-end premium products with a questionable market need.

- **Promote regional and local best practices in industrial symbiosis through platforms such as EU4Algae and other stakeholder initiatives.**
- **Support brokerage and innovation facilities for circular and organic solutions**, such as the CBE-JU Co-Pilots project, and the CBE-JU Primary Producers WG that stimulate innovation and demonstrate circular bioeconomy solutions, facilitate match-making between technology developers and buyers, and promote circular business models, including those involving organic algae in blue/green sectors.

5.5. Factsheet 3: Environmental dimensions

5.5.1. Assessment of the environmental performance of circular algae products

The environmental life-cycle assessment (LCA) is an essential tool for evaluating the environmental performance of the value chain, based on accounting for the impact of production and valorisation, which is also relevant to microalgae. LCA (ISO 14040/44, PEF/OEF) ([122]) is a standard methodology used to assess the environmental aspects associated with a product. It is carried out by collecting and quantifying energy and materials needed for production, system inputs, and waste and emissions released to the environment.

A problem foreseen with LCA using circular nutrients and carbon for microalgae production is the **lack of facilities that operate under actual conditions.** Therefore, in many cases, extrapolation is required to estimate the performance of facilities based on real models and reliable data. Consequently, a wide range of processes for microalgae production (cultivation systems, cultivated species, harvesting processes, value products) results in **significant variability of technical primary data inputs** ([123]).

In addition, at the implementation stages of the LCA, the **methodological perspectives**, such as functional units and system boundaries, are also widely variable. Different methodological choices cause discrepancies in current research results even when the technical data are similar. Adding to this complexity, **LCAs for zero-waste algae value chains are even more complex**, primarily when multiple products are produced in biorefineries or when circular processes are employed. While specific product benefits can be determined, the high cost and time requirements of LCAs make them inaccessible to small companies ([124]).

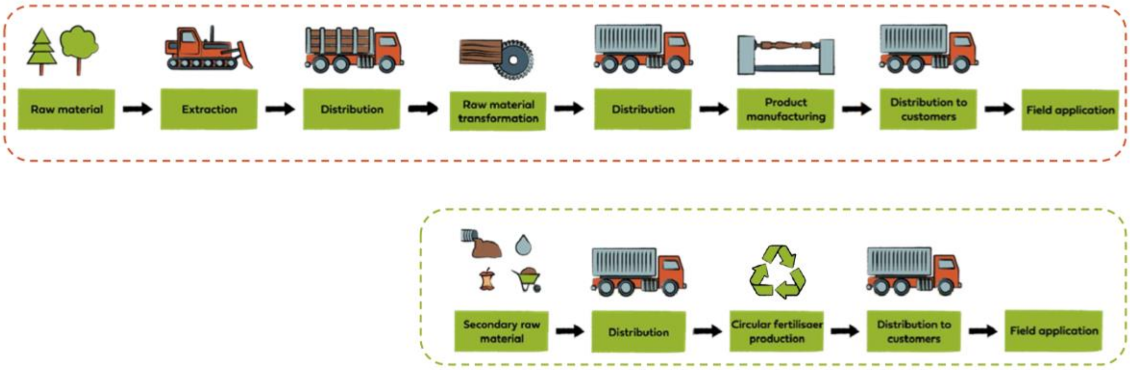
In summary, the assessment of the environmental performance of circular organic products cannot be considered robust, verifiable, and transparent due to a lack of standard methodologies and industry-relevant data. As a result, multiple

([122]) Arvaniti et al. (2025) Verification of high potential Algae products and possible criteria, labels, tools (LCAs) to assess environmental footprint of algae products & services. EU4Algae. Available here.
([123]) de Souza, M. H. B., Calijuri, M. L., Assemany, P. P., et al. (2019). Soil application of microalgae for nitrogen recovery: A life-cycle approach. *Journal of cleaner production*, *211*, 342-349. https://doi.org/10.1016/j.jclepro.2018.06.133
([124]) Arvaniti et al. (2025) Verification of high potential Algae products and possible criteria, labels, tools (LCAs) to assess environmental footprint of algae products & services. EU4Algae. Available here.

European microalgae projects, such as LOCALITY and REALM, are developing new robust tools and environmental assessment methods to increase confidence in data-based decision-making. AlgaeProBANOS is developing a **new sustainability assessment framework for circular algae value chains** to increase decision-making confidence, e.g. planning and investment, by ensuring that environmental safety goes hand in hand with economic growth and social resilience, and assessing scale-up and carrying capacities, **considering also local terms and particularities of a system** ([125]).

Regarding circular biobased fertilisers, the and NOVA-FERT projects observed similar gaps: there is no product-specific LCA guidance, no specific EU PEF instructions or other available guidelines. As a result, NOVA-FERT is **developing a new PEF methodology for circular fertilisers** to fill this gap ([126]). Projects observed similar gaps: there is no product-specific LCA guidance, no specific EU PEF instructions or other available guidelines. As a result, NOVA-FERT is **developing a new PEF methodology for circular fertilisers** to fill this gap ([127]).

Figure 15 - The system boundaries for an environmental LCA for side-streams valorisation do not cover the whole value chain: RED block: the main production line; GREEN block: the side-stream valorisation line.



Source: FER-PLAY

As explained, circular value chains are complex to analyse with LCAs, due to a lack of standard methodologies. For example, to define how upstream emissions are allocated within circular value chains, NOVA-FERT suggested a new PEF methodology, adapted from EC Recommendation (EU) 2021/2279, Section 4.5.1 on "Allocation in animal husbandry" ([128]). The suggestion uses the same typology:

([125]) Kotta, J., Kõivupuu, A., Rätsep, M., et al. (2024). MONITORING AND EVALUATION SUSTAINABILITY ASSESSMENT FRAMEWORK OF MICRO- AND MACROALGAL VALUE CHAINS. In Report. Available here.

