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Actor groups influencing and shaping sustainable microalgae value chains in Europe

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Microalgae are an evolving field to produce sustainable nutritious food with low environmental impact. To shape the emerging European value chain in a sustainable way, all actors and processes need to be considered. This article builds on the results of multi-stakeholder scenario workshops organised within the EC-H2020-funded project ProFuture. It investigates the roles different actors along the microalgae value chain hold to shape it. A qualitative analysis identified three actor groups: (1) microalgae producers and processors, and researchers who work with microalgae and their development, (2) policy makers, and large industrial players, who influence the political and economic possibilities of the microalgae value chain and (3) consumers, who play a key role in order to root sustainable microalgae food products in the market. The paper shows how these groups interlink and draws conclusions about their roles for shaping the European microalgae value chain.

KEYWORDS

microalgae, value chain, sustainability, food sector, actor groups

1 Introduction

Microalgae are fascinating and versatile organisms, which grow under a variety of different conditions and offer manifold possibilities for vast fields of applications. At a global level, their potential has been recognised for centuries, however, compared with other biotechnological industries, microalgae production remains challenging (Niccolai et al., 2019; Verdelho Vieira et al., 2022). In Europe, the potential of microalgae is explored in the food and feed sector, as well as the chemical, pharmaceutical, cosmetic and energy sector, with production volumes growing in the last decades (Araújo et al., 2021).[1] Based on the specific microalgal metabolism and composition (their high content of proteins, fatty acids, micronutrients and pigments), their high growth-rates and their possibilities to grow without the use of arable land (photobioreactors are the most common method in the EU

1 On a global scale, microalgae have been used as food and feed for centuries. Already in the 1950s, Burlew (1976 [first published in 1953]) proposed the use of microalgae as candidates for alternative protein sources to face global food demand, and in the 1960s Japan started the first industrial scale production of the microalgae species Chlorella for human consumption (Vigani et al., 2015).

(Araújo et al., 2021)) as well as the possibility to grow with residual waters, microalgae are promoted as promising source of nutrients (Ferreira de Oliveira and Bragotto, 2022). They have the potential of supplying a substantial portion of the EU food market showing important implications for food sovereignty (Vigani et al., 2015; Rumin et al., 2020).

In contrast to Europe, several countries located in Asia, the USA and Australia already succeeded in the 1980ies with establishing large-scale microalgae production facilities (Enzing et al., 2014; Rumin et al., 2020; Araújo et al., 2021). Despite its recognized potential, European microalgae production is still only operating on a small scale, but spreading across the continent with the largest production facilities in Germany, Spain and Italy (Araújo et al., 2021). At EU level, while official reports are lacking, total annually produced volumes were estimated being 324 tons of dry weight microalgae (Araújo et al., 2021). About one quarter of this amount is currently used in the cosmetics industry, one third is used for food supplements, nutraceuticals and feed (Araújo et al., 2021). In the food sector, microalgae are not eaten as raw products, but rather consumed in a processed form. They can be consumed in a pure, powdered form as food supplement or used to enrich the nutritional value (and often colour) of processed foods such as for instance pastries, soups, cereals or dairy alternatives (Boukid et al., 2021; Ferreira de Oliveira and Bragotto, 2022).

Of an estimated number of 30,000 to 1,000,000 microalgal species (Rumin et al., 2020), currently only a few species are approved for food and feed ingredients in the EU (Niccolai et al., 2019). This low share is related to specific regulations applying to microalgae as novel food in the realm of the EU Novel Food Regulation (European Parliament and European Council, 2015). For approval, studies proving the non-toxicity and sufficient digestibility of the species are required, which are costly and time-consuming (Niccolai et al., 2019).

