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Study to support a Sustainable EU Algae Industry

Final report

European Maritime, Aquaculture and Fisheries Fund (EMFAF)

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Executive summary

This report presents a synthesis of the activities and outputs produced within the scope of a study commissioned by the European Climate, Infrastructure and Environment Executive Agency (CINEA) on "*Support for a Sustainable EU Algae Industry*". The study was structured into the six following Work Packages:

- Work Package 1: Advancing algae-based alternatives in EU aquafeeds: pathways to reducing fish-based ingredients
- Work Package 2: Regulatory barriers, sustainable good practices, and recommendations on future paths on using viable recycled media in microalgae fertilising products for organic farming
- Work Package 3: Algae potential for (waste)water treatment and fertiliser/plant biostimulants production
- Work Package 4: The role of algae in climate change mitigation in European seas
- Work Package 5: Recommendations for sustainable wild seaweed harvesting and beach collection of seaweed on European coasts
- Work Package 6: The role of algae in sustainable food and feed systems

For each Work Package, this report describes the activities conducted and the methodology followed, as well as priority research needs for future studies, lessons learnt, outcomes and recommendations (sections 1-6). This is followed by a synthesis of the main conclusions and challenges encountered (section 7) and a list of deliverables and outputs (section 8). The detailed findings of each Work Package are included as annexes to this report (see here).

1. Work Package 1: Advancing algae-based alternatives in EU aquafeeds: pathways to reducing fish-based ingredients

1.1. Activities

As per the technical proposal submitted by the consortium, Work Package 1 (WP1) contained the following sub-tasks:

- Task 1.1: Analysis of feeding aquaculture by various feed ingredients/ mixtures;
- Task 1.2: Examine methods and methodologies for replacing fish-based feed ingredients;
- Task 1.3: Forecast analysis for the potential replacement of fish-based feed ingredients by algae-based feed ingredients in the EU.

Work undertaken as part of Work Package 1 evolved throughout the duration of the contract as per the below table.

Table 1 Information on progress of WP1 at key moments of the project

Key contract moment	Information on progress
Inception report	The following changes in the methodology were agreed: • Workshops may be online or physical back-to-back to European events, e.g. EAS or AlgaEurope; • The work will analyse national strategies, implementation plans, laws and industry standards, which are formatted in national languages. For this, the researchers have defined a solid methodology to collect intelligence via desk work and consultations; • In Task 1.2 ecological impacts will be assessed through consultations' _findings and access to available data, e.g. carbon footprint. However, conducted an LCA or comparing LCA tools was deemed beyond the scope of the study.
First progress meeting	The WP was progressing on-track, and the work conducted at this stage focused on literature research and the identification of stakeholders.
Interim meeting	The following activities had been conducted at the time oft the interim meeting: • The name of WP was fine-tuned to better reflect its scope; • The team started approaching private sector actors to collect information on ALARA and FFDR; • On 07.06.2024, the EU4Algae Algae4Feed online meeting took place, announcing WP1 and used to gather additional information; • The team started to work on the forecast analysis. An additionnal meeting took place on the 30 October 2024 to discuss certain comments regarding the Task1.3 draft report in more detail. The outcomes of the meeting were: • To exclude the spatial calculations at Sea-basin level (Task 1.3.1), from the study, as this had not been offered in the Technical proposal or Inception Report;

Key contract moment	Information on progress
	• To exclude a list of sources for CO_2 supply for microalgae production (Task 1.3.1), considering that this had not been offered in the Technical proposal. This topic was partly covered in Work Package 2; • Additionally to what was written in the initial offer and in the Inception Report, s.Pro agreed to explore the availability of sugar wastes/sources in the EU for the production of the microalgae *Schizochytrium* for algae oil aqua feed applications.
Interim report	No significant progress was made between the interim meeting and the interim report.
Third progress meeting	A draft of Chapter 3 was submitted in October 2024, followed by Chapter 1 in January 2025. The interviews and surveys for Chapters 1 and 2 were merged, and the validation of results was planned to be conducted through questionnaires sent to stakeholders. On 20 November 2024, an EU4Algae Algae4Feed online meeting was held to validate WP1 results and gather additional input.
WP report submission	WP1 report was submitted for feedback on the 23rd December of 2024 for Tasks 1.1, on the 15th of October 2024 for 1.3, and on the 22nd of April 2025 for Task 1.2. The report presented the full results of the Work Package, following a structure previously agreed upon between the client and the contractor.
Final report	The final report includes a revised and final version of the WP1 report which incorporates the feedback received.

The full Work Package 1 report is available in the annex (see here).

1.2. Methods

The following methods were used to complete the Work Package:

- **Literature review and sources**: approximately 260 literature sources were deemed relevant for the study, which reflects the broad variety of topics covered. Key literature was provided by experts in their respective sub-topics and was complemented by academic articles, scientific reports and industry publications, with a focus on literature sources published in 2020 or later. An extensive literature review was conducted to evaluate and compare the performance of different types of aquafeed and to assess the nutritional suitability of specific algae for aquafeed;
- **Interviews and expert consultation**: a total of 12 interviews were conducted with relevant stakeholders across the value chain to gather insights on both operational and industry scale. Participants include producers of algae and algae-based ingredients, as well as aquaculture feed and fish producers utilising algae in their feeds. Additionally, several aquaculture associations were consulted. Prior to the interviews, participants received questionnaires that were discussed during the online interviews. The primary focus of these stakeholders consultations were to inform the multi-criteria analysis (MCA), although other relevant topics

were also addressed. For specific individual topics, further consultations with experts in the relevant fields were conducted;

- **Multi Criteria Analysis (MCA):** the findings from the literature review and interviews were used to perform an MCA, comparing the performance of various feed types, including algae-containing feeds, insect-containing feeds and traditional feeds with fish-based ingredients. Only results from sources that compared at least two of the targeted feed types were included to prevent misinterpretation of differences arising from varying settings across sources. The MCA also allows for weighted emphasis on specific criteria, enabling an assessment of which feed type performs best under different weighting scenarios;
- **Working groups**: the study was introduced to an EU4Algae working group focused on algae feed. During the working group meeting, further insights regarding the use of algae in aquafeed were gathered. In a second working group meeting, the results of the MCA were presented and discussed for further validation;
- **Questionnaires for free-form responses**: three companies that are currently using or producing algae feed ingredient were provided with questions, which were answered thoroughly. The questionnaires and feedback obtained are included in this report, to highlight successful industry examples across the value chain that are already utilising algae;
- **Forecast analysis**: for the forecast analysis, the calculations were based on the anticipated inclusion rate for algae in aquafeeds within the next five years, as estimated during the interviews. This value was considered alongside recent reports on fishmeal and fish oil demand, especially those from the European Market Observatory for Fisheries and Aquaculture products (EUMOFA) and the Food and Agriculture Organization of the United Nations (FAO);
- **Surveys for validation**: the recommendations presented in this report were developed based on the results of the MCA, expert discussions and further literature search. A survey was designed to present the preliminary recommendations and reasoning behind them. Stakeholders across the entire value chain were invited to provide their opinion on these recommendations. Feedback from seven organisations was received, considered, and integrated into the final study where applicable.

1.3. Priority research needs for future studies

The aquaculture and aquafeed industries agree that the usually higher costs of algal ingredients compared to fish-based ingredients are the primary factor limiting the incorporation of algae-based ingredients into aquafeeds. Aside from the recommended methodologies (Section 1.6. of this report), further upscaling of production as well as optimisation of technology and production methods is essential to overcome this challenge.

1.3.1. Sugar side streams for algae production in Europe

Most of the large producers of algae oil are currently not producing in Europe. According to some of the industry stakeholders interviewed, the challenge lies in the lack of large-scale algae fermentation facilities with access to low-cost sugar source with a relatively low carbon footprint in Europe. According to the industry stakeholders, the conditions in Europe are not ideal for producing such large quantities of suitable sugar crops for algae production.

However, in the report, various option for the utilisation of sugar side streams for heterotrophic algae growth in Europe were identified. Some of these options were found to significantly lower production costs and reduce disposal costs for the producers of these side streams. To overcome this challenge, funding opportunities to promote research and development, as well as investments in this sector should be prioritised.

1.3.2. Strain selection and enhanced processing technologies

Increasing the efficiency of algae production, both in terms of yield and resource use, is expected to be a key driver for broader adoption in the aquafeed industry. This can also include further research on pre-treatments to improve digestibility and reduce anti-nutritional factors and achieve specific health benefits.

Further research and development into algae species and strain selection can be advantageous. High value strains or species that can offer additional bioactive compounds such as antioxidants, vitamins, and other essential nutrients can be beneficial. The ability to tailor algae strains to meet the specific nutritional needs of different fish species would be a significant advantage. Such high-value algae-derived components could provide economic benefits in addition to the nutritional advantages for aquaculture feed. However, a noticeable challenge regarding the bioactive components in algae lies in their considerable variability. This variability occurs not only between species, but also due to factors such as harvesting time, origin and production method. As a result, it is difficult to reliably provide a beneficial effect of a particular algae biomass on fish performance. More research in this field will be needed to produce algae biomass with consistent nutrient profiles or bioactive compounds that deliver reliable and beneficial results in farmed aquatic animals.

1.4. Lessons learnt

The following lessons learnt are noted for Work Package 1:

- Some highly specific and valuable information, such as certain market reports, was inaccessible. Including a budget for purchasing such documents or for attending relevant events could have been beneficial;

- Work Package 1 covered a wide and complex scope. For projects of this scale, it may be worth considering either extending the project duration or dividing the work into two separate studies to achieve more focused and effective outcomes.

