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From livestock to algae: Developing the European spirulina sector for sustainable protein

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KEY POINTS

1. Spirulina is a low-impact, nutrient-dense, and protein-rich alternative for sustainable food systems.

2. It can reduce the environmental impacts of livestock farming, while contributing to key EU goals.

3. EU policy gaps hinder the expansion of an EU sustainable spirulina sector and must be addressed.

Summary

Livestock farming is a major driver of environmental degradation and a burden to achieve EU environmental and food security targets. Spirulina, a sustainable and nutrient-dense microalga with a high protein content, is a strategic alternative to unsustainable food systems. Its low impact across several indicators, including land use, water use and GHG emissions makes it a strong candidate for improving how we produce protein in Europe, while contributing to decarbonisation, and land and water use optimisation. As a healthy source of protein, spirulina aligns with the *From farm to fork strategy*. Using spirulina-based animal feed would be a promising opportunity to decrease the environmental pressures of livestock farming. However, several barriers hinder the uptake of an EU spirulina sector: a fragmented algal-related regulatory framework, unsupportive CAP subsidies, and limited funding to support efficient technologies. Multiple policy recommendations aim to address these barriers and support the uptake of the sector.

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1. Unsustainable livestock farming

Livestock farming causes significant environmental damage that affect several environmental impact categories (Figure 1) and contribute to food insecurity and to the transgression of planetary boundaries [1,2]. In 2017, it was shown that of the five planetary boundaries that were in a high-risk zone [2], agriculture, and particularly livestock farming, were the main contributors to four of them – biogeochemical flows, freshwater use, land-system change, biosphere integrity, and contributed to the deterioration of the fifth: climate change (Figure 2) [3]. No more recent studies have assessed the current environmental impact of livestock.

Furthermore, livestock farming depends on feeds such as soy, maize and wheat, whose cultivation is vulnerable to both biotic and abiotic stresses. These pressures have already increased as a result of climate change. Besides, these crops occupy significant amounts of agricultural land and contribute to land conversion. In addition, certain institutional hazards, such as international food trade restrictions and armed conflicts, threaten the stability of food prices and the supply chain, contributing to food insecurity [4,5]. Furthermore, large-scale factory farms facilitate the emergence of new infectious diseases, not only because they are densely populated, but also because of the close contact between humans and animals that may be immunocompromised due to poor living conditions [6].

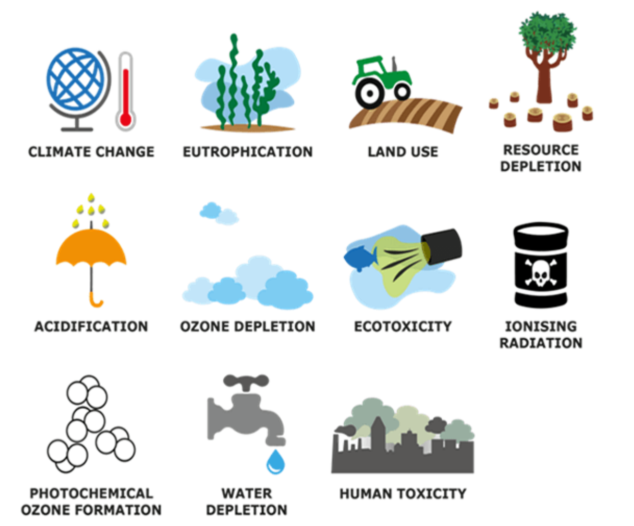

Figure 1: Environmental impact categories considered for Life Cycle Assessment (source: European Platform on Life Cycle Assessment)

Current food production practices, if intended to feed the entire human population, have no choice but to violate planetary boundaries [7]. In 2020, researchers found that *"almost half of current global food production depends on planetary boundary transgression. [...] If these boundaries were strictly respected, the present food system could provide a balanced diet [...] for 3.4 billion people only."* [7]

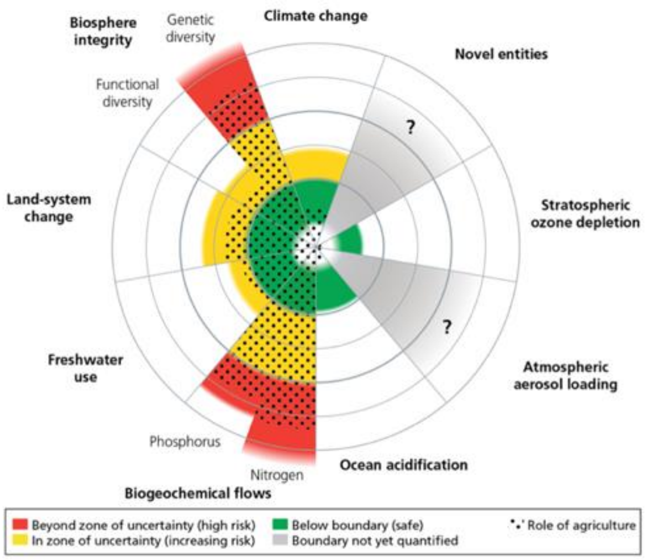

Figure 2: The state of planetary boundaries and the contribution of agricultural activities to their transgression (source: Campbell et al., 2017)