Microalgae represent a rapidly developing area of research and investment involving, however, many unknown factors such as the actual emissions and resource use related to large-scale cultivation, not-yet optimised cultivation technologies, the efficiency of bioaccumulation depending on algae species, the pollutant accumulation and the impact on land use change (Grossmann et al., 2020; Araújo et al., 2021). In general, the existing European microalgae value chains are characterised by a long and unspecialised way from farm to fork, high production costs, extensively long returns on investments, and significant knowledge gaps related to technological developments in production and processing, which vary with different microalgae species- and also involve issues such as contamination of the aquaculture and toxins. (Rumin et al., 2020; Araújo et al., 2021; Verdelho Vieira et al., 2022). For large-scale commercial production data for the economic and ecologic impact of microalgae production is not available beyond laboratory- or pilot-scale data, which makes its viability difficult to assess (Rösch et al., 2019). At the current stage of development, microalgae based products are expensive, and, for example in relation to proteins derived from microalgae, not competitive with other plant-based or animal based protein sources (Grossmann et al., 2020). The market demand for microalgae based food products is limited (Verdelho Vieira et al., 2022). These economic limitations are also mirrored in the current micro algae value chains in Europe; they are subject to rapid change, and remain fragmented (Usher et al., 2014; Araújo et al., 2021; Verdelho Vieira et al., 2022).

In light of the climate crises and rising social inequalities, recent calls for a growing 'European blue bioeconomy' (European Commission, 2021) – with microalgae being an important part thereof – need to be combined with calls for ecologically and socially sustainable microalgae value chains. As microalgae value chains are still emerging and under development, there is a window of opportunity to shape this development in a sustainable manner. Since the Brundtland report in 1987, sustainability and sustainable development are key concepts to ensure that today's activities do not compromise future generations at an economic, environmental or social level (World Commission on Environment and Development, 1987). The food sector lies at the heart of sustainable development, striving to ensure the survival of generations.[2] When limiting the use of resources and energy as well as resulting waste streams and simultaneously providing for decent working conditions, microalgae might contribute to food security and balanced diets of the future in a sustainable way.

Therefore, the sustainability of microalgae as an end-product also relies on the economic, social and environmental processes and hence the sustainability of the underlying value chain. Discussions on sustainable supply chain management range back to the 1990s, with more holistic perspectives on corporate social responsibility and sustainability evolving since the beginning of the 21st century (Carter and Easton, 2011). Toussaint et al. (2022) emphasise that supply chain management literature has dominantly influenced discussions about the manner how supply chains can be designed in a sustainable way. A broader perspective that does not only encompass the activities of individual companies (like for example corporate social responsibility strategies) is crucial. It is necessary to consider the whole value chain and the multiple stakeholder groups involved in related processes. Relevant discussions of sustainable value chains are also to be found in literature relating to the global value chains framework, which similarly started in the 1990s and centres discussions of how globalised production networks are organised and how the gains of these processes are unevenly distributed to actors in the Global South (Gereffi, 2019). The European microalgae value chain can be categorised as additive (global) value chain, whose involved processes sequentially add value to intermediate goods and inputs to the final product (Kaplinsky and Morris, 2016; Gereffi, 2019). In order to thrive in a sustainable way at an economic and social level, additive global value chains are recommended to pursue strategies of 'thickening', i.e. building linkages with the actors in the value chain (Kaplinsky and Morris, 2016). Vurro et al. (2009) also discussed the importance of stakeholder networks and dialogues and engagement processes for sustainable value chains from a sustainable supply chain management perspective. As Petit et al. (2018) elaborate for the agrifood sector, recent processes of globalisation have caused a

2 Several sustainable development goals relate to food and food security. See for example Toussaint et al. (2022, 2478) for a review.