1.5. Outcomes

The outcomes of Work Package 1 are fully aligned with its stated objectives and the following has been achieved:

1. A literature review regarding the nutritional suitability of algae-based feed ingredients for the replacement of fish-based ingredients was performed, focusing on the European key fish species and the six selected algae species.
2. Optimal processing methods for the different algae species to enhance digestibility and bioavailability were outlined.
3. A Multi Criteria Analysis to compare the performance (feed and fish performance, economic performance, environmental performance) of different feed types, including algae-containing feeds, has been performed. Overall, incorporating algae into feed for farmed aquatic species was found to be a promising alternative to wild-caught fish ingredients.
4. Based on this assessment, optimal inclusion levels for algae in aquafeed have been determined.
5. Several methods for replacing fish based ingredients with algae were analysed in detail, and specific recommendations were developed for :
    - The introduction of minimum inclusion targets for EPA & DHA from non-fish sources;
    - The lowering of the Forage Fish Dependency Ratio (FFDR);
    - The reduction of the allowable limits for PCBs and dioxins in the feed contaminant regulation;
    - The adoption of the 'as low as reasonably achievable' (ALARA) principle in the feed contaminant regulation;
    - The development of additional official standards to support inclusion of algae in feed;
    - The Introduction of a framework of strategies and financial incentives for algae in aquafeed.
6. Regulations, certifications and industry standards relevant to algae feed were mapped.
7. Successful market examples across the value chain were given.
8. A forecast analysis was performed, analysing historical and current data and quantifying amounts of algae oil and algae meal that could be included in aquafeed in the future.

9. Requirements for replacing fish-based ingredients with algae in terms of the required algae species as well as technological and special feasibility have been determined.

1.6. Recommendations

The following recommendations were developed in Work Package 1:

1. **Optimal inclusion levels of algae in aquafeeds**

   Theoretic optimum of algal inclusion: A complete replacement of fish-based ingredients with algal alternatives is technically possible. Algae meal and oil **together** could account for 10-15% of the total feed for salmon and trout and approximately 20-25% for seabass and seabream (the upper value would equal approximately the replacement of all whole forage fish derived ingredients currently used in feeds for these species); However, economic factors would be limiting for a long time, especially for lower priced fish species. A more practical and scalable approach may involve a combination of algae, other alternative ingredients, and sustainably sourced fish-based ingredients, in particular trimmings and offal from aquaculture production.

2. **Introducing minimum targets for non-fish-derived EPA+DHA**

   In terms of fish oil, a minimum of 25% of the total included EPA+DHA should be set as an initial target for the inclusion of non-fish-derived EPA+DHA. It is also recommended to re-evaluate the minimum target for non-fish-derived sources as the market continues to evolve.

3. **Reducing the forage fish dependency ratio (FFDR)**

   An FFDR (possibly individually considered as FFDRm and FFDRo) around the current average values should be encouraged. Additionally, a significantly lower FFDR could be rewarded with incentives to promote the use of by-products and alternative ingredients. It is recommended to simultaneously integrate these targets with other indicators such as LCAs and certifications, which can provide a more holistic approach. As the aquaculture sector grows, the average FFDR values will decrease further, due to forage fish being a limited resource. Therefore, the targets should not be static but re-evaluated and potentially lowered accordingly in regular time frames, for example every five years.

4. **Including the ALARA principle for feed contaminants**

   It is advisable to include the ALARA principle also for feed in Directive 2002/32/EC (Directive on undesirable substances in animal feed), when it is evaluated in the next round.

5. **Reducing allowable contaminant levels**

The lowering of the current limit values according to the feed contaminant regulation (Directive 2002/32/EC) for dioxins and the sum of dioxins and dioxin-like PCBs is recommended. A lowering of non-dioxin like PCBs should also be feasible. Additionally, the action threshold for dioxins and dioxin-like PCBs is suggested to be lowered.

6. **Developing additional industry standards**

In addition to existing industry standards, key gaps remain in the algae feed sector where new standards would be beneficial. It is recommended to develop standards that cover the following aspects:

- Claims: Specification of potentially suitable claims (e.g. nutritional, environmental, health) for algae and algae-containing feed, supporting their use;
- Origin of biomass: Specification of appropriate methods for verifying the origin of biomass, enhancing accurate labelling;
- Contaminants: Specification of analytical detection methods for contaminants in algae, also including an overview of all known algae contaminants;
- Water management: Guidelines for water reuse and measurements of water consumption in algae cultivation;
- Preservation methods: Specification of suitable preservation methods and storage for algae for the various end purposes.

7. **Developing a framework of strategies and financial incentives**

The development of a comprehensive EU-wide framework (described in 4.1.3 above) of strategies and financial incentives supporting the inclusion of algae in feed is recommended. For this framework, an inclusion of the following aspects is recommended:

- Establishing an enabling regulatory and policy environment, including policies, enhanced certification schemes, and technical support;
- Correcting market distortions through fiscal measures, such as phasing out subsidies for unsustainable fish feeds and providing tax incentives for more sustainable options;
- Integrating sustainable aquaculture into the EU Taxonomy;
- Introducing innovative financing mechanisms, including blue bonds, loans and guarantees;
- Strengthening data infrastructure and transparency.

2. Work Package 2: Regulatory barriers, sustainable good practices, and recommendations on future paths on using viable recycled media in microalgae fertilising products for organic farming

2.1. Activities

As per the technical proposal submitted by the consortium, Work Package 2 was focused on task 2 which aim was to:

- Assess the state of play of alternative sources of carbon and nutrients in the cultivation of organic microalgae for fertiliser markets, with emphasis on analysing legal framework and elucidating interpretation of EU laws by Member States;
- Create a set of validated recommendations of viable alternative sources of carbon and nutrients considering economic, legal and environmental dimensions.

Work undertaken as part of Work Package 2 evolved throughout the duration of the contract as per the below table.

Table 2 Information on progress of Work Package 2 at key moments of the project

Key contract moment	Information on progress
Inception report	Changes in methodology compared to Technical Proposal: Information on nutrient and CO_2 availability is to be collected through desk research, focusing on EU project results (e.g. Alg-AD, EnAlgae). National strategies and legal texts were agreed to be analysed only when accessible, considering language barriers. Consultation was agreed to involve selected experts and stakeholders (e.g. EU4Algae WG 5 Algae 4 Eco, EABA, ESPP), without creating sub-working groups. Instead, ad-hoc expert groups should be used when needed, while EU4Algae WGs served for validation and dissemination.
First progress meeting	The team reported on the progress of Work Package 2, which was going as planned. A joint consultative meeting was planned with EU4Algae WG5 and WG6 Algae 4 Fertilisers, with the idea to form an advisory team from selected WG members to provide some guidance for the work of this WP.
Interim meeting	The team delivered an interim report. Work Package 2 content focused on how EU Member States implement Regulation 2021/1165 on authorised products and substances in organic production. Preliminary research showed no major issues with its application. The focus would shift to documenting implementation practices. As the regulation falls under DG AGRI, the team agreed to contact them to discuss implementation progress and clarify any observed issues.
Interim report	The report was submitted and the scope was improved. A new theory of change was suggested by the client.

Key contract moment	Information on progress
Third progress meeting	Work on the work package continued. The next steps at this stage were contact DG Agri to get feedback on findings, arrange interviews with three companies (AlgaEnergy, Algiecel, Algaia), and expand the factsheet with recommendations for economic, environmental, and legal considerations.
WP report submission	Work Package 2 report was submitted for feedback. The report contained the full results of the Work Package, following a structure previously agreed upon between the client and the contractor.
Final report	The final report includes a revised and final version of the Work Package 2 report which incorporates the feedback received.

The full Work Package 2 report is available in the annex (see here).

2.2. Methods

Work Package 2 (WP2) started with an extensive desk study, using European project results (EU4Algae Airtable, proposal project list). We also used AI tools such as Perplexity AI, with a step of verifying the findings and information sources, to ensure the quality of the data and findings. Data without validated sources were not used. Sources are always given in the Work Package 2 report as footnotes or web links.

The team facilitated sessions during four events, in order to collect data and insights on circular nutrients and carbon, microalgae production, and algae-based fertilisers and biostimulants, relevant to organic products:

1. ESNI 2023, Brussels: Workshop on Standardise algae circular products to market in agricultural applications.
2. ESNI 2024, Brussels: Workshop on Algae-based fertilizing products from recycled side-streams: the legal journey.
3. Mission Ocean Arena 3, Amsterdam: The Blue on Land: Agriculture Applications of Algae Produced with Circular Resources.
4. EU4Algae joint WG5/WG6 online meeting.

In addition, interviews were conducted with DG AGRI and with industry representatives, namely Allmicroalgae/NECTON (PT) and Algiecel (DK). The team tried to contact several additional industry practices who unfortunately did not accept to participate. Finally, the results and recommendations of Work Package 2 were validated by the EABA, and the legal analysis by DG AGRI .

The full and traceable documentation of sources, data, statistics, etc. is available in the WP2 report in the annex (see here).

2.3. Priority research needs for future studies

Work Package 2 showed that effluents from plant-based anaerobic digestion (AD), winery and brewery plants, are suitable for cultivating microalgae biomass, economic competitive and abundantly available in Europe, and also compliant with organic production rules of algae-based fertilising products (especially 2021/1165 and 2018/848).