Moreover, the United Nations projections [8] estimate that the global population will reach 9.7 billion in 2050, leading to an increase in food demand. In addition, the daily consumption of animal protein has increased by around 30% in rich countries since the 1960s [9] and global demand for meat is expected to rise by 78% between 2005 and 2050 [10] (Figure 3). This increase not only has environmental impacts but also poses risks to human health. For example, data on Blue Zones, which are regions in the world where the longest-lived people are found, demonstrate that approximately 95% of their diet is plant-based [11].

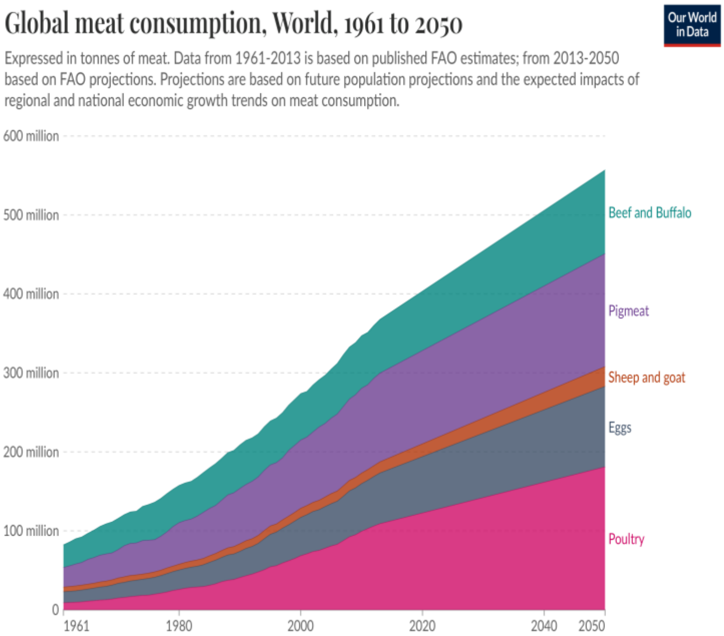

Figure 3: Global meat consumption (1961-2050) (source: Our World In Data)

2. Using spirulina as a solution

A transformation of food production and consumption systems is needed to design a food system that is simultaneously capable of providing a healthy diet to a growing population while remaining within planetary boundaries.

The aim of this transformation is to decouple food production from the environmental pressures it causes [9]. This transformation would be based, among other elements, on the integration of low-impact protein-rich foods, which would partially replace both animal proteins in human diets and high-impact livestock feed.

The integration of alternatives to animal proteins into the market aligns with the objectives of the *Green Deal* and the *From farm to fork strategy*, which encourage the development of low-impact and resilient protein-rich food sources, such as insects and algae, so as to support sustainable food systems [12, 13,14].

Several studies have identified low-impact protein-rich food sources [5,15]. These sources include legumes, microalgae, macroalgae, mycoproteins from fungi and insects [5]. These foods have several advantages, such as being less vulnerable to biotic and abiotic stresses, being practicable in various conditions and regions where conventional crops may not feasible, thereby increasing the resilience of the protein supply [5]. Finally, they have a comparatively low footprint on the environment. Among these alternatives, spirulina – a microalga – stands out (Figure 4) for its safety, nutritional value and particularly low environmental impact, if grown in favourable conditions [5,16].

First, spirulina's long history of human consumption demonstrates its safety. Although it has recently gained popularity, and is now considered a "superfood" [18], it is an ancient food, already consumed daily by populations living near alkaline lakes where spirulina grows naturally [16]. Its use dates back to the Aztecs in Mexico, who harvested it from Lake Texcoco [19], and to people of

Central and East Africa, such as Kanembu people still living on the shores of Lake Chad [16]. More generally speaking, seaweed has always been an integral part of the traditional Asian diet.

Second, it is a highly protein-rich food (60-70% by dry weight compared to 20-30% for fresh meat) and provides all essential amino acids needed by the human body to be healthy [20,21].