([126]) Karetta, V., Luke, P., Luke, H., et al. (2024). D2.2 – PEF-wise PCR methodology to implement LCA for the environmental assessment of alternative fertilizing products – 1st version (for public consultancy) (M. Jednačak, IPS, P. Zapata Aranda, & BIOAZUL, Eds.). Available here.

([128]) EC Recommendation (EU) 2021/2279 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and

a) residual, b) co-product, or c) manure as waste but adapts it for nutrient inputs to produce (algae-based) fertilisers. The suggestion, adapted to our report, is as follows:

1. **Co-product:** if biomass (e.g. plant-based digestate or effluents) has an economic value (market price), it is considered a product or co-product. The biomass feedstock will enter the foreground system (fertiliser manufacturing plant) with environmental burdens assigned by its system of origin (supply chain). Thus, the user of these flows will account for a share of the feedstock production environmental burdens.
2. **Residual:** if biomass feedstock (digestate or effluent) is utilised, exported to further processing (manufacturing plant), and does not have an economic value (market price) but a use value (e.g. fertilisation value), it is regarded as a residual with zero emissions allocation of an upstream burden.

This is **a key component in the emission allocation in environmental assessments, and it depends on the economic value of the nutrient inputs** (in our case, macronutrients or carbon dioxide in this report), which can change over time as the market develops (see also Chapter 5.4 on Economic Factsheet).

5.5.2. Environmental performance categories for circular algae agricultural products

An analysis of the standard PEF impact categories, using microalgae fertilisers produced with AD digestate and circular carbon dioxide as an example, reveals the following hotspots and performance. **Analysis of plant-derived effluents performance, such as from wineries and breweries, was explicitly included.**

organisations – available here: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021H2279

Table 19 - Environmental footprint (EF) impact categories and identified hotspots, using microalgae fertilisers produced with digestate and circular carbon dioxide as an example

EF impact category	Sub-category	Performance when using digestate as nutrient source for microalgae production in agricultural products
Climate change	Carbon Footprint	-- **Carbon footprint:** Higher levels of carbon dioxide emissions can be avoided as algae consumes CO_2 as inorganic carbon source and for pH control ([129]). Algae offer promising CO_2 sequestration capacity by utilising it as inorganic carbon source and for pH control. If recycled CO_2 can be provided, algae actively assist in large-scale CO_2 mitigation to produce biomass. This biomass could present a future alternative to replace imported fertilisers in Europe, further mitigating climate change emissions associated with transcontinental transportation ([130]) Instead of storing and compressing, on site recovery of CO_2, is an essential option for the sustainability of microalgae-related production chains ([131]).
	N_2O, ammonia release	- **Ammonia (air) and Nitrous oxide (air)**: The nitrogen-based emissions are limited during algae growth on digestate in closed bioreactors. Reduced levels of ammonia and dinitrogen monoxide (N_2O) emissions are possible during bioreactor operation due to high pH buffering capacity of digestate and ammonia-oxidation bioprocess, respectively ([132]).
Human toxicity	Heavy metals, PCBs	- **Ecotoxicity of water bodies**: No direct incidents ([133]).

([129]) D'Imporzano, G., Veronesi, D., Salati, S., & Adani, F. (2018). Carbon and nutrient recovery in the cultivation of Chlorella vulgaris: A life cycle assessment approach to comparing environmental performance. *Journal of Cleaner Production*, *194*, 685-694. https://doi.org/10.1016/j.jclepro.2018.05.174
([130]) Vigani, M., Parisi, C., Rodríguez-Cerezo, E., Barbosa, M. J., Sijtsma, L., Ploeg, M., & Enzing, C. (2015). Food and feed products from micro-algae: Market opportunities and challenges for the EU. Trends in Food Science & Technology, 42(1), 81-92. https://doi.org/10.1016/j.tifs.2014.12.004
([131]) Carfagna, S., Lanzuise, S., Napolitano, M., Gotor, C., Sellitto, V. M., & Fiorentino, A. (2018). On the use of microalgal biomass for plant biostimulation and protection. Bioresource Technology, 267, 271–276. https://doi.org/10.1016/j.biortech.2018.07.083
([132]) Rajasekaran, C., & Ponnuswamy, V. K. (2014). Production of biogas using algae and cyanobacteria: A review. Bioresource Technology, 165, 278–282. https://doi.org/10.1016/j.biortech.2013.12.107
([133]) de Souza, M. H. B., Calijuri, M. L., Assemany, P. P., de Siqueira Castro, J., & de Oliveira, A. C. M. (2019). Soil application of microalgae for nitrogen recovery: A life-cycle approach. Journal of cleaner production, 211, 342-349. https://doi.org/10.1016/j.jclepro.2018.06.133

EF impact category	Sub-category	Performance when using digestate as nutrient source for microalgae production in agricultural products
Acidification	Nitrogen (nitrate) to soil	¯ **Ammonia (soil):** The category is linked to the atmospheric deposition of nitrates that cause a change in the acidity of soils. The highest values were linked with recovered nutrients from side-streams, e.g. digestate, that contain ammonia which undergoes volatilisation during the production of microalgae ([134]). **- Nitrate (soil):** The algae cultivation on digestate helps in avoiding over-application of excess N from digestate to the field, which is very relevant to Nitrate Vulnerable Zones ([135;136;137])
Eutrophication, terrestrial, freshwater & marine	Nitrogen, and phosphorus leaching	**- Nitrates (water**): High levels of ammonia release and nitrate discharge into water bodies are avoided by diverting land application of digestate towards algae cultivation. This is because ammonia within digestate is converted to nitrate when applied to the soil, which is prone to surface run-off and causes nitrate-polluted water bodies. **- Phosphorus (water):** In terms of phosphorus and particulate matter emissions, soluble **phosphate available in digestate is used up by the algae cultures** which, upon dewatering, produces clear and dischargeable liquids free of soluble phosphate ([138])
Water use	Water use	-¯ **Water:** The tap water used for digestate dilution and for algal growth but might be recirculated after membrane filtration, thereby reducing overall water demand ([139])