Regulation 2018/848 that 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, was first enacted in 2021, while its implementation regulation 2021/1165, has been amended twice so far (February 2023, November 2023) and plans one more amendment (announced June 2025). So, especially concerning agricultural products that were the topic of Work Package 2, the rules address a new niche market supported mainly by small producers, which are not well "used in practice". Because of its market nature and recent developments, the primary identified research need is to:

- Bridge the regulatory and data gap, by **clearly identifying which alternative nutrient inputs could be used under organic regulation with associated provisions and conditions and prioritise research to advance relevant value chains**. Furthermore;
- Develop **marketing strategies for side streams and effluents** can stimulate the use of circular economy concepts. For example, study 'End of Waste' cases compatible with organic production and meriting algae fertilising products. Such new specifications can open the road to the commodification of effluents for fertiliser production.

As this is a niche new field of study, we recommend selecting the most promising algae-based circular biofertilisers and biostimulants produced with effluents from plant-based AD, winery and brewery plants, to **perform in-depth multi-assessments, as multi-topic assessments** are resource intensive. We suggest choosing 5-10 value chains and analysing and benchmarking them from economic, environmental, and social perspectives. Such analysis shall include:

- Economic viability compared to conventional fertilisers;
- Environmental performance (LCA) compared to conventional products, including methodologies (LCA, PEF) for circular value chains;
- Test field safety using circular nutrient and carbon inputs, such as contaminants, compared to competing and conventional products;
- Investigate standardisation/specification needs for commodification of viable effluents and side-streams.

Future projects should also include clear policy analysis to map how existing EU rules apply to specific recycled inputs and production setups. Finally, shared reporting standards (e.g., nitrogen and phosphorus uptake, productivity rates, reactor footprint) should be enforced in publicly funded projects to allow comparison and replication of results.

2.4. Lessons learnt

The following lessons learnt are noted for Work Package 2:

- Identifying stakeholders willing and able to contribute to the topic was challenging. The niche scope and regulatory uncertainty created hesitation, especially from industry players. Better linking with EU4Algae and industry associations could improve the success of future consultations on the topic.
- Data availability was limited. Few case studies exist, and those that do often lack regulatory clarity or focus on conventional systems, not organic-certified ones. Increasing the accessibility of national court proceedings that challenge European rules in the future would facilitate the in-depth analysis of regulations.

2.5. Outcomes

1. No existing European project has specifically focused on developing **organic-certified algae-based fertilising products**, highlighting a clear gap in current research and innovation efforts.
2. While current initiatives emphasize **circularity**, they do not adequately address **compatibility with organic regulation**, which is essential for the development of products suitable for organic agriculture.
3. There is significant **potential** to use **circular sources of nutrients and CO_2** - such as those derived from **plant-based anaerobic digestion (AD), winery, and brewery by-products** - to enhance organic algae cultivation, though their **legal acceptance remains uncertain**.
4. **Work Package 2** successfully identified and outlined the **key research and policy needs** to support the use of circular algae-based products in organic agriculture, including: (1) Validation of permitted inputs; (2) Methodological improvements in **life cycle assessment (LCA)**.and (3) Targeted **legal and regulatory updates**.
5. The overall **objective of Work Package 2 was satisfactorily achieved**; however, the **collection of good practices** - especially input from **Member State authorities and industry stakeholders -** was limited due to the **low level of practical application** of algae-based inputs in organic farming.

2.6. Recommendations

The following recommendations were developed in Work Package 2:

1. Recommendations for DG AGRI, DG GROW and EU MS:
    a. **Create a level playing field in organic regulations 848/2018 and 2011/1165 for algae and algae products with other terrestrial plants and products.**
    b. Consider the provisional **use of organic manure digestate** (no factory farming) **as input for algae** organic agriculture products.
    c. **Shared definitions across regulations e.g. FPR, Reg. (EU) 848/2018 and 2011/1165**: clear definitions for algae and organic.
    d. **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.
    e. **Allocate MS contact points for "circular nutrients for organic products" and develop a Q&A guide**.
2. Recommendations for DG AGRI, DG ENV, & DG MARE:
    a. 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.
    b. Connected to the above, consider establishing ambitious European nutrient recycling targets with MS-level recommendations.
    c. Consider integrating agriculture into the EU Emissions Trading System (ETS), taking the new Danish Farm CO2 tax as an example. The Danish tax plans to trade carbon and nutrients in the EU ETS.
    d. 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.
    e. **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.
    f. **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.

3. Recommendations for industry and research:
    a. **Promote circular solutions and business models** for algae and algae-based agronomic products.
    b. **Encourage regional and local showcasing of industrial best practices** through platforms such as **EU4Algae, CBE-JU** and others.
    c. **Develop European marketing strategies for side-streams and residues.**
    d. **Map European side-streams relevant to organic production.**
    e. **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.
    f. **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.
    g. **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.

3. Work Package 3: Algae potential for (waste)water treatment and fertiliser/plant biostimulants production

3.1. Activities

As per the technical proposal submitted by the consortium, WP3 contained the following sub-tasks:

- Task 3.1: Examine algae potential, opportunities and risks when grown on waste in the EU;
- Task 3.2: Examine the potential of using algae for cleaning natural waters from nutrients and use of relevant algae biomass in fertilisation;
- Task 3.3: To prepare a comparison table summarizing the potential of algae for closing nutrient cycles.

Work undertaken as part of Work Package 3 evolved throughout the duration of the contract as per the below table.

Table 3 Information on progress of WP3 at key moments of the project

Key contract moment	Information on progress
Inception report	During the inception phase, the following changes to methodology were done in relation to the contract: (i) focus on wastewaters in which algae has been cultivated at a relevant scale based on European projects instead of mapping all wastewaters generated at the EU in significant volumes; (ii) LCA and TEA focus on summarising existing information from previous studies rather than carrying out new analyses as relevant information is already available; (iii) the evaluation of the biostimulant potential of algae by analysing their composition, as proposed in the contract, was not deemed a feasible approach and, therefore, only algae already known for their biostimulant effects are mentioned in the report.
First progress meeting	By the first progress meeting, four wastewaters were identified as relevant for the study: urban wastewaters, aquaculture effluent, horticulture effluent, and manure-based digestate. Policy officers were also mapped for future contact to validate the findings, a first survey of the relevant legal documents to be analysed was conducted, and data started to be gathered for analysing the fertilising potential of algae. For task 3.2, relevant reports (HELCOM, OSPAR, UNEP/MAP) were used to assess nutrient availability and load in the EU coastal marine areas and sea basins and data was gathered to calculate the impact on Baltic Sea eutrophication levels if establishing seaweed farms.

Key contract moment	Information on progress
Interim meeting	By the interim meeting, the first legal analysis was concluded, and policy officers from the relevant DGs were being contacted for interviews. A lack of some relevant data at higher TRL had also been highlighted, and interviews with European projects to try to mitigate this gap were started. Work Package 2 and WP3 organised a webinar on June 25, 2024, within the EU4Algae community, and a workshop at ESNI on September 18, 2024, to gather feedback from policy officers and experts on the initial conclusions of their legal analysis. Moreover, WP3 interacted with ESPP to organise an event to discuss the legal status of algae grown on waste, which took place on November 13, 2024, in Brussels. For task 3.2, three seaweed species were selected (*Saccharina latissima, Ulva intestinalis, Fucus vesiculosus*) and their potential for nutrient removal was analysed.
Interim report	No significant progress was made between the interim meeting and the interim report, with the latter reporting the advances achieved thus far and highlighting some data gathering difficulties for the industrial symbiosis calculations.
Third progress meeting	It was agreed that the recommendations should be made clearer in the report, which had been delivered previously for comments from the Client. Most of the data was gathered by then and was being compiled into the final report that was expected to be submitted in April, while some chapters were also delivered in February and March for a first revision.
WP report submission	WP3 report was submitted to CINEA and DG MARE for feedback on the 25th of April 2025. The report presented the full results of the Work Package, following a structure previously agreed upon between the client and the contractor.
Final report	The final report includes a revised and final version of the WP3 report which incorporates the feedback received.

The full Work Package 3 report is available in the annex (see here).

3.2. Methods

Data gathering via desk research primarily relied on scientific literature, European legal documents, and European reports. Other information sources were relied upon, including:

1. The CORDIS database to map European projects investigating the use of wastewaters for algae cultivation.
2. European environmental databases.
3. Direct contact with several policy officers from DG ENV, DG AGRI and DG GROW.
4. Consultation with a policy officer from the EBA.
5. Webinars and workshops with experts and policy officers to validate the Work Package findings.
6. Interviews with European projects and experts working on algae growth on the proposed wastewaters to gather relevant data and validate the proposed recommendations.

The full and traceable documentation of sources, data, statistics, etc. is available in the Work Package report in the annex (see here).

3.3. Priority research needs for future studies

1. **Pilot/full-scale studies on growing algae on effluents**.
    a. Key parameters regarding algae cultivation at higher TRL (enumerated below) should be clearly reported when conducting these experiments. This is often not reported as the research is conducted by companies, but the Commission is urged to better enforce the requirement for open access for data gathered in publicly-funded European projects while enabling the company to maintain some key aspects of their technology confidential.
        - Algae productivity in g/L/d
        - N and P uptake in g/g_{algae} or g/L/d
        - Area footprint of the used reactor in m2/L
    b. Algae biomass should be characterised for contaminants to provide relevant data for making decisions on their suitability for different applications.
2. **Developing/optimising novel types of microalgae reactors**. One key outcome was the significant land requirement of algae-based effluent treatment, so the development of novel reactors with a lower area footprint would improve the adoption of this technology.
3. **Assessing the suitability of algae as a fertiliser in field trials**. These should focus not only on their nutrient replacement value when compared to mineral fertilisers, but also on the technical feasibility of their application (as powders are not compatible with the current existing machinery) and their economic feasibility.
4. **Expand the reference data on nutrient uptake across different environments and region-specific macroalgae species**. This is especially important for nutrient-rich (eutrophicated) coastal regions, where macroalgae cultivation could serve a dual role in both biomass production and nutrient removal, although current assessments still rely largely on modelling estimates. In addition to fertiliser use, future research should explore other processing options to enable broader applications of macroalgae grown on eutrophicated waters.