Third, spirulina is nutrient-dense, supplying essential fatty acids, vitamins, minerals and pigments, that all have therapeutic properties [19,22] and multiple health benefits, including immune system modulation, anti-viral properties, cancer preventive activity, and cardiovascular benefits [19,22,23].

Fourth, spirulina cultivation has a low environmental impact across multiple impact indicators [18] (Figure 5). It contributes to the capture of atmospheric CO_2 and photosynthesizes at rates of on average ten times higher than terrestrial plants [24].

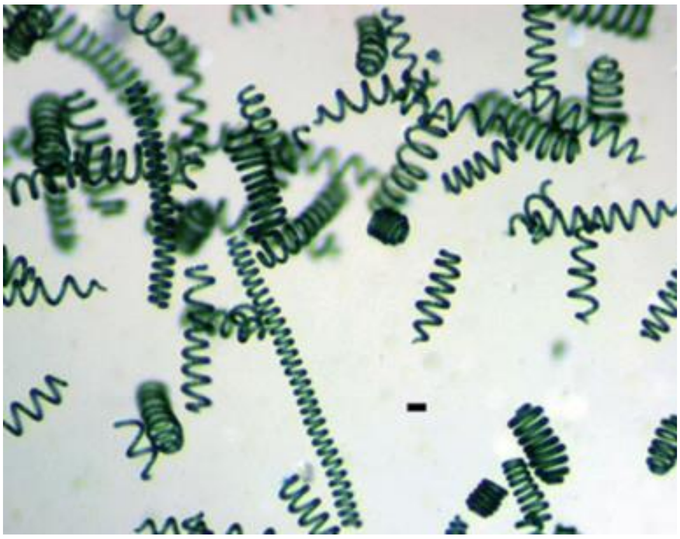

Figure 4: Microscopic view of spirulina (Arthrospira platensis) (source: Sili et al., 2012)

Modeling has shown that if 10% of Iceland's currently installed electricity were dedicated to produce spirulina, Iceland could become self-sufficient and meet the protein and amino acid requirements of over 6 million northern Europeans through spirulina exports. Simultaneously, it could reduce between 6.5 million and 75 million tons of CO_2-eq, depending on the scenario [25].

In addition, its cultivation can take place on non-arable soils [16], which is promising in a context of arable land scarcity. Naturally occurring in tropical and subtropical climates, spirulina's resilience and adaptability to climatic conditions make it suitable for cultivation in a wide variety of countries, including all European countries [26]. It is produced at scale in either open ponds or photobioreactors, depending on the climatic conditions [26]. Currently, it is mainly produced in Asian countries, the main producer being China [16].

Furthermore, its water requirement is exceptionally low. Growing spirulina requires up to 1/5 the water used for conventional irrigated crops and around 30 times less water than beef [26]. Put another way, producing 1kg of spirulina requires around 1/30 the water used to produce 1kg of beef [27].

This microalga also has a high yield: under optimal conditions, spirulina grows by 30% per day, which is on average ten times faster than terrestrial plants [28]. Due to its high protein content, the protein yield per unit of cultivated area of spirulina is 40 times greater than that of soy and 200 times greater than that of beef [16].

Spirulina has also various applications, ranging from human food and livestock feed to fertiliser, biofuel, bioplastic and pollution control (e.g. heavy metal capture) [29]. It is also used in developing countries to combat child malnutrition and respond to humanitarian emergencies [26]. Its versatility makes it a promising crop to include in a Europe that seeks to ensure both its strategic autonomy and environmental sustainability [30].

Expanding spirulina production could foster the development of alternative livestock feed, based not on soy or fish, but on microalgae. This would reduce the livestock farming's reliance on soy cultivation and fishing, which both have a high environmental footprint [31]. Incorporating spirulina into the production of livestock for human consumption, would grow the resiliency and sustainability of the livestock sector [32]. The partial inclusion of spirulina in animal feed does not cause a drop in performance; on the contrary, it not only increases both product quality and quantity (e.g. increase in the omega-3 content of meat and eggs, enhancement of the colour of egg yolks, increase of milk quality and production), but it also enhances the overall animal physiology [16,23,33,34,35]. Microalgae-based feeds are already used in Asian countries [36], with positive results, and have started to spread to the United States and United Kingdom [32].

The potential of spirulina as a promising alternative to livestock-derived proteins is highlighted in both academic and decision-making spheres. At the European level, the *From farm to fork strategy* states that '*algae should become an important source of alternative protein for a sustainable food system and global food security'* [37]. Spirulina can help achieve key European objectives such as decarbonisation, preserving and restoring biodiversity and protecting ecosystems [30].