([134]) Tasca, A. L., di Capaci, R. B., Tognotti, L., & Puccini, M. (2019). Biomethane from short rotation forestry and microalgal open ponds: system modeling and life cycle assessment. Bioresource technology, 273, 468-477. https://doi.org/10.1016/j.biortech.2018.07.083
([135]) Chuka-Ogwude, D., Ogbonna, J., & Moheimani, N. R. (2020). A review on microalgal culture to treat anaerobic digestate food waste effluent. Algal Research, 47, 101841. https://doi.org/10.1016/j.algal.2020.101841
([136]) Xia, A., & Murphy, J. D. (2016). Microalgal cultivation in treating liquid digestate from biogas systems. Trends in Biotechnology, 34(4), 264-275. https://doi.org/10.1016/j.tibtech.2015.12.010
([137]) Nitrate vulnerable zones, EU. (2009c, November 12). European Environment Agency's Home Page. Available here.
([138]) Franco, A. F. T., Da Encarnação Araújo, S., Passos, F., De Lemos Chernicharo, C. A., Filho, C. R. M., & Figueredo, C. C. (2018). Treatment of food waste digestate using microalgae-based systems with low-intensity light-emitting diodes. Water Science & Technology, 78(1), 225–234. https://doi.org/10.2166/wst.2018.198
([139]) Fret, J., Roef, L., Diels, L., Tavernier, S., Vyverman, W., & Michiels, M. (2020). Combining medium recirculation with alternating the microalga production strain: a laboratory and pilot scale cultivation test. Algal Research, 46, 101763. https://doi.org/10.1016/j.algal.2019.101763

EF impact category	Sub-category	Performance when using digestate as nutrient source for microalgae production in agricultural products
Resource use, minerals, metals & fossils	Energy consumption, coagulant NaOH.	**-¯ Rock phosphate:** During microalgae growth on liquid agro residues, such as digestate, the main nutrients are directly supplied without the need for additional primary resources. However, the additional supply of phosphate might be needed, as few digestate sources may be poor in soluble P. **-¯ Non-renewable energy consumption:** The electricity requirement is high during digestate pre-treatment, operation of closed bioreactors, and harvesting systems. Renewable energy systems, such as solar panels, can substitute non-renewable electricity. **Transport** causes higher impacts when manure is transported, because for each unit of fertiliser, a large amount of water is also moved ([140]). Industrial symbiosis coupling algae production on-site can reduce transport.

Note: Indicators: - High performance, -¯ Medium performance, ¯ Low performance.

5.5.3. Comparison of open and closed microalgae production systems

In Spain, microalgae open raceway ponds are more widespread than closed PBR reactor types. Comparing the environmental performance of pilot microalgae production in open raceway pond systems (naturally lit) against closed PBR systems (naturally or artificially lit) in Spain, the **open cultivation systems outperform the closed reactors across environmental impact categories.** Closed reactors offer advantages – notably reduced contamination risks, smaller physical footprint and enhanced control over the growth conditions, thus benefiting both yields and biomass quality. Further, with regards to CO_2 fixation efficiency, open systems have 30% efficiency ([141]), while closed systems have 60% efficiency ([142]).

However, there are some disadvantages to PBRs. Compared to an open raceway reactor design, a closed system has additional material and electrical requirements to control, e.g. lighting, agitation, and gas exchange. Furthermore, closed systems with artificial lighting can be in places devoid of natural light availability, e.g. indoors, inside containers, or in any European geography ([143]).

([140]) Tasca, A. L., Di Capaci, R. B., Tognotti, L., & Puccini, M. (2018). Biomethane from Short Rotation Forestry and Microalgal Open Ponds: System Modeling and Life Cycle Assessment. Bioresource Technology, 273, 468–477. https://doi.org/10.1016/j.biortech.2018.11.038
([141]) It is anticipated that an enclosed raceway should have a higher than 30% CO2 fixation efficiency.
([142]) CINEA Algae & Climate Study. Available here.
([143]) Pechsiri, J. S., Thomas, J. B. E., El Bahraoui, N., et al. (2023). Comparative life cycle assessment of conventional and novel microalgae production systems and environmental impact mitigation in urban industrial symbiosis. Science of the Total Environment, 854, 158445. https://doi.org/10.1016/j.scitotenv.2022.158445

5.5.4. Recommendations

Table 20 - Environmental performance indicators and findings for the two regional scenarios

Factor	Scenario 1: North European case	Scenario 1: Environmental performance	Scenario 2: South European case	Scenario 2: Environmental performance
Reactor type	Photobioreactor	- Electricity requirement for pumping and artificial lightning ¯ Land use	Raceway pond enclosed in a greenhouse	¯ Electricity requirement for pumping in raceway ponds - Land use
CO_2 sources	Winery, brewery, bioethanol, AD	- Carbon dioxide removal from fixing industrial residues	Winery, brewery, bioethanol, AD	- Carbon dioxide removal from fixing industrial residues
Dissolved macro-nutrient sources	Winery, brewery, bioethanol, AD	- Electricity requirement for diluting AD effluents	Winery, brewery, bioethanol, AD	- Electricity requirement for diluting AD effluents
Light	Artificial	- Electricity requirement for lightning	Sunlight	¯ Electricity requirement for lightning
Temperature control	Mainly for heating	- Electricity requirement for heating	Mainly for cooling	-¯ Electricity requirement for cooling, depending on time and location
Microalgae species	Mainly *Chlorella spp., Scenedesmus spp.; also* relevant are *Acutodesmus spp., Dunaliella spp., and Calothrix elenkini* (144;145); *(Spirulina plantensis*)	- Flexible options: Autotrophic microalgae/ cyanobacteria species ideally use macronutrients from pretreated effluents (no sugars); mixotrophic can use mixed carbon e.g. sugars and CO_2, in addition to macronutrients; heterotrophic can ferment sugars and macronutrients (no CO_2).	Mainly *Chlorella spp., Scenedesmus spp.; also* relevant are *Acutodesmus spp., Dunaliella spp., and Calothrix elenkini* (146;147); *(Spirulina plantensis*)	- Flexible: Autotrophic need pretreated effluents (removed COD), while mixotrophic can remove both carbon and macronutrients. ¯ System prone to contamination.