3.4. Lessons learnt

The following lessons learnt are noted for Work Package 3:

- Work Package 3 covered a wide and complex scope. For projects of this scale, it may be worth considering dividing the work into two separate studies to achieve more focused and effective outcomes. Specifically, task 3.2 dealing with the cultivation of macroalgae in natural eutrophicated waters does not really converse with task 3.1 and could have been a separate work package altogether;

- Several European projects did not have detailed reports and often had only limited publicly available data in their summary reports that did not provide advanced knowledge compared to the state-of-the-art from the beginning of the project. Such projects should have more targeted questions to answer besides only implementing a certain technology, like compliance of the produced biomass with legal requirements for the intended use, and these results should be publicly available;
- Earlier consultation with the policy officers of the different DGs would have been beneficial, as quite some time was spent looking for specific legal information, while the contact with the policy officers was quite responsive, and they provided relevant information for the report.

3.5. Outcomes

1. Four types of wastewater (urban, aquaculture effluent, horticulture effluent, and manure-based digestate) were identified as suitable for algae cultivation, and their potential was evaluated and compared.
2. Urban and horticulture effluents show the most promising potential for microalgae integration, particularly in smaller urban areas, due to their manageable land requirements and potential for effective water treatment and biomass production. While aquaculture effluent and manure-based digestate are also viable, their large volumes (aquaculture) or high nutrient content (digestate) necessitate substantial land areas, making algae-only treatment systems impractical. Instead, they are best considered as sustainable nutrient sources within integrated systems.
3. The cultivation of macroalgae in open waters holds great potential for nutrient removal from eutrophicated waters.
4. Integrating macroalgae cultivation with offshore wind energy projects offers additional environmental and spatial synergies. It is recommended that new offshore development zones be designated for multi-use purposes, including macroalgae aquaculture.
5. Some of the effluents analysed bring potential contaminants to the produced algae biomass and, therefore, careful monitoring of these is required when developing products from this biomass.
6. While legal clarity on the use of algae cultivated on wastewater streams is gradually improving, it remains incomplete and requires further development to ensure regulatory certainty and safe market integration. Algae grown on untreated wastewater are classified as sewage sludge, subject to the Sewage Sludge Directive. In contrast, algae from aquaculture and horticulture effluents may qualify as high-quality products

if integrated into the production process and approved by environmental authorities. Manure-based digestate-grown algae could qualify under the Fertilising Product Regulation, but clarification is needed regarding their use under the Nitrates Directive, which may restrict their role to biostimulants rather than fertilisers.

7. Economically, producing biostimulants from algae currently presents the most viable market route, given that production costs remain too high to compete with conventional fertilisers.

3.6. Recommendations

Recommendations for better integrating **microalgae** production and wastewater treatment include:

1. Introducing tax incentives at the Member State level to support the development of industrial symbiosis initiatives, thereby promoting greater sustainability and accelerating the growth of the European algae industry.
2. Ensuring the proper adoption of algae grown on wastewaters in the legal framework of the EU via the creation of an interservice group with representatives from the JRC, DG RTD, DG ENV, DG MARE, DG AGRI and DG GROW (and possibly others depending on the target end-use of the produced algae). This service could look at opportunities to further integrate the growth of algae in wastewaters into the existing legislation, using the recommendations below as a starting point, and highlight the research needs that should be prioritised to assess the potential risks of this inclusion.
3. Conducting an evaluation on whether the production process of biostimulants from microalgae can mitigate the risks associated with their cultivation on urban wastewaters. If that is the case, leaf-applied biostimulants from this biomass could be included in an amended version of the Sewage Sludge Directive to enable such application in national markets. This could eventually be expanded to the Fertilising Product Regulation (European market).
4. Regarding algae grown on treated urban wastewater, Member States could consider using the minimum requirements described in Section 2 of Annex I of the Water Reuse Regulation to inform their decisions to allow the use of reclaimed water for algae cultivation.
5. For the production of fertilising products from algae cultivated in treated urban wastewater (reclaimed water), all qualities of water (A-D, Table 2 of Annex I of the Water Reuse Regulation) could be used as long as the final product is also only suitable for the specific group category as specified in Table 1 of Annex I of the Water Reuse Regulation. For instance, if algae are grown with reclaimed water of quality class D, the final algae product should only be used for growing industrial, energy, and seeded crops.

6. The Fertilising Product Regulation could be amended to add to CMC 2 a list of accepted growing media for algae cultivation, including treated urban wastewater (reclaimed water), aquaculture effluent, horticulture effluent, and digestate (following the requirements of CMCs 4 and 5). The list should be open for further amendments upon new evidence of suitable recycled nutrients for algae cultivation. Moreover, a clarification in the FAQ of the Fertilising Product Regulation could be included that such biomass is also eligible as input for CMC 1. Alternatively, a new CMC could be created for algae, including all the abovementioned requirements and clarifications.
7. Cyanobacteria species allowed for human consumption under the Novel Food status catalogue should be considered for inclusion in the Fertilising Product Regulation.

Recommendations for advancing **macroalgae** aquaculture in the Baltic Sea include:

8. Improving macroalgae cultivation methods and infrastructure. This requires the development of site-specific guidelines that optimise farm location selection by considering salinity gradients, nutrient availability, and hydrodynamic conditions.
9. Establishing a standardised monitoring framework for assessing nutrient assimilation efficiency and the long-term ecosystem impacts of macroalgae farms.
10. Strengthening regional value chains and promoting macroalgae-derived products. Additionally, industry-academia partnerships can facilitate scaling up pilot projects and attract investment into sustainable macroalgae aquacultures.
11. Regulatory and policy barriers could be reduced by facilitating access to marine space and licensing for macroalgae farms.

4. Work Package 4: The role of algae in climate change mitigation in European seas

4.1. Activities

As per the technical proposal submitted by the consortium, WP4 contained the following sub-tasks:

- Task 4.1: Summarize and map the total extent of seaweed (kelp and other species) forests within EU waters;
- Task 4.2: Blue carbon – good practices, technologies, and methodologies;
- Task 4.3: Future research, technological development, innovation, and study needs;
- Task 4.4: Pros and cons of seaweed growing and sinking for carbon sequestration.

Work undertaken as part of Work Package 4 evolved throughout the duration of the contract as per the below table.

Table 4 Information on progress of WP4 at key moments of the project

Key contract moment	Information on progress
Inception report	The methodology of WP4 was refined, taking into consideration feedback received during the inception phase. While no major changes were proposed, the option to use of qualitative data in case major data gaps are identified was presented. In addition, the scope for the identification of blue carbon practices was set at the global level, given the limited number of such practices undertaken. Furthermore, a strong emphasis on how to advance the EU algae sector, rather than depicting the state of play, was agreed upon.
First progress meeting	By the first progress meeting, WP4 was progressing slightly ahead of schedule. Regarding Task 4.1, all existing open-source data on kelp (e.g., OBIS) had been successfully compiled and standardised into harmonised datasets. In addition, all relevant open-source environmental data that can be used to predict the spatial patterns of kelp species had been collected and harmonised. All compiled data had been aligned to the EU ETRS 1km grid. The literature review for Tasks 4.2 – 4.4 had progressed and was almost completed, while the annotated outline of the WP4 report was under development.
Interim meeting	A modelling approach that can predict both the presence and biomass of underwater forests over time by using a megatrend approach to kelp distribution was developed for Task 4.1. This method helps to address the data gap, particularly where information on biomass or coverage is lacking in some MS. In relation to Tasks 4.2 – 4.4, stakeholder consultations were ongoing, allowing the team to deep-dive with stakeholders on some aspects of macro- and micro-algae production and carbon sequestration pathways that are conflicting in literature.

Key contract moment	Information on progress
Interim report	No significant progress was made between the interim meeting and the interim report, with the latter describing the modelling approach undertaken for Task 4.1, as well as the literature review and consultation for Tasks 4.2-4.4.
Third progress meeting	Regarding Task 4.1, contact was established with several scientists and projects to collect additional data that is not publicly available. Concerning Task 4.2-4.4, stakeholder consultations were still ongoing. The team was also restructuring the overall report to reduce overlaps throughout the WP.
WP report submission	WP4 report was submitted to CINEA and DG MARE for feedback on the 31st of March 2025. The report contained presented the full results of the Work Package, following a structure previously agreed upon between the client and the contractor.
Final report	The final report includes a revised and final version of the WP4 report which incorporates the feedback received.

The full Work Package 4 report (WP4) is available in the annex (see here).

4.2. Methods

The **mapping of the total extent of seaweed forests (Task 4.1)** within EU waters was undertaken by collecting and harmonising measurements of the abundance and density of kelps and other algal species that make up kelp forests in each EU marine region. This was done using existing data products from EMODnet services, OBIS, LIFEWATCH products and results from past and ongoing Horizon projects, as well as a variety of national data products. Environmental data from the Copernicus data products, such as the global ocean biogeochemistry hindcast (GLOBAL_MULTIYEAR_BGC_001_029) and the global ocean physics reanalysis (GLOBAL_MULTIYEAR_PHY_001_030), surface radiation budget from 1982 was also relied upon.