The demand for spirulina increased by approximately 8.7% in Europe between 2022 and 2025, and this growth is expected to continue [38]. The EU is one of the world's main importers of seaweed products (€554 million recorded in 2016 [30]). Thus, the potential of a sustainable European spirulina sector is an opportunity to promote an industry that is regenerative for the environment, innovative, and that can generate employment, especially in coastal areas [30].

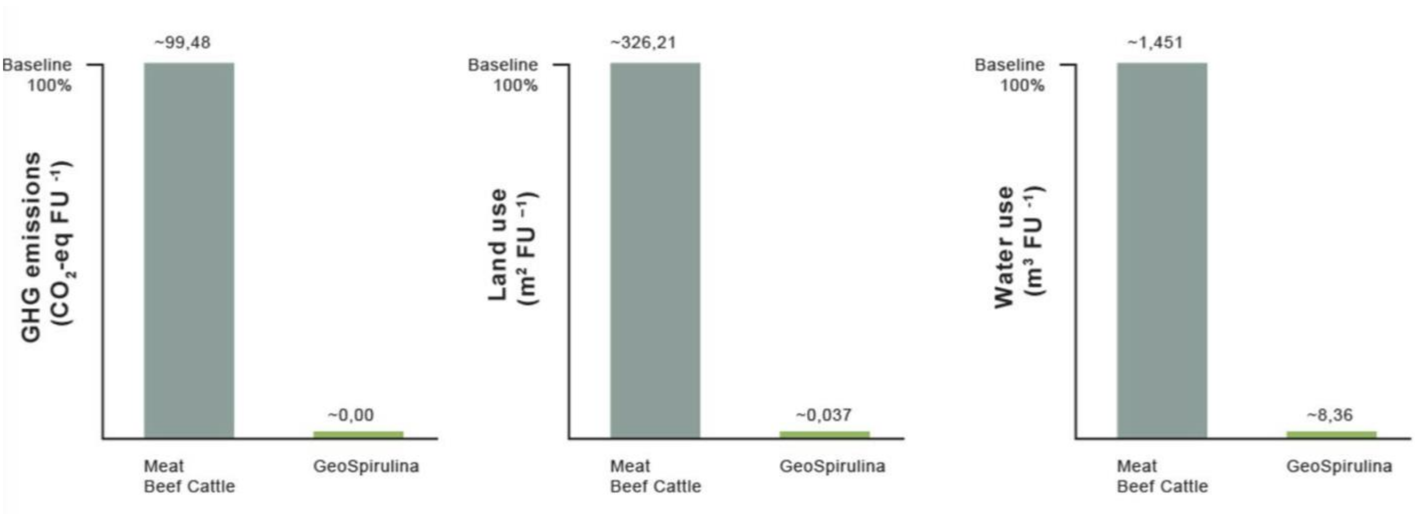

Figure 5: Comparison of the environmental impact of spirulina produced in Hellisheidi Geotherma Park (Iceland) and beef on GHG emissions, land use and water use (source: Tzachor et al., 2022)

3. Current obstacles and policy responses

The European spirulina production sector is in its early stages. In 2021, 447 algae and spirulina production units were identified across 23 European countries, with more than 50% of them producing microalgae and/or spirulina (Figure 6) [39].

The sector's growth is hampered by economic factors such as high production costs, small-scale production, and its high cost for consumers [30,40]. To overcome these barriers and support seaweed-related projects, funding has been allocated by several EU funds: the *European Maritime and Fisheries Fund*, the *European Regional Development Fund* and the EU research and innovation funds, such as *Horizon 2020* and *Horizon Europe* [30].

Further limitations include the lack of knowledge of algae cultivation techniques in the European context and limited knowledge of markets, consumer preferences and the potential environmental risks of spirulina cultivation [40]. In addition, there is limited consumer awareness of spirulina's environmental potential and food uses. To address these knowledge gaps, a number of European initiatives have been launched. Some examples include the *European Marine Data and Observation Network*, which maps algae production, and the European Commission's *Knowledge Centre for the Bioeconomy* [30].

The two main barriers remain the fragmented governance framework and the dominance of the livestock sector in the political arena, which include its monopolisation of *Common Agriculture Policy* (CAP) subsidies for animal-based foods [30,41,42].