Indicators: - High performance, -¯ Medium performance, ¯ Low performance.

(144) Parmar, P., Kumar, R., Neha, Y., & Srivatsan, V. (2023d). Microalgae as next generation plant growth additives: Functions, applications, challenges and circular bioeconomy based solutions. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1073546

The findings of the analysis in the previous sub-section are summarised in the table above.

Based on the identified gaps, some environmental recommendations are:

- **Standardise metrics and terminology**. The lack of standardised metrics and terminologies across studies and industries complicates the comparison of products. This makes it essential to develop harmonised indicators for assessing the performance and potential of circular fertilisers, was one of the recommendations of the FER-PLAY and NOVAFERFT projects ([148]).
- **Select wisely the most interesting circular fertilisers and biostimulants to perform in-depth multi-assessments**. Multi-topic assessments are resource-intensive, taking months to evaluate 5-10 value chains from economic, environmental, and social perspectives.
- **Be mindful of methodology limitations and discuss results accordingly to avoid misleading conclusions**. There is a lack of robust, comprehensive, multi-assessment methods for evaluating the environmental and economic impact of circular fertilisers. Most widely endorsed assessment methodologies, such as Life Cycle Assessment (LCA), social LCA (s-LCA), and Life Cycle Cost (LCC), do not effectively model circular and complex systems. In general, these methodologies fail to account for key characteristics of circularity ([149]).

([145]) Çakirsoy, I., Miyamoto, T., & Ohtake, N. (2022c). Physiology of microalgae and their application to sustainable agriculture: A mini-review. Frontiers in Plant Science, 13. (https://doi.org/10.3389/fpls.2022.1005991

([146]) Parmar, P., Kumar, R., Neha, Y., & Srivatsan, V. (2023e). Microalgae as next generation plant growth additives: Functions, applications, challenges and circular bioeconomy based solutions. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1073546

([147]) Çakirsoy, I., Miyamoto, T., & Ohtake, N. (2022d). Physiology of microalgae and their application to sustainable agriculture: A mini-review. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1005991

([148]) Gambuzzi, E., Iglesias Yañez, H. I., SORIANO DISLA, J., Edayilam, N., meers, E., & Genua, M. (2025). Important aspects for a successful implementation of projects for the market uptake of circular fertilisers. Zenodo. https://zenodo.org/records/14966009

([149]) Gambuzzi, E., Iván, I. Y. H., Jose, S. D., Edayilam, N., Meers, E., & Genua, M. (2025). Important aspects for a successful implementation of projects for the market uptake of circular fertilisers. Zenodo. https://doi.org/10.5281/zenodo.14966009

5.6. SWOT analysis of three hypothetical scenarios for European conditions

Below, we analyse three scenarios of alternative sources for macronutrients and CO_2, suitable for growing microalgae biomass for fertilisers and biostimulants in organic agriculture.

1. **AD effluents** – Microalgae produced in industrial symbiosis with a plant-based AD or biomethanation plant, which supplies liquid digestate macronutrients and upgraded CO_2 gas (autotrophic conditions).
2. **Treated winery and brewery effluents** - Microalgae in industrial symbiosis with a winery or brewery, which supplies treated ([150]) liquid effluents containing macronutrients and CO_2 gas (autotrophic conditions).
3. **Untreated winery/brewery effluents** - Algae produced in industrial symbiosis with winery or brewery, which are supplied with **untreated** effluents containing macronutrients and sugars, and CO_2 gas (mixotrophic conditions).

A SWOT analysis is prepared for each scenario. The analysis can be read independently. There are many similarities and overlaps.

5.6.1. Scenario A: AD effluents

Algae produced in industrial symbiosis with a **plant-based AD or biomethanation** plant, which supplies **liquid digestate** macronutrients and **upgraded CO_2 gas** (autotrophic conditions).

Suggested setup: in **PBR supported by artificial light.**

This solution takes advantage of the expanding AD sector and suggests using AD liquid digestate rich in macronutrients and CO_2 from bioremediation plants. It is relevant mainly for **Northern Europe**, or where AD plants exist.