Following data collection, spatial models were built to predict and map the current and historical extent of kelp forests in terms of area (km^2) and mass (tons). Novel machine learning techniques, such as boosted regression trees, were used to explore relationships between environmental variables and kelp forest data. This modelling process was implemented in two stages: first, the direction of effect was identified for each variable using an unconstrained generalized boosted regression model; then, these directions were used to fit a constrained model with monotonic predictor effects.

In parallel, the drivers of change in kelp forests were identified using a meta-analytic approach. This involved a systematic review of existing scientific publications and reports to understand the separate and synergistic effects of different natural environmental variables and human-induced pressures, including those resulting from climate change, on the kelp forests under study.

The desk research on the status and trends of kelp forests, as well as the effectiveness of various restoration techniques, was primarily based on textual analysis and narrative accounts, due to the limited availability of standardised quantitative data. However, for each case, supporting information, such as environmental conditions, scale and duration of interventions, and observed trends in response variables, was compiled to contextualise the findings and identify both generic and site-specific outcomes.

Research on **the use of macroalgae and microalgae for carbon sequestration (Tasks 4.2-4.4)** was undertaken via two main data collection methods: desk research and stakeholder consultations. These two complementary approaches enabled the team to compare and triangulate findings as well as to identify knowledge gaps. The literature review was undertaken by focusing particularly on the following sources of information: Scientific literature, Industry websites and publications (notably for the case study research), and NGO publications.

A database of relevant literature was developed and used to assess the various elements of relevance to this task (e.g., carbon sequestration pathways, methodologies, barriers, etc.). In addition, a total of four interviews were conducted and two written contributions were received from scientists and stakeholders from the algae industry. The interviews were conducted online and lasted between 45-60 minutes.

Information was analysed and integrated into the WP 4 report, paying particular attention to the identification of barriers, knowledge gaps, and recommendations on how to advance the EU algae sector. In particular, the assessment of business model opportunities was undertaken by identifying case studies and undertaking a discounted cah flow analysis using data from existing studies to quantify expected costs and revenues from macroalgae carbon credits.

The full and traceable documentation of sources, data, statistics, etc. is available in the Work Package 4 report in the annex (see here).

4.3. Priority research needs for future studies

4.3.1. Restoration of seaweed forests

To better identify priority areas for the restoration of seaweed forests, future research **should focus on enhancing and expanding analytical tools that evaluate spatial patterns, restoration costs, and benefits**. The prioritizer tool available via the Blue Bio Sites portal—based on the "prioritizr" R package—could be used and extended to all European marine areas. This will require broader spatial data on human pressures and underwater forests. Additionally, **comprehensive reviews and meta-analyses are needed to assess how**

specific pressures affect key underwater forest species. This will strengthen the evidence base for identifying high-potential restoration sites across Europe.

4.3.2. Macroalgae cultivation

Future research related to the cultivation of **macroalgae** for carbon sequestration should focus on the following priorities:

- Improve understanding sequestration pathways by:
    - Supporting research into air–sea CO_2 exchange dynamics around macroalgal farms, particularly whether oceanic re-equilibration limits atmospheric drawdown;
    - Quantifying the fate of cultivated biomass, including the proportion that detaches, is consumed, decomposes in the water column, sinks, or is transported to deep-sea sinks;
    - Investigating the role of oceanographic conditions, such as seabed composition, oxygen levels, and current velocities, —in determining carbon permanence;
    - Assessing sequestration rates by macroalgae species and cultivars, focusing on those native to Europe (*Saccharina latissima*, *Laminaria digitata*, *Fucus vesiculosus*) to optimise both yield and environmental compatibility.
- Assessment of the ecological effects of deep-sea sinking:
    - Studying the long-term effects of biomass deposition on benthic ecosystems, including biodiversity loss, changes in nutrient dynamics, and methane release risks under anaerobic conditions;
    - Determining whether repeated sinking events could cause hypoxia or ecosystem disruption in low-energy deep-sea basins.
- As a next step, demonstration and pilot sites should be used to:
    - Validate cultivation methods, biomass yield, carbon flow, and sequestration under real-world conditions;
    - Assess economic feasibility, environmental impacts, and MRV system performance through these trials.
- Finally, life cycle emissions of various Carbon Dioxide Removal systems should be further researched by:
    - Conducting full life cycle assessments (LCA) of macroalgal CDR systems, including farm infrastructure, energy inputs, vessel use, and biomass transport;
    - Comparing emissions profiles across system designs (e.g. anchored vs. free-floating) and energy mixes (e.g. fossil fuel vs. renewables).

These findings would be essential to the development of a robust MRV system to quantify and reward carbon sequestration from macroalga cultivation, provided that this path is validated as desirable by the scientific evidence (i.e., no important adverse impacts on ecology, proven impacts on net GHG emissions reductions on a whole life cycle perspective).

4.3.3. Microalgae cultivation

To realise the full potential of **microalgae** in long-term carbon sequestration, stakeholders, such as researchers, industry leaders, and policymakers, could jointly establish a holistic research and innovation roadmap that addresses technical, biological, economic, and ecological dimensions. In particular, the following research needs should be prioritised:

- Conducting more accurate modelling of microalgae production and operational costs to assess its economic feasibility and large-scale applicability, including via large-scale verification tests to validate theoretical models and optimise facility operations;
- Accurately measuring carbon sequestration potential and developing strategies to enhance CO_2 bioavailability, enabling microalgae to absorb high concentrations of CO_2 at stable rates;
- Delving deeper into the potential for microalgae to sequester carbon in long-term products (notably biochar and biocement), in terms of economic feasibility as well as climate mitigation potential using a life-cycle approach;
- The identification of microalgae strains that can tolerate high temperatures, elevated CO_2 concentrations, and pollutants such as NO_x and SO_x from flue gases or heavy metals from contaminated waters are crucial focal points;
- Understanding and containing any risks associated with microalgal applications, specifically if microalgae contains heavy metals or toxic compounds.

4.4. Lessons learnt

The following lessons learnt are noted for Work Package 4:

- Regarding the mapping of underwater seaweed forests, while scattered and unharmonized datasets as well as lack of data hindered the process, big data and modelling approaches have been instrumental in addressing those gaps, which resulted in tailored, context-specific solutions.
- Moreover, a lower than expected response rate was achieved regarding interview requests, which points to the need to reach out to high number of potential interviewees early on in the process, as well as identifying alternative interviewees to achieve desired outreach targets in case of non-responsiveness.

4.5. Outcomes

Work Package 4 examined the potential role of algae in contributing to climate change mitigation, with a focus on the restoration of natural seaweed ecosystems across European seas and the purposeful cultivation of macroalgae for carbon sequestration.

1. As a result of the research undertaken during this process, the following outputs were produced:
    - The creation of underwater seaweed forest maps, for key algae species in the EU;
    - A synthesis on the status and trends of these forests as well as an outline of restoration needs, priorities and associated recommendations;
    - An overview of carbon sequestration pathways (refractory dissolved organic carbon storage, sediment burial and deep sea sinking) and cultivation methods for algae-based carbon sequestration (nearshore and offshore), including pro's and con's and case studies;
    - An analysis of various methods for quantifying carbon sequestration (remote and autonomous sensing, physical and biogeochemical sampling, modelling, experiments and frameworks);
    - The identification of recommendations and future needs for macroalgae and microalgae-based sequestration.

2. The cultivation and deep-sea sinking of macroalgae was found to present a compelling but complex opportunity for carbon dioxide removal (CDR).

Macroalgae exhibit high productivity and can, in theory, contribute to atmospheric CO_2 removal. However, the feasibility of deploying this strategy at scale remains uncertain due to major scientific, technical, economic, and governance gaps. Robust monitoring, reporting, and verification (MRV) systems were identified to be essential to ensure the environmental integrity of macroalgal carbon removal, particularly if this pathway is to enter carbon markets. Economic modelling also shows that macroalgae farming for sequestration alone is not yet financially viable, unless paired with biomass valorisation or ecosystem co-benefits. To ensure environmental integrity, scientific credibility, and regulatory accountability, the European Union must take a phased approach, which is laid out in the conclusions of the WP report.

While the report highlights the potential of microalgae to capture CO_2 in long-lasting products such as biochar, realising this potential will require targeted actions to overcome current challenges related to scalability, sustainability, policy support, and research.

4.6. Recommendations

The recommendations made to increase carbon sequestration in EU underwater forests include:

1. Strengthen habitat and pressures mapping.
2. Expand monitoring and predictive modelling.
3. Align Marine Spatial Planning (MSP) and conservation management.
4. Advance ecosystem-based restoration techniques.
5. Integrate blue carbon into restoration planning.
6. Coordinate governance, funding, and knowledge sharing.

Enhancing sequestration from macroalgae cultivation should only be pursued once scientific and environmental uncertainties are resolved, and the risk of adverse impacts is deemed low. The recommendations made as a result of the research undertaken within this Work Package 4 include:

1. Resolve scientific and environmental uncertainties.
2. Establish demonstration and field trials.
3. Develop cultivation technologies and LCA.
4. Build a robust Monitoring, Reporting and Verification (MRV) framework.
5. Clarify governance and market readiness.
6. Coordinate transboundary and market governance.