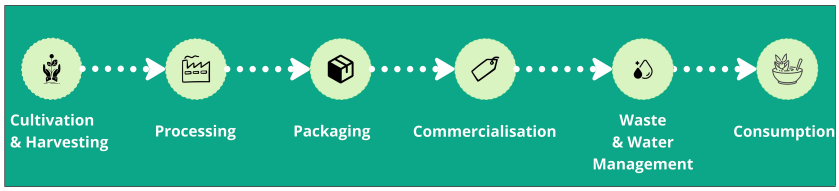

FIGURE 1
The microalgae value chain, illustration by the authors using Miro and Iconfinder.

specific concentration of power amongst processors and distributors, impacting the possibilities of governing the value chain and its multiple actors. Also in this regard, the framework of global value chains provides important insights in governance patterns arising within specific supply chains and hints at possible policy support measures (Gereffi et al., 2005; Kaplinsky and Morris, 2016).

The microalgae value chain (Figure 1) encompasses processes of cultivation and harvesting, processing (drying or extracting specific components like proteins, vitamins or pigments), and distributing the end-products (Araújo et al., 2021). Additionally, processes of packaging, commercialisation, waste and in particular water re-use management and consumption can be considered part of the chain (Lewandowski et al., 2019; Toussaint et al., 2022).

The sustainability of European microalgae value chains remains an open question. Given that microalgae value chains in Europe are evolving yet possibly promising pathways to provide sustainable future nutrients, the very organisation of the value chain strongly affects whether and how these processes can be ecologically and socially sustainable. Several different actor groups have a stake in the development and functioning of microalgae value chains, ranging from producers, retailers, national/supranational policy makers to researchers, consumers, employees and many more.

As this has – to our best knowledge – not been researched in the European context, we consider it pertinent to investigate the role of different actors involved in the European microalgae value chain and their agency in shaping it. We were scrutinising their role and agency based on a scenario process that took place in the framework of the ProFuture[3] project. In order to investigate the ecological and social dimensions of microalgae value chain development, it was our role in the project to organise and facilitate two multi-stakeholder workshops with actors across the value chain. In the workshops, we co-created scenarios for sustainable microalgae value chains in Europe, which are the basis of the analysis and results at hand.

In the following, we elaborate on the methodology employed; we introduce a five-step approach of the workshop and its operationalisation including a descriptive overview of important insights per step. In the subsequent section on results, in a first step we report on the workshop participants' views of the issues evolving around the currently implemented European microalgae value chain. In a next step, we analyse the roles and agency of three actor groups for shaping microalgae value chains, namely: i) microalgae producers, processors and researchers, ii) policy makers, large companies and funding institutions, as well as iii) consumers of microalgae food products. In the last section, we summarise our results and embed our results in relevant discussions.

2 Materials and methods

The microalgae value chain in Europe is characterised by uncertainties. Scenario planning is a tool to work with uncertain futures (Schneider and Rist, 2014; Freeth and Drimie, 2016). Historically, scenarios were used by military strategists to anticipate manoeuvres of enemies and by oil companies to consider the possible effects of climate change and resource depletion (Garb et al., 2008; Durance and Godet, 2010; Freeth and Drimie, 2016; Johnson and Karlberg, 2017). More recently the method of scenario building has become a usual practice to investigate complex long-term interactions of social and environmental systems and been used more broadly to make heterogeneous groups think about possible future trajectories (Freeth and Drimie, 2016; Johnson and Karlberg, 2017). In contrast to forecasting, scenarios do not aim at predicting what future will be like. Rather, scenarios strive to provide the basis to anticipate or envision the effect of specific policies, measures and actions beyond the immediate present, to illustrate possibilities and stimulate creative thinking (Schneider and Rist, 2014; Vervoort et al., 2015). Thereby, scenarios allow working with future uncertainties and envisioning mutually preferred futures (Freeth and Drimie, 2016).

The scenarios analysed in this paper had been created in the course of a specifically designed co-creative multi-stakeholder scenario process. The scenario process was set up as a one-and-a-half-days workshop, which was facilitated in an online setting twice, once in June 2021 and once in September 2021 with different participants. The scenario process in both workshops followed five distinctive steps inspired by the process of Freeth and Drimie (2016). In the following, we elaborate on our specific workshop set-up, including brief summaries of intermediate results that have led to the four final scenarios, which are analysed in the results section.