([150]) With aerobic or anaerobic bacteria

Strengths	Weaknesses
• High year-round availability of co-located anaerobic digestion (AD)/biomethanation plants in Europe, which can supply both macronutrient-rich effluents and CO_2 gas for use in industrial symbiosis setups; availability is especially high in Germany, the UK, and Denmark, with other EU countries also presenting viable options. • Widespread availability of AD liquid digestate effluents rich in macronutrients across Europe. • AD liquid digestate is available at low prices per tonne, and in NVZs may even be offered at negative prices due to disposal pressures. • Liquid digestate can be upgraded to premium quality while still remaining cost-effective. • Effluents from methanation plants typically contain 99% CO_2, which can be easily refined to food-grade quality. • Many microalgae species, including *Chlorella* spp. and *Scenedesmus* spp., have been successfully tested with these effluents and are suitable for agronomic applications (e.g. biostimulants and fertilisers). • The use of solar panels or geothermal energy can help increase the renewable energy mix for operations such as transporting, mixing, pumping, heating, and cooling. • PBR systems have low land and water usage, and emit minimal greenhouse gases. • Food-grade CO_2 is permitted as a nutrient input for algae under the organic production rules.	• Liquid digestate must be diluted - typically around 100-fold - to achieve appropriate macronutrient concentrations for use. • Digestate often requires pre-treatment, such as removal of suspended solids, to reduce opacity and colour, which increases processing costs. • High ammonia content in digestate necessitates oxidation to nitrate before use, due to toxicity concerns for microalgae. • The availability of soluble phosphorus in digestate is often low; supplementation may be needed (e.g. with struvite), although struvite is not currently permitted under organic regulations for algae production. • PBRs are not cost-efficient reactors, but they offer higher product yields. • Biosecurity levels are significantly higher in PBRs, reducing contamination risk. • No clear statistics currently exist on the number of plant-based anaerobic digestion (AD) plants in Europe (Eurostat, IEA Bioenergy Task 37, EBA) • Cyanobacteria are not permitted under FPR CMC 2. However, food safe cyanobacteria such as Spirulina should be allowed for use in agronomic products without prior processing; to utilise cyanobacterial biomass in fertilising products, further processing to extracts compliant with CMC1 is required.
Opportunities	**Threats**
• Mapping activities can help attract investment and support marketing strategies for plant-based digestate and CO_2 as valuable inputs in circular systems. • The REPowerEU strategy includes a target to scale biogas production tenfold via AD by 2030. • The Circular Economy Act has the potential to create a single market for effluents containing phosphorus, such as digestate, and to introduce nutrient recycling targets, incentives, and support for industrial symbiosis. • There are ongoing discussions with DG GROW for including cyanobacteria in FPR rule, including *Spirulina*, in other categories of component materials which is the most produced algae species in Europe. Currently the FPR rules allow the use of bacterial extracts under CMC 1 without exempting cyanobacteria. • ABP (manure) - derived digestate from non-factory farms is conditionally allowed in organic production rules in Switzerland, but not in the EU; but if this is allowed, abundance of liquid digestate will be even higher in Europe.	• Plant-based AD digestate is not permitted under current organic product regulations, due to concerns such as biosecurity risks and potential contaminant levels. • There is growing competition from other market uses of digestate and CO_2, which is leading to increased prices and reduced availability for use in organic and circular systems. • The REPowerEU strategy is at risk of missing its targets, limiting the projected growth of biogas infrastructure and associated circular inputs. • The REPowerEU strategy currently does not explicitly include plant-based AD within its scope, which may hinder opportunities for circular nutrient sourcing from agricultural residues.

5.6.2. Scenario B: Treated winery and brewery effluents

Algae produced in industrial symbiosis with a **brewery/winery**, which supplies **treated** ([151]) **liquid effluents** containing macronutrients and **CO_2 gas (**autotrophic conditions).

Suggested setup: using natural light in an **enclosed** reactor (raceway pond or a PBR).

The solution uses winery/brewery effluents, abundant in Southern Europe, but other similar agro-industrial effluents can be used, e.g., bioethanol, horticulture, food processing, etc. These effluents might need to be treated to remove the COD before use in autotrophic conditions (see alternative below). This solution is relevant for Southern Europe or other areas with similar effluents

([151]) With aerobic or anaerobic bacteria

Strengths	Weaknesses
• High yearly availability of brewery effluents (and seasonal winery effluents) that can supply both macronutrient-rich wastewater and CO_2 gas for industrial symbiosis setups. Availability is highest in Central/Western, Eastern, and Southern Europe. • Brewery/winery liquid effluents are available at low or negative prices per tonne in Europe, especially in NVZs. • Liquid effluents have a relatively good N/P/K ratio and have relevant concentration levels, so they do not require dilution. • Effluent gas is food-grade CO_2, ready to use for organic production • There are many species, including *Chlorella spp. Scenedesmus spp.* that have been tested with such effluents, and are relevant for agronomic applications (biostimulants, fertilisers) • Open cultivation systems outperform the closed reactors across all environmental impact categories, and are more cost efficient (CAPEX, OPEX), however they offer less control on quality of product and yield, compared to PBRs. • If artificial lightning is required, solar panels or geothermal energy can increase renewable energy mix for transporting, mixing, pumping, heating and cooling. • Food-grade CO_2 is allowed as a nutrient for algae in organic production rule.	• Winery/brewery effluents have a variable annual availability, accessibility and quality specifications, thereby it is complex to analyse as cumulative scenario. • There are no clear statistics of available plant-based effluents in Europe, e.g. winery, brewery, bakery, irrigation waters, or horticulture. • Treatment of winery/brewery effluents for removing the COD increases cost. • Dark colour or suspended solids can decrease light penetration, and increase needed surface area, potentially impacting the costs and land-use area. • Land and water-use as well as release of gas emissions are higher with enclosed raceway reactors, than with PBR. • Biosecurity risk is higher in raceway ponds than in PBR. • Whole cyanobacteria species, like Spirulina are not allowed by FPR rule under CMC2 to use for agronomic products without prior processing. However, cyanobacteria extracts may be used under CMC 1 if they meet all relevant requirements. There is no specific restriction on cyanobacteria extracts in CMC 1. • Regarding CO_2 fixation efficiency, open systems have 30% efficiency ([152]), while closed systems have 60% efficiency ([153]). • A comparison between enclosed and open raceway is missing, and it was not analysed well, due to lack of data.
Opportunities	**Threats**
• Mapping activities can increase investments and marketing of effluents. • The Circular Economy Act can potentially create single markets for effluents containing phosphorus, such as digestate, with nutrient recycling targets, create incentives, support industrial symbiosis, etc. • There are ongoing discussions with DG GROW for including cyanobacteria in FPR rule, including *Spirulina.*	• Rising competition from other market uses of effluents and CO_2, increasing prices and reducing availability.

([152]) It is anticipated that an enclosed raceway should have a higher than 30% CO2 fixation efficiency.
([153]) Pechsiri, J. S., Thomas, J. B. E., El Bahraoui, N., et al. (2023). Comparative life cycle assessment of conventional and novel microalgae production systems and environmental impact mitigation in urban-industrial symbiosis. *Science of the Total Environment*, *854*, 158445. https://doi.org/10.1016/j.scitotenv.2022.158445

5.6.3. Scenario C: Untreated winery/brewery effluents

Algae produced in industrial symbiosis **with a brewery/winery**, supplying them with **untreated effluents** containing macronutrients, and sugars, and **CO_2 gas** (mixotrophic conditions).

Suggested setup: in a **PBR reactor supported by artificial light.**

This scenario is like the previous one but relevant for many European regions. It is different in that the solution valorises sugars present in untreated winery/brewery liquid effluents, thus taking advantage of the mixotrophic growth of algae. This is relevant to all of Europe, where treated effluents exist.