Finally, the recommendations made regarding enhancing carbon sequestration from microalgae include:

1. Undertake comprehensive research to fill remaining knowledge gaps, notably via Life Cycle Assessment (LCA) studies.
2. Develop technologies (e.g., to reduce energy consumption during manufacturing and improve nutrient recycling).
3. Increase funding and financial incentives for experimental work.

5. Work Package 5: Recommendations for sustainable wild seaweed harvesting and beach collection of seaweed on European coasts

5.1. Activities

As per the technical proposal submitted by the consortium, WP5 contained the following sub-tasks:

- Task 5.1: Examine and provide an overview of the existing seaweed harvesting from wild practices and data management and monitoring schemes in the EU countries;
- Task 5.2: To examine and provide an overview of the existing beached seaweed collection and management practices and data in the EU countries;
- Task 5.3: To prepare valid and realistic recommendations to promote regenerative harvesting and environmentally friendly beachcast collection of seaweed.

Work undertaken as part of Work Package 5 evolved throughout the duration of the contract as per the below table.

Table 5 Information on progress of WP5 at key moments of the project

Key contract moment	Information on progress
Inception report	The scope of WP5 was refined. The methodology was not corrected or changed at this point, and the option to make amendments on an ad-hoc basis during the implementation was agreed with CINEA and DG MARE.
First progress meeting	By the first progress meeting in May 2024, the desk study necessary for Tasks 5.1. and 5.2 was progressing as planned and first draft on these tasks was planned in June, 2024. The submitted drafts were reviewed by Client and the suggestions were discussed at pre-interim meeting with Client on July 4, 2024.
Interim meeting	The collection of wild harvest data was not completed yet; therefore, the harvest data base was promised for the next draft of the report. Use cases of the EMODnet Data Portal were conducted. A stakeholder survey was planned for October 2024, using the GDPR-compliant software Quest Back.
Interim report	No substantial progress has occurred between the interim meeting and the submission of the interim report. Comments by the Client on the report have been addressed and integrated into the report, where necessary.
Third progress meeting	Data collection on beach cast seaweed was still ongoing and the data base was planned to be ready by the end of January 2025. The stakeholder survey had collected about 50 responses and was prolonged until end of January. The Client's suggestion to contact EMODnet secretariat for feedback was implemented.

Key contract moment	Information on progress
WP report submission	The WP5 report was submitted to CINEA and DG MARE for feedback on the 22nd of April 2025. The report presented the full results of the Work Package, following a structure previously agreed upon between the client and the contractor.
Final report	The final report includes a revised and final version of the WP5 report which incorporates the feedback received.

The full Work Package 5 report is available in the annex (see here).

5.2. Methods

For all three tasks, an extensive literature review was conducted, covering over 100 sources, including research articles, project reports, and publications from relevant authorities. Throughout the project, the number of research articles (particularly those addressing the ecological significance and future uses of beach cast seaweed) increased steadily each month. As a result, the literature collection was updated at least once every three months.

For Tasks 5.1 and 5.2, a stakeholder survey was conducted using the GDPR-compliant survey software Questback, between November 2024 and January 2025. The survey included questions on the use of the EMODnet Data Portal, management practices, and data collection related to wild seaweed harvesting and beach cast seaweed.

The survey was initially distributed to targeted stakeholders, including regional and local authorities and companies active in the sector. In a second phase, it was promoted through various channels, such as the blue bioeconomy networking platform BlueBioMatch and within the networks of Horizon projects AlgaeProBANOS and SeaMark. To refine the survey's focus, the EMODnet Data Portal Secretariat was also consulted.

Additionally, to verify either the absence of data or the lack of beach cast accumulation along specific national shorelines, experts from Ireland, the Netherlands, Belgium, and Finland were contacted directly via email.

The complete documentation of sources and survey results is available in the Work Package 5 report in the annex (see here).

5.3. Priority research needs for future studies

To follow and assess the changes in the stocks of harvested seaweed, a **set of methods should be developed, combining remote observations by UAVs**

and modelling results. Moreover, to fully understand the ecological role of beach cast seaweed, **studies of cast fate, decomposition, nutrient flows and significance in the food webs should be promoted**. Further investigation is needed into the effects of rising temperatures - linked to climate change - on the decomposition of beach cast, and its potential impact on the microbial quality of bathing waters.

5.4. Lessons learnt

The following lessons learnt are noted for Work Package 5:

- Future studies should anticipate that national data reports on wild seaweed harvests from centralised databases (e.g. Eurostat or ICES) do not contain the most updated information, and that a lot of data publications in national languages need to be checked. For beach cast data, the information is even more fragmented, as there is no requirement to report it in any centralised database. As a result, substantial recalculations are often needed to standardise and unify the data;
- Very strict compliance with GDPR requirements reduced the value and representativeness of acquired information from a survey. We excluded any traceable information, also on country and thus missed the knowledge on distribution across EU of seaweed management practices.

5.5. Outcomes

The outcomes of Work Package 5 are fully aligned with its stated objectives and the following has been achieved:

1. Two robust datasets were successfully compiled, providing up-to-date information on wild seaweed harvesting and beach cast collection across relevant EU Member States.
2. The analysis of the EMODnet Data Portal revealed relevant themes, parameters, and use cases, while also identifying a need to improve the portal's visibility and accessibility to increase stakeholder engagement.
3. Practical recommendations were developed for the sustainable management of wild seaweed harvesting and beach cast collection.

5.6. Recommendations

Recommendations towards increase of publicity and usage of the EMODnet Data Portal include:

1. Further promoteEMODnet, including its services and possibilities.

2. Organise more events targeting specific practical topics, like the recent webinar organised by EUSPA on the use of Copernicus Earth Observation and EMODnet data for seaweed farming, and the EMODnet Open Sea Lab 4.0 Virtual hackathon for ocean restoration, in order to raise awareness on data usages and the importance of reporting.
3. Gradually introduce mandatory data reporting to EMODnet for international projects working on wild seaweed harvesting and, eventually, implement mandatory reporting for national contact points on relevant data themes.

Recommendations for wild seaweed harvesting management alignment include:

1. Develop EU-level guidance for wild seaweed harvesting: Procure a targeted research study or pilot project to define best-practice protocols and draft an informal guidance document, built on the Common Fisheries Policy and Circular Economy Action Plan. Establish seaweed as a distinct resource category and align domestic quotas, harvesting zones and certification schemes accordingly.
2. Harmonise sustainability standards across Member States: Initiate the drafting of a unified protocol for sustainable wild seaweed harvesting with the respective business or sectoral organisations. This informal guidance should include ecosystem-based management principles, science-based harvesting quotas, seasonal and spatial restrictions in harvested areas, and species specific low-impact collection methods.
3. Enhance monitoring and data sharing at EU scale: Promote the interoperability of the monitored data by following the FAIR principles (findable, available, interoperable, reusable). Activate the submission of ecosystem-impact monitoring data via the EMODnet Portal.

Recommendations for beach cast seaweed collection and management alignment include:

1. Harmonisation with existing EU Directives: Procure a research-led study to define best-practice protocols identifying when and how beach-cast seaweed may be removed without adverse impacts on coastal biodiversity. Establish minimum retention thresholds based on location-specific ecological roles of beach-cast seaweed to ensure that essential ecosystem functions are preserved. As a result of the study, prepare an informal guidance on beached seaweed collection to clarify potential conflicts between beach-cast removal (Bathing Water Directive) and habitat protection (Habitats and Birds Directives).
2. Develop a sustainability framework: Initiate a comprehensive review of national coastal management policies to prepare an informal EU-level guidance on sustainable beach-cast seaweed collection. Allow for regional adaptation by incorporating criteria for local seaweed composition, seasonal occurrence and biomass dynamics. Embed core sustainability measures, including temporal and spatial harvesting restrictions, adoption of low-impact collection techniques and biomass-based collection limits to prevent over-removal.

3. Enhance Data Collection and Monitoring: Pilot a real-time monitoring system for beach-cast seaweed accumulation, leveraging remote sensing and citizen-science contributions. Require systematic recording of harvested volumes under existing reporting frameworks (e.g., Habitats and Birds Directives). Cooperate with EMODnet data Portal to implement the integration of the collected data to facilitate trend analysis, inform adaptive management and underpin future policy updates.

6. Work Package 6: The role of algae in sustainable food and feed systems

6.1. Activities

This Work Package contained the following sub-tasks:

- Task 6.1: Evaluate and quantify overall benefits of algae production and consumption for human food as compared to other protein sources;
- Task 6.2: Collect information on algae consumption;
- Task 6.3: Investigate the potential to reduce methane emissions from animals thanks to seaweed-based additives;
- Task 6.4: Examine and provide valid and justified recommendations for using algae as animal feed.

Work undertaken as part of Work Package 6 evolved throughout the duration of the contract as per the below table.

Table 6 Information on progress of WP6 at key moments of the project

Key contract moment	Information on progress
Inception report	The methodology of WP6 was refined, taking into consideration first findings and feedback received during the inception phase. No major changes to the methodology were proposed.
First progress meeting	By the first progress meeting, WP6 was progressing according to schedule. A literature log was created, an extensive list of sources compiled, and the literature review for sub-tasks 6.1-6.4 was ongoing. The pre-selection of 6 algae species for analysis (component 6.1) was made, to be validated by internal project experts. The first findings regarding component 6.3 confirmed that *Asparagopsis* is by far the most convincing species with regard GHG emission reduction potential; therefore, it was agreed to focus further research on the necessary (market) conditions for a supply chain of *Asparagopsis* for livestock feed (while removing other species from the scope of the analysis).
Interim meeting	By the Interim meeting, some challenges were identified (e.g., data availability and accessibility, differences in measuring units). The team reached out to algae experts in order to obtain information and find additional literature sources. Furthermore, the outline of business case to be developed for various algae species and the proposed matrix for data collection and analysis were presented.
Interim report	No significant progress was made between the interim meeting and the interim report. The only significant addition was the agreed and updated business case template (part of component 6.4).
Third progress meeting	Desk research for all components was ongoing (including reviewing new publications, which were released in the last 4 months). For sub-task 6.2, the survey was in preparation, with a planned launch date in January. Selected interviews were also planned to complement the findings of all sub-tasks.