Regarding the fragmented governance framework, the seaweed aquaculture is regulated by several national and European regulations (e.g. *Marine Strategy Framework Directive, Regulation on Novel Foods, Habitats Directive, Alien Species Regulation*), creating a fragmentation that is not conducive to the sectoral development [30,41]. A harmonised regulatory framework would facilitate the growth of the seaweed sector.

With regard to the second main barrier, the strong dominance of livestock sector stakeholders in the political discourse has led to European agricultural policies that are unsupportive of alternative proteins [42]. 82% of the agricultural subsidies granted by the CAP go to animal-based food production, with 38% allocated as direct subsidies and 44% as animal feed support [43].

Finally, the barriers related to the use of spirulina in livestock feed are the lack of research into the most suitable spirulina strains for animal nutrition and appropriate feed formulations for each species [31,32]. Above all, there is a lack of cultivation and harvesting technologies that are energy-efficient enough to make spirulina-based feed cost-competitive with conventional feeds. Together, these factors hinder the adoption of spirulina as an animal feed [34].

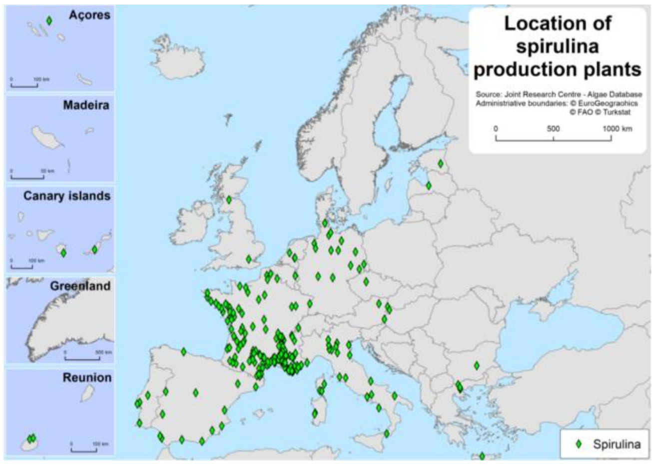

Figure 6: Location of spirulina production plants in Europe in 2021 (source: Araújo *et al., 2021)*

Despite efforts already made at European level, these obstacles contribute to the lock-in phenomenon hindering the development of the European spirulina sector.

4. Policy recommendations

To unlock the situation and increase the effectiveness of support for the development of the spirulina sector, several policy recommendations are suggested. Given the potential of the algae sector, and more specifically spirulina, the following actions are advised.

General policy recommendation to support the European spirulina sector:

- Improve the governance framework and streamline legislation by harmonising and simplifying the existing legislation regulating algae aquaculture.
- Strengthen support for spirulina-related SMEs and initiatives by financing production projects and creating collaborative platforms for sharing cultivation techniques, best practices and facilitating producers' networks [30].
- Enhance consumer awareness of the health and environmental benefits of consuming spirulina, not only as a sustainable source of protein but also as a source of nutrition. This could be achieved through regional advertising campaigns in food retail outlets and suggestions for incorporating spirulina into recipes specific to each region.
- Support the development of more efficient and scalable spirulina farming systems, through EU research programmes, in order to address the current technical constraints of spirulina production systems, increase production and reduce production costs.

Guidelines specific to fostering a spirulina-based feed sector:

- Develop guidelines to promote the substitution of fish- and soy-based feeds with algae-based feeds, so as to decrease the environmental impact of livestock. In Europe, livestock farming consumes 70% of oilseeds and 60% of cereals (162.5 million tons) [44]. An option would be to build partnerships between the livestock industry and the spirulina sector, in order to foster the use of spirulina-based feeds. This action would reduce the environmental footprint of conventional feeds, mitigate the pressure on the oceans caused by overfishing and fish farming, and free up a large area of arable land [33,34] – in 2019, 63% of EU farmland was dedicated to cereal crops for livestock feed [45].
- In parallel, it is crucial to mobilise European funding for the research and development of low-impact and economically viable algae-based feed production technologies. Despite the great potential of algae-based feeds, the immaturity of the sector and its related cultivation and harvesting technologies lead to processes that are often energy-inefficient, limited in scale and costly compared with conventional feeds [31,36].

- In addition, it is important to support, through research funding, the selection of strains of spirulina most suitable to incorporate into animal feeds, as digestibility varies across strains [35,36]. Generally speaking, spirulina is a particularly promising microalga, as unlike other microalgae, it lacks a cell wall, making it the most digestible microalga and thus the most suitable to incorporate into feeds [31].

By implementing these seven recommendations into existing European policies, European policy will offer a strong support for the spirulina sector and meaningfully contribute to the creation of the EU blue bioeconomy [30].

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