Strengths	Weaknesses
• Brewery (and seasonal winery) effluents are widely available across Central/Western, Eastern, and Southern Europe, and can supply both macronutrient-rich wastewater and CO_2 gas for use in industrial symbiosis with algae cultivation. • Brewery/winery liquid effluents are available at low prices per tonne in Europe, even at negative prices in NVZ areas. • Liquid effluents have a relatively good N/P/K ratio and have relevant concentration levels, so they do not require dilution. • No treatment of effluents is needed for removing the COD (sugars) before use. Algae can convert also sugars to biomass. • Effluent gas is food-grade CO_2, ready to use for organic production • There are many species, including *Chlorella spp. Scenedesmus spp.* that have been tested in mixorophic conditions with such effluents, and are relevant for agronomic applications (biostimulants, fertilisers). • Open cultivation systems outperform the closed reactors across all environmental impact categories, and are more economic (CAPEX, OPEX), however they offer less control on quality of product and yield, compared to PBRs. • If artificial lightning is required, solar panels or geothermal energy can increase renewable energy mix for transporting, mixing, pumping, heating and cooling. • Food-grade CO_2 is allowed as a nutrient for algae in organic production rule.	• Winery/brewery effluents have variable annual availability, accessibility and quality specifications, thereby it is complex to analyse as cumulative scenario. • There are no clear statistics of available plant-based effluents in Europe, e.g. winery, brewery, bakery, irrigation waters, or horticulture. • Land and water -use as well as release of gas emissions are higher with enclosed raceway reactors, than with PBR. • Biosecurity risk is higher in raceway ponds than in PBR. • Cyanobacteria species, like *Spirulina,* are not allowed under FPR CMC 2 for use in agronomic products without prior processing; however, cyanobacteria extracts may be permitted if they comply with CMC 1 requirements. • regarding CO_2 fixation efficiency, open systems have 30% efficiency ([154]), while closed systems have 60% efficiency ([155]). • A comparison between enclosed and open raceway is missing, and it was not analysed well, due to lack of data.
Opportunities	**Threats**
• The Circular Economy Act can potentially create single markets for effluents containing phosphorus, such as digestate, with nutrient recycling targets, create incentives, support industrial symbiosis, etc. • There are ongoing discussions with DG GROW about the possible inclusion of whole cyanobacteria, including Spirulina, under CMC 2 of the FPR.	• Rising competition in market uses of effluents and CO_2, increasing prices and reducing availability.

([154]) It is anticipated that an enclosed raceway should have a higher than 30% CO2 fixation efficiency.
([155]) Pechsiri, J. S., Thomas, J. B. E., El Bahraoui, N. et al. (2023). Comparative life cycle assessment of conventional and novel microalgae production systems and environmental impact mitigation in urban-industrial symbiosis. Science of the Total Environment, 854, 158445. https://doi.org/10.1016/j.scitotenv.2022.158445

5.7. Summary Outlook

All scenarios are promising for scaling up as they are well tested in European industry, and several European projects have demonstrated technologies and enabling tools. **The priority here would be to improve the legal framework** to open the way for new investments and industry confidence and to stimulate circular nutrient standardisation and trade.

The scenarios had a European geographic scope, designed to reflect North European and South European regions' specificities, such as climate. But this was only indicative and should not be taken as conclusive. Each project would require due diligence and a feasibility report to identify viability, local conditions, and particularities. This report was the first assessment step.

6. Recommendations for policy, industry and research

Organic farming and the circular economy must be developed in parallel and strategically aligned to achieve the Farm to Fork Strategy's target of 30% organic agricultural land by 2030. To support this transition, the existing regulatory framework urgently needs to be updated to become more accessible, resilient, and equitable – particularly in relation to fertilisers and biostimulants.

Algae-based innovations offer a promising pathway forward. These premium, scalable, next-generation products have the potential to enhance the yield and sustainability of organic primary production across environmental, social, and economic dimensions. The circularity potential is significant: Europe has abundant industrial effluents rich in compliant macronutrients and food-grade CO_2, which could be harnessed to support organic algae cultivation and the production of agronomic inputs.

Still, high investment risk remains a major barrier. This is due to the fragmented and complex nature of harmonised EU rules on organic production and algae, the absence of a recognised market for secondary inputs such as nutrient-rich effluents and CO_2, and the high costs associated with logistics and microalgae production. It is also important to note that many innovators and practitioners in this field are SMEs and waste management companies – entities with far fewer resources than large mineral fertiliser corporations.

After considering these terms, we **set up a list of high-priority recommendations for the next 5 years, for enabling the organic production of algae.** Recommendations have been drawn in various chapters in this report, including Chapters 3.4 and the factsheets of Chapter 5. Here, we summarise them by relevance to industry, EU policymakers and MS authorities and researchers.

6.1. Recommendations for DG AGRI, DG GROW and EU MS

6.1.1. Recommendations for improving organic rules in future amendments

- **Create a level playing field in organic regulations 848/2018 and 2011/1165 for algae and algae products with other terrestrial plants and products**:
    - For example, concretely harmonise rules for algae biomass and other plants as fertilisers, by a targeted change in the text in Annex II of Regulation (EU) 2021/1165, under Algae and algae products, by removing the term 'only from organic or collected in a sustainable way'; the term is regarded as confusing and controversial. Article 2.4 of Part III of Annex II to Regulation (EU) 2018/848 concerns the sustainable collection of wild algae and is irrelevant to microalgae cultivation.
    - Clarify the eligibility of cyanobacteria such as Spirulina under FPR CMC1, given their exclusion under CMC2, to ensure regulatory consistency and support innovative biostimulants.
- Consider the provisional **use of organic manure digestate** (no factory farming) **as input for algae** organic agriculture products.
- **Shared definitions across regulations e.g. FPR, Reg. (EU) 848/2018 and 2011/1165**: clear definitions for algae and organic.