3 ProFuture is a Horizon 2020 funded research project (GA number 862980) striving to answer technological challenges of the current European microalgae production and down-streaming processes and to broaden the use of microalgae-based proteins in the field of food and feed.

2.1 Step 1: Convene a team across the microalgae value chain

Who are the people building the scenarios and taking decisions? Whose voices are represented in the scenarios? Results need to be relevant for stakeholders to meet their needs and priorities (Johnson and Karlberg, 2017). Also different perspectives have to be part of the group (Freeth and Drimie, 2016). When it comes to participatory scenario planning addressing complex topics such as sustainable microalgae value chains, it is key to convene a team of participants encompassing the whole value chain. To do so, we conducted a detailed stakeholder mapping process: In a first step, we clustered stakeholder groups according to the following areas: i) production of raw material; ii) processing companies; iii) logistics and retail; iv) consumers & CSOs; v) policy makers; and vi) researchers. In a next step, we searched for potential participants aiming to reach heterogeneous groups in the workshops.

In total, we selected and invited 55 stakeholders by email. 11 persons participated in online workshop 1 (June 2021) and 11 participants participated in online workshop 2 (September 2021). Representatives from the microalgae production (3), processing (4), retail (2), microalgae researchers (9) and consumer researchers (2) as well as policy makers (2) were involved in the workshops. Their locations of work place involved Portugal, Belgium, Germany, Italy, Spain, France, the Netherlands, Latvia and Switzerland. Despite our active efforts to engage representatives of environmental NGOs, all of our invitations were declined, resulting in a non-participation of this stakeholder group. It can be assumed that – given the small role of microalgae in Europe so far – the microalgae value chain does not play an important role for ecological questions yet and therefore, little attention is received from environmental NGOs. It was striking that workshop participants did not mention environmental NGOs at all during discussions. They were seemingly not perceived being a stakeholder of the microalgae value chain.

Our stakeholder selection does not serve as a representative group in a statistical sense. Instead, the small groups of 11 participants per workshop collaborated and discussed extensively, with every engaged person bringing in their own perspective, producing dense materials for qualitative analysis.

2.2 Step 2: State-of-the art: collection of influencing factors

In the workshops, a considerable amount of time was allocated to discussing the state-of-the art of microalgae value chains and to collect influencing factors for i) an environmentally sustainable and ii) socially responsible microalgae value chain in the realm of food production. Influencing factors were clustered by 'regulations', 'job market', 'consumer perceptions and attitudes', 'production systems' and 'social factors' such as affordability and accessibility of products.

2.3 Step 3: In an ideal future…: Construct stories that should happen

In step 3, the group created visions and was encouraged to think 'out of the box'. Participants discussed the question how the future of the European microalgae value chains could ideally be like. Based on the results of step 2, participants constructed a list of positive future sentences, representing an ideal future for a sustainable microalgae value chain. Groups chose 2 to 3 sentences to elaborate their ideas by gathering critical and enabling aspects for each ideal future sentence.

2.4 Step 4: Measures: explore what must be done

In step 4, based on personal preferences and interest, participants selected one of the created future visions from step 3. They outlined the current state, identified gaps and underlying reasons and defined goals on how to achieve the promising future scenario. The participants gathered and concretised ideas; they formulated suggestions for measures and actions and clarified responsibilities. The groups considered burdens and barriers, but focussed on solutions and investigated ways to meet their ambitious idealistic futures. The outcomes of this step were key for the analysis reported in the paper at hand.

2.5 Step 5: Recommendations to start transforming the system

Initiating a broad systemic transformation process was beyond the scale of our scenario process. However, the results of the previous four steps led to concrete recommendations for each scenario with some potential to initiate transformative actions.