Key contract moment	Information on progress
WP report submission	The WP6 report was submitted to CINEA and DG MARE for feedback on the 11th of April 2025. The report contained presented the full results of the Work Package, following a structure previously agreed upon between the client and the contractor.
Final report	The final report includes a revised and final version of the WP6 report which incorporates the feedback received.

The full Work Package 6 report is available in the annex (see here).

6.2. Methods

A mix of methods was used, including: literature review, cost-benefit assessment (sub-task 6.1), stakeholder survey (sub-component 6.2), PESTEL analysis (sub-task 6.3), and business case analysis (sub-task 6.4). The analysis of 6 European algae species in terms of GHG emissions per kg of protein produced and the evaluation of the direct benefits and avoided costs of the algae production and consumption for human food when compared to other protein sources was carried out. Additionally, an updated graph comparing the analysed European algae species with other food sources in terms of GHG emissions per kg of protein produced was prepared. A high-level map, showing the cultivation potential of *Asparagopsis* spp. in relevant EU maritime regions, was also provided. Finally, a business case analysis, including agreed assessment criteria ([1]) for 3 algae species was undertaken.

These methods were combined with individual interviews, regular exchange with the internal project team and external experts, and direct communication with relevant EU4Algae working groups. In total, 2 internal project experts were consulted on various aspects of our research throughout the study, as well as 6 stakeholders via online interviews and 3 experts via written contributions.

An extensive database of relevant literature (containing over 130 sources) was developed and used to assess the various elements of relevance to the Work Package. Given the length of the study, the database was regularly updated with new publications (including grey literature). We used also AI tools such as Copilot and ChatGPT to complete the research, but for input to Final Report, the findings were verified by internal expert review and findings through literature in order to ensure quality of data and findings.

([1]) carbon and environmental footprint; social impact; information about the production costs and selling price; availability of sufficient amount of biomass required to introduce algae in animal feed; feeding logistics; feed safety aspects and impact to animal health; and welfare, ethical and other relevant considerations of using algae in animal feed, as well as market analysis.

The full and traceable documentation of sources, data, statistics, etc. is available in the WP6 report in the annex (see here).

The information received via the above-mentioned sources (literature review, survey and expert consultations) was analysed and integrated into the WP6 report, paying particular attention to the identification of barriers, knowledge gaps, and recommendations on how to advance the EU algae sector.

6.3. Priority research needs for future studies

Priority research needs for future studies:

- To enable the safe and effective use of *Asparagopsis* as a methane-reducing feed additive, several critical research gaps must be addressed. First, the long-term health implications of bromoform exposure in animals and potential residues in milk and meat require urgent and thorough investigation, given the current lack of comprehensive and reproducible long-term data. Existing studies are often short-term and yield variable results depending on livestock type, diet, and inclusion rates, underscoring the need for larger-scale, clinically robust trials.
- From an economic and scalability standpoint, the high cost of production, limited infrastructure, and logistical challenges hinder commercial viability. Research into cost-effective cultivation methods, especially land-based systems, and the use of GIS tools to identify optimal farming zones is needed to reduce costs and enhance spatial planning. Additionally, environmental assessments - including Life Cycle Assessments (LCA) and Environmental Impact Assessments (EIA) - are essential to understand the broader implications of large-scale farming of *Asparagopsis*.
- Finally, integrated approaches should be explored, combining *Asparagopsis* with other promising methane mitigation strategies such as plant-based inhibitors, microbiome management, and selective breeding. Given its potential, the successful adoption of *Asparagopsis* depends on resolving current uncertainties around efficacy, safety, economic feasibility, and environmental impact through a coordinated, multidisciplinary research effort.

6.4. Lessons learnt

The following lessons learnt are noted for Work Package 6:

The study faced several challenges, primarily due to limited and inconsistent data across key areas:

- For algae production, the lack of standardised Life Cycle Assessments (LCAs) and low technology readiness levels complicated comparisons with other protein sources.
- Access to some EU-funded research was restricted, highlighting the need for budget allocation to obtain essential data.
- Algae consumption data was scarce, often limited to production figures, with little information on processing or end use.
- In evaluating seaweed's potential to reduce methane emissions, data gaps and environmental variability hindered accurate mapping of cultivation zones, while research on its use in animal diets was constrained by inconsistent methodologies and insufficient long-term studies.
- Lastly, assessing algae as animal feed was difficult due to a lack of data on costs, logistics, safety, and social impact, as well as limited comparative analysis with conventional feed ingredients.

Overall, given the limited resources of the study, it was realistic to identify the above gaps, but they could not be fully addressed. Therefore, further research is needed on the above mentioned aspects. The Work Package 6 covered a wide and complex scope, and the topics covered have only a few interrelations. For projects of similar scale, it may be worth considering to divide the work into separate studies (or work packages) to achieve more focused outcomes.

Given the rapid developments of algae research, regular update of literature log, internal expert review and interrelation with other major initiatives (such as, EU4Algae, taking into account their recent findings; including unpublished materials) has been very important for ensuring validity of conclusions.

6.5. Outcomes

The objectives and achievements of WP6 are fully aligned with the commitments made. Specifically, the following main outputs has been produced:

1. A Multi-Criteria Decision Analysis (MCDA) table evaluating six algae species, along with an updated graph illustrating greenhouse gas (GHG) emissions per kilogram of protein.
2. A table summarising algae consumption data was incorporated into both the Draft Final and Final Reports, and a one-pager illustrating algae consumption intensity across EU and non-EU countries.
3. A map showing the cultivation potential of Asparagopsis, accompanied by an overview of the impacts of incorporating varying amounts of Asparagopsis into cow diets. The report also identified future research needs to support the introduction of seaweed ingredients into livestock feed.
4. An analysis of three business cases for the use of algae in animal feed.

6.6. Recommendations

The following recommendations were developed in Work Package 6:

1. The potential environmental and ecological risks of large-scale seaweed farming (e.g. effects on local marine ecosystems, biodiversity, and nutrient cycles) must be thoroughly assessed.
2. Policymakers and other stakeholders should invest in R&D and biotech innovation, while also providing financial support to algae farmers and start-ups.
3. The regulatory framework for the algae sector should be simplified, with increased awareness through marketing, education, and engagement with influencers.
4. The approved species list for algae under EU Novel Food legislation should be expanded. Streamline authorisation for safe algae species with a tradition of consumption to broaden the permitted range of algae ingredients in food.
5. Update food safety regulations in line with current scientific understanding. Set clear EU benchmarks for the safety of algae products (e.g. maximum permissible levels of iodine and heavy metals) to ensure consumer protection and build trust in algae-based foods.
6. Enhance labelling and consumer information. Ensure that algae-based products feature clear, transparent labelling regarding content, origin, and nutritional benefits. Clear labelling will aid consumer recognition and help normalise algae in everyday diets. Consumers should be able to easily identify algae ingredients in products to overcome perceptions of unfamiliarity.
7. Promote algae within food education and culture. Encourage Member States to include algae in dietary guidelines and educational programmes, emphasising its nutritional and sustainability benefits.
8. Provide financial incentives and business support to algae-based food SMEs and start-ups seeking to enter mainstream commercial markets. This will facilitate market entry, introduce algae to a wider audience, and build market confidence for larger food companies to invest in algae-based products.
9. Cooperation and integration with agricultural and fisheries policies are essential for the development of the European algae industry. This includes ensuring that frameworks such as the Common Agricultural Policy (CAP) and Common Fisheries Policy (CFP) explicitly support algae sector development.
10. Asparagopsis shows promising potential for reducing greenhouse gas emissions in livestock production. However, due to outstanding safety concerns and high production costs - particularly in land-based cultivation -widespread adoption is not yet recommended. Further research is needed to address these challenges and to explore how integrating

Asparagopsis with other mitigation strategies may enhance overall sustainability and effectiveness.

11. Further research should identify optimal cultivation zones for different algae species using GIS tools and models. Higher-resolution models are needed to assess site suitability at more localised scales, accounting for seasonal and climatic variations and species-specific resilience.
12. Consumer awareness campaigns could help overcome concerns about taste and accessibility by promoting the integration of algae into familiar foods and eating habits, thereby enhancing market acceptance.
13. Supportive policies and streamlined regulations can help strengthen the algae market in Europe. These should complement strategies that encourage collaboration among stakeholders in agriculture, aquaculture, and biotechnology. This includes updating regulatory frameworks to support the use of algae as a feed ingredient while addressing safety and sustainability concerns.
14. Transitioning to controlled cultivation systems and promoting stakeholder collaboration would help fortify the European algae industry.
15. To fully realise the potential of algae species and the broader industry, it is essential to standardise research on animal and human health, environmental benefits, and nutritional value. This will ensure consistent data on the feasibility of algae as a feed ingredient. Further studies are also needed to assess long-term impacts and optimise feeding logistics.
16. Support targeted research and risk-benefit assessments of Asparagopsis as a methane-reducing feed additive, while advancing regulatory and safety frameworks to enable its safe and effective integration into ruminant diets.
17. Promote the development of clear, standardised life cycle assessment (LCA) guidelines for algae value chains to better quantify and compare their GHG reduction potential as sustainable alternatives to conventional animal-based proteins.