6.1.2. Recommendations to improve the implementation of European harmonised rules in MS

- **Build capacities among MS public administration bodies** as they may perceive the regulatory environment of their country or EU harmonised rules as complex and perhaps conflicting, which hinders regulatory and approval processes;
- **Allocate MS contact points for "circular nutrients for organic products" and develop a Q&A guide**.

6.2. Recommendations for DG AGRI, DG ENV, & DG MARE

- **Consider recommendations**, under statutory management requirements (SMRs) or good agricultural and environmental conditions (GAECs), **requiring farmers to produce or use circular fertilisers in the CAP 2023-2027** ([156];[157]).
- Connected to the above, consider **establishing ambitious European nutrient recycling targets** with MS-level recommendations;
- **Consider integrating agriculture into the EU Emissions Trading System (ETS)**, taking the new Danish Farm CO_2 tax as an example. The Danish tax plans to trade carbon and nutrients in the EU ETS.
- **Use incentives, such as tax exemptions, to encourage industry to reduce or valorise their waste streams.** Incentives should also support the uptake of side-streams over virgin inputs and **promote the marketing of circular organic products, including those derived from algae.**
    - Provide CAP funding support for farmers involved in processing or standardising digestates.
    - Include nutrient recycling activities under the EU Taxonomy;
- **Promote algae as a measure in the MSFD**: EU MS should be encouraged to include algae bioremediation/recycling of nutrients and carbon dioxide in MSFD Programmes of Measures (PoM) aiming to reduce the load and inflow of nutrients into marine waters and mitigate eutrophication ([158]).
- **Develop an updated, simplified, and fair impacts allocation system in the Environmental Footprint Inventory Analysis of the PEF** to accelerate and scale up zero-waste approaches in algae value chains, such as circular solutions, residual streams, and biorefining ([159]).

([156]) Conditionality. (2024b, February 22). Agriculture and Rural Development. Available here.
([157]) European Commission. (2023). Approved 28 CAP strategic plans 2023–27. Directorate-General for Agriculture and Rural Development. Available here.
([158]) Arvaniti, et al. (2025). Verification of high potential Algae products and possible criteria, labels, tools (LCAs) to assess environmental footprint of algae products & services, *EU4Algae.* Available here.
([159]) For additional information, check the EU4Algae report on "Business Case For Regenerative Aquaculture In Europe." Available here.

6.3. Recommendations for industry and research

The following recommendations for the industry and research are suggested based on findings (160).

- **Promote circular solutions and business models** for algae and algae-based agronomic products.
- **Encourage regional and local showcasing of industrial best practices** through platforms such as **EU4Algae, CBE-JU** and others.
- **Develop European marketing strategies for side-streams and residues.**
  - **Establish End-of-Waste cases** that are compatible with organic production and applicable to algae fertilisers. These new specifications could support the commodification of effluents for fertiliser production.
- **Map European side-streams relevant to organic production.**
  - Include categories such as plant-based digestate and food-grade CO_2.
  - Incorporate "organic" typologies, e.g. plant-based digestate and food-grade CO_2 in IEA Bioenergy Task 37 scope.
- **Support brokerage and innovation facilities for circular and organic solutions**, such as the CBE-JU Co-Pilots project, and the CBE-JU Primary Producers WG that stimulate innovation and demonstrate circular bioeconomy solutions, facilitate matchmaking between technology developers and buyers, and promote circular business models that include organic algae blue/green solutions.
- **Carefully select the most promising circular fertilisers and biostimulants for detailed multi-criteria assessments.** These are resource-intensive efforts, typically requiring several months to analyse 5-10 value chains across economic, environmental, and social dimensions.
- **Define standardised monitoring methods for organic fertiliser products in research.** The absence of consistent metrics and terminology makes it difficult to compare products across studies and industries. This highlights the importance of integrating economic performance indicators in evaluating circular fertilisers.

(160) The recommendations are also relevant for the EU4Algae stakeholder forum.

Annex 1 - EU Industry standards relevant to algae and algae fertilisers

Table 21 – EU Industry standards relevant to algae and algae fertilisers

Committee	Reference	Title	Status	Scope
CEN/TC 454 - Algae and algae products	EN 17399:2024	Algae and algae products - Vocabulary	Published	It defines the terms related to functions, products, and properties of algae and algae products. It includes microalgae, macroalgae, cyanobacteria and Labyrinthulomycetes.
	EN 17980:2024	Algae and algae products - Sampling - Guidelines for the definition of sampling programs and sampling protocols	Published	Guidelines for creating sampling programs and protocols for algae and algae products, including microalgae, macroalgae, and cyanobacteria for lot characterisation in commercial or regulatory contexts.
	CEN/TR 17559:2022	Algae and algae products - Food and feed applications: General overview of limits, procedures, and methods	Published	Broadly applicable for assessing algae-derived inputs in fertilisers and regulatory considerations.
	CEN/TR 17739:2021	Specifications for chemicals and biofuels sector applications	Published	Provides guidance on algae, algae products and intermediates relevant for chemical and bioenergy applications.
CEN/TC 260 - Fertilizers and liming materials	CEN/TS 17756:2022	Organic and organo-mineral fertilisers - Determination of chloride content	Published	Evaluates chloride levels in fertilisers, ensuring suitability for organic standards.
	CEN/TS 17776:2022	Organic fertilisers - Determination of total organic carbon (TOC) content by dry combustion	Published	Relevant for analysing carbon sources in organic microalgae-based fertilisers.
	CEN/TS 17777:2022	Organic and organo-mineral fertilisers - Determination of specific elements	Published	Supports the evaluation of nutrient content in algae-derived fertilisers.