2.6 Data collection & analysis

We used the virtual whiteboard tool Miro[4] to facilitate the co-creative scenario workshops online. By this means, the results of the discussions were documented by workshop participants on virtual post-its. Based on these notes, the authors of this paper applied a fine-grained word-by-word analysis to elicit multiple possible readings and uncover latent meanings (Flick, 2018). While each of the analysed four scenarios represented a coherent narrative of a possible future by itself, the different steps of analysis crossed the boundaries of the scenarios, and rather delved into latent and manifest dimensions (Mayring, 2000). As a result, the positioning of the workshop participants became a recurring frame latently structuring most of the written material and thus a leitmotif in the analysis. On this basis, the results of the fine-grained analysis were systematised and coded again using a deductive code set emerging

4 https://miro.com

from the literature review as well as the identified main actor groups. The results thereof are reported in the following results section.

3 Results

Our results are based on four co-created scenarios with actors of the microalgae value chain emerging as strong motif. In the following, we summarise the scenarios as well as the current barriers to the microalgae value chain. Afterwards, we introduce the main actor groups as identified in the analysis to delve into their specific roles in more detail.

3.1 Scenarios for sustainable microalgae value chains

Whilst being different in perspective, all four of the scenarios relate to the established presence of microalgae in the food market:

1. Microalgae as acknowledged part of a healthy diet
2. Microalgae as substitute for meat and plant-based proteins
3. Microalgae as integral, safe and affordable part of a daily diet
4. Microalgae as common food for the wider public

Participants of all scenarios emphasised that an ideal microalgae value chain causes a low environmental impact, is sustainable based on zero-waste policies, provides for full biomass utilisation, and exclusively uses renewable energy sources. Three out of four scenarios were set in the currently dominant version of a growth-based capitalist market economy, which accumulates wealth by fostering growth of production and externalises its costs to marginalised groups and regions. In this vein, the need for upscaling microalgae production is perceived as a necessary step for achieving significant market shares. Economies of scale, accompanying goals of profitability and affordability are seen as requirements for successful market entry. However, scenario participants also considered economies of scale a 'market-problem', not being easily reconcilable with necessary principles of sustainability. Instead, in one scenario participants explicitly used a circular economy approach for sustainable microalgae value chains and thereby minimised the use of energy and resources needed.

The scenarios were formulated on the basis of current deficiencies in the European microalgae value chains. These hurdles are not new, and well discussed in the literature (see the introduction section and e.g. Rumin et al., 2020; Araújo et al., 2021; Verdelho Vieira et al., 2022). Since the critical analysis of the state-of-the-art provides the basis for changes, we will shortly outline the main points discussed in the scenarios:

- **Microalgae value chains are not yet sustainable**, as their side-streams are not well used, and their production requires a lot of energy, which is dependent from the locally available energy provision, which is largely fossil fuel-based and not renewable.
- **Microalgae are not well established at the market for end-users**, which might relate to their innate properties, their relatively high price in relation to their cost of production, and the insufficient communication structures between stakeholders of the microalgae value chain – national and European networks, producers, different food formulators for final products and consumers.
- **Workshop participants perceived inertial effects** as major reasons behind the current situation of microalgae production. Discussants stated that advocacy for microalgae needs a lot of perseverance and patience. The eating and consumption habits of end-users were considered as hard to change. In addition, the existing legal frameworks and political support of microalgae are perceived as weak. The workshop participants experienced resistance and a lack of interest of well-established big players in food production and reported that the openness for innovations, which are not profitable first and foremost, is rather low.
- **The current microalgae value chain is limited** as it heavily relies on research, development, experimenting and piloting due to significant knowledge gaps concerning practically all stakeholders along the value chain including researchers, producers and consumers. The research and development logic implicates that the chain still builds on individual, subsequent projects having a specific focus for a limited time. There are several knowledge deficits and gaps ranging from risks (health risks of consumption but also contamination risks in production) to potentials and