7. Conclusions

7.1. Incorporating algae in acquaculture feed

Incorporating algae into feed for farmed aquatic species offers a promising alternative to wild-caught fish ingredients. Algae-based feeds match the performance of traditional options while easing pressure on wild fish stocks and supporting healthier marine ecosystems. They can enhance fish quality, improve seafood safety by reducing contaminants, offer greater price stability and supply reliability, and help address shortages in fish-based ingredients—diversifying feed options for aquaculture.

Though currently more expensive, algae-based feeds could become more affordable with increased support and investment. Practical strategies include setting minimum inclusion targets for EPA and DHA from non-fish sources, reducing the Forage Fish Dependency Ratio (FFDR), tightening limits for PCBs([2]) and dioxins using the ALARA principle, developing official feed standards, and implementing financial incentives and value chain strategies. Circular production methods and large-scale operations can further boost the environmental performance of algae feeds. Although the current lack of large-scale fermentation facilities in Europe is a key obstacle, potential sugar side streams in the EU for algae production have been identified. The support and scale up of algae-based solutions is essential to meet growing demand and foster a more sustainable aquaculture industry.

7.2. Nutrients for organic/cyanobacteria production

Using recycled side-streams and effluents for cultivating microalgae to produce fertilising products for organic agriculture shows potential but faces regulatory and practical challenges. The study identified viable effluent sources and CO_2 side-streams in Europe, hindered by inconsistent terminology and fragmented rules at EU and Data gaps, few case studies, and stakeholder reluctance due to novelty and complexity are significant barriers. Nevertheless, three production scenarios using plant-based AD digestate, treated winery/brewery effluents, and untreated winery/brewery effluents were assessed legally, economically, and environmentally. Targeted regulatory updates and clearer standards could help these pathways in contributing to Europe's circular nutrient use, sustainable agriculture, and organic production goals.

([2]) PCBs (polychlorinated biphenyls) are toxic, man-made chemical compounds once widely used in electrical equipment and industrial applications, now banned in many countries due to their persistence in the environment and harmful effects on human and animal health.

7.3. Use of algae for wastewater and water treatment and use of resulting algae biomass in fertilisation

The integration of algae cultivation with wastewater treatment for the production of fertilising products is feasible. However, careful consideration must be given to the area requirements for an algae treatment system, which depends on the volume and nutrient concentration present in specific wastewaters. It may not always be practical to implement an algae system in-house. In such cases, an industrial symbiosis configuration may be more appropriate. Additionally, the type of wastewater can influence the legal status of the produced biomass, affecting its final use, especially if contaminants are present, as algae are known to bioaccumulate various molecules. Regardless of the cultivation medium used, the use of algae for the production of biostimulants appears to be the most promising route from an economic perspective, as the cost of algae production remains too high to compete with conventional fertilisers.

Concerning macroalgae cultivation in eutrophicated waters, anchored systems are more suitable for sheltered, shallow areas, while floating cultivation systems are better adapted to nutrient-rich, cold or temperate EU waters. Floating systems offer greater scalability and flexibility for offshore, large-scale seaweed farming. *Fucus vesiculosus* is more effective in high-salinity areas, whereas *Ulva intestinalis* performs better in low-salinity environments. These species can remove, on average, 150 kgN/km^2 and 30 kgP/km^2 respectively.

7.4. Role of algae in climate change mitigation in European seas

Seaweed forests across European waters play a vital ecological role and vary by region, with kelp species like *Laminaria spp*, *Saccharina latissima* and *Alaria esculenta* dominating colder northern seas, and *Fucus* and *Cystoseira* species more common in temperate and Mediterranean zones. These ecosystems support marine biodiversity and have the potential to sequester up to 4.2 million tonnes of carbon annually (around 15 million tonnes of CO_2). However, many seaweed forests are in decline due to climate change, habitat loss, and invasive species. Restoration priorities include the Iberian Peninsula, the Mediterranean, and parts of the North Sea and British Isles, while Arctic regions may require protection rather than restoration. Cultivated macroalgae could sequester an additional 1.1 million tonnes of carbon per year, but scientific uncertainty as well as economic and regulatory barriers persist. Microalgae offers particular opportunities for producing long-lasting products like biochar. Moreover, for both macroalgae and microalgae, the ecological impacts of scaling up cultivation need to be carefully assessed due to potential risks to local biodiversity and ecosystems. To fully participate in the efforts for climate mitigation, the algae industry will require investment, robust monitoring, and clear policy support to ensure that climate benefits are both measurable, lasting and not outweighed by any overlooked undesirable feature.

7.5. Wild harvesting and seaweed beachcast on European coasts

Wild seaweed harvesting remains commercially important in Denmark, Estonia, France, Ireland, Portugal, and Spain. Annual yields range from 10 tonnes in Denmark to 60,000 tonnes in France, with Estonia harvesting 2 species and over 20 species collected in France, Spain, and Portugal. All six countries use permit or licensing systems aligned with EU environmental policies. Harvest data is kept nationally but remains fragmented.

Beach-cast seaweed collection practices differ by region: it complements wild harvesting along the North Sea and Atlantic; aligns with beach cleaning in the Baltic; and in the Mediterranean, primarily involves protected *Posidonia* seagrass. Data collection is sporadic and usually tied to research projects, with no central reporting system. Drone-based monitoring is being developed to cover large accumulation areas. Recorded volumes range from 50 tonnes in Lithuania to over 50,000 in France.

While future EU seaweed production will focus on cultivation, wild harvesting continues to support coastal jobs and rural economies. Beach-cast seaweed is a valuable source of compost and fertiliser, especially in eutrophic regions, with volumes ranging from hundreds to thousands of tonnes. Sustainable permit systems, MPAs with collection limits, and improved monitoring are essential. Establishing EU-wide beach-cast data reporting, potentially through EMODnet, would help close current gaps and support better management.

7.6. Role of algae in sustainable food and feed systems

Certain algae species - particularly Arthrospira (spirulina), Saccharina latissima, and Alaria esculenta - offer significant potential to reduce greenhouse gas (GHG) emissions compared to conventional animal-based proteins. However, differences in life cycle assessment methods limit the comparability of results.

Despite global industry growth, Europe’s algae sector remains small and relies heavily on wild harvesting (99%) rather than cultivation. Per capita algae consumption in Europe is low—well under 1 kg annually—compared to over 2 kg in parts of Asia. In countries with specific data, consumption ranges from just 107 g in France to 182 g in the Netherlands. This limited uptake is due to cultural unfamiliarity, regulatory hurdles, and limited availability, all of which restrict market growth.

Studies show that *Asparagopsis* spp can cut methane emissions in ruminants by over 50% at inclusion rates of 0.2–0.5% of dry matter intake (DMI), and by more than 80% at around 1% DMI. As a feed supplement, Asparagopsis has proven effective in reducing methane while potentially enhancing feed efficiency and animal performance. However, safety concerns remain due to compounds like bromoform and iodine, and further research is needed to assess their impact on animal and human health before widespread use.

7.7. Challenges encountered

The two most common challenges encountered were data availability and low stakeholder response rates. Data availability issues were marked by gaps in coverage, granularity, and comparability, which in some cases hindered the analysis and necessitated a reliance on assumptions or on modelling to circumvent the issue. Research needs were also identified to fill knowledge gaps. Additionally, a low response rate from stakeholders during the consultation processes of some Work Packages (WPs), particularly in WP 2, WP4 and WP6 and restricted the representativeness and depth of the consultation findings.

The challenges specific to each Work Package are synthesised below:

- **WP1**: industry secrecy and inconsistent environmental assessment data necessitated combining lab and industrial data with high uncertainty in the Multi-Criteria Analysis (MCA);
- **WP2**: limited stakeholder engagement due to topic unfamiliarity, inconsistent terminology (e.g., “organic,” “biostimulant”), and regulatory ambiguity created challenges in assessing adoption potential and policy impacts;
- **WP3**: lack of field trial data, especially in Europe, and uncertainty around legal status and contaminants of algae biomass limited the reliability of results. Eutrophication mitigation data was largely modelling-based, lacking real-world validation;
- **WP4**: significant data gaps on biomass and species cover, as well as limited environmental data resolution and stakeholder input, constrained model accuracy and carbon sequestration estimates;
- **WP5**: data inconsistencies and gaps were exacerbated by the absence of centralised databases and unclear policy coverage;
- **WP6**: limited and inconsistent Life Cycle Assessment (LCA) data, often due to low Technology Readiness Levels (TRLs) and absent methodological guidelines, hindered environmental impact evaluations. Access to some EU-funded research results was restricted, and available data lacked depth on processing and consumption stages across countries.

8. List of deliverables and outputs

The list of all deliverables and outputs, alongside their submission dates, is presented in the table below.

Table 7 Overview of deliverables and outputs

Item	Submission date
Kick-off meeting minutes	15/01/2024
DLV1: Inception report	13/03/2024
First progress meeting minutes	21/05/2024
Interim meeting minutes	24/09/2024
DLV2: Interim report	14/10/2024
Third progress meeting minutes	16/01/2025
Final meeting minutes	26/05/2025
DLV3: Draft final report	30/05/2025
DLV4: Final report	13/06/2025
DLV5: Study factsheet	06/06/2025
DLV6: PowerPoint slide deck	06/06/2025

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