Committee	Reference	Title	Status	Scope
	EN 1482-1:2007	Fertilisers and liming materials - Sampling and sample preparation - Part 1: Sampling	Published	Ensures proper sampling for nutrient and fertiliser analysis, crucial for validating alternative sources.
	EN 14888:2005	Fertilisers and liming materials - Determination of cadmium content	Published	Ensures compliance with heavy metal limits in algae-based fertilisers.
	EN16319:2013+A1:2015	Fertilisers and liming materials - Determination of cadmium, chromium, lead, and nickel by ICP-AES	Published	Validates compliance with contaminant thresholds for organic fertilisers.
	EN 12047:1996	Solid fertilisers - Measurement of static angle of repose	Published	Assesses physical handling properties of solid fertilisers derived from algae.
	EN 15957:2011	Fertilisers - Extraction of phosphorus soluble in neutral ammonium citrate	Published	Relevant for testing phosphorus availability in algae-based fertilisers.
	EN 17778:2022	Organic and organo-mineral fertilisers - Determination of chromium (VI) content by chromatography	Published	Ensures compliance with safety regulations for fertilisers containing microalgae.
	(WI=0026027)	Inorganic fertilisers - Determination of organic carbon content	Under development	Useful for evaluating carbon inputs from recycled organic sources, including biochar or algae residues.
	(WI=0026022)	Fertilisers and liming materials - Sampling and sample preparation - Part 4: Sampling of organic and organo-mineral fertilisers	Preliminary	

Committee	Reference	Title	Status	Scope
	(WI=0026022)	Fertilisers and liming materials - Determination of phosphonates content in fertilisers	Under development	Ensures compliance with nutrient composition regulations for fertilisers derived from algae.

Annex 2 - European standards relevant to algae biostimulants

Figure 16 – European standards relevant to algae biostimulants (CEN/TC 455)

Reference	Title	WI Status	Standard Status
EN 17723:2024	Plant biostimulants - Determination of chloride	Active	Published
EN 17709:2024	Plant biostimulants - Determination of Azotobacter spp.	Active	Published
	Plant biostimulants - Determination of the aerobic plate count	Abandoned	Not Published
EN 17707:2024	Plant biostimulants - Determination of the yeast and mould content	Active	Published
EN 17700-2:2024	Plant biostimulants - Claims - Part 2: Nutrient use efficiency resulting from the use of a plant biostimulant	Active	Published
EN 17700-3:2024	Plant biostimulants - Claims - Part 3: Tolerance to abiotic stress resulting from the use of a plant biostimulant	Active	Published
EN 17724:2024	Plant biostimulants - Terminology	Active	Published
EN 17702-1:2024	Plant biostimulants - Sampling and sample preparation - Part 1: Sampling	Active	Published
EN 17725:2024	Plant biostimulants - Determination of the quantity (indicated by mass or volume)	Active	Published
EN 17700-4:2024	Plant biostimulants - Claims - Part 4: Determination of quality traits resulting from the use of a plant biostimulant	Active	Published
EN 17700-1:2024	Plant biostimulants - Claims - Part 1: General principles	Active	Published
EN 17701-1:2024	Plant biostimulants - Determination of specific elements - Part 1: Digestion by aqua regia for subsequent determination of elements	Active	Published
EN 17701-2:2024	Plant biostimulants - Determination of specific elements - Part 2: Determination of total content of Cd, Pb, Ni, As, Cr, Cu and Zn	Active	Published
EN 17715:2024	Plant biostimulants - Detection of Shigella spp.	Active	Published
EN 17712:2024	Plant biostimulants - Detection of Staphylococcus aureus	Active	Published
EN 17713:2024	Plant biostimulants - Determination of Azospirillum spp.	Active	Published
EN 17710:2024	Plant biostimulants - Detection of Listeria monocytogenes	Active	Published
EN 17717:2024	Plant biostimulants - Detection of Salmonella spp.	Active	Published
EN 17718:2024	Plant biostimulants - Determination of Rhizobium spp.	Active	Published
EN 17702-2:2024	Plant biostimulants - Sampling and sample preparation - Part 2: Sample preparation	Active	Published
EN 17700-5:2024	Plant biostimulants - Claims - Part 5: Determination of availability of confined nutrients in the soil or rhizosphere	Active	Published
EN 17719:2024	Plant biostimulants - Determination of the anaerobic plate count	Active	Published
EN 17722:2024	Plant biostimulants - Determination of mycorrhizal fungi	Active	Published
EN 17721:2024	Plant biostimulants - Determination of the pH for liquid microbial plant biostimulants/pH in microbial products - Determination of pH	Active	Published
EN 17720:2024	Plant biostimulants - Determination of enterococci	Active	Published

EN 17711:2024	Plant biostimulants - Detection of Vibrio spp.	Active	Published
EN 17716:2024	Plant biostimulants - Determination of Escherichia coli	Active	Published
EN 17723:2024	Plant biostimulants - Determination of chloride	Active	Published
EN 17709:2024	Plant biostimulants - Determination of Azotobacter spp.	Active	Published
EN 17707:2024	Plant biostimulants - Determination of the yeast and mould content	Active	Published
EN 17714:2024	Plant biostimulants - Determination of microorganisms' concentration	Active	Published
EN 17701-3:2024	Plant biostimulants - Determination of specific elements - Part 3: Determination of mercury	Active	Published
EN 17708:2024	Plant biostimulants - Preparation of sample for microbial analysis	Active	Published
EN 17704:2024	Plant biostimulants - Determination of dry matter	Active	Published
EN 17706:2024	Plant biostimulants - Determination of inorganic arsenic	Active	Published
EN 17703:2024	Plant biostimulants - Determination of chromium(VI)	Active	Published
EN 17705:2024	Plant biostimulants - Determination of phosphonates	Active	Published

Important note on standards and regulatory alignment:

This table lists EU and industry standards relevant to algae and algae-derived fertilisers. Only the standards developed by CEN/TC 260 (Fertilisers and liming materials) from 2022 onwards and from CEN/TC 455 are specifically designed to support compliance with the EU Fertilising Products Regulation (FPR, Regulation (EU) 2019/1009). Earlier standards, as well as standards developed by committees such as CEN/TC 454 (Algae and algae products), are included for industry reference but are not harmonized with FPR requirements and may not fully reflect the Regulation’s legal and technical provisions. Users should ensure that any standard applied for CE-marked fertilising products aligns with the FPR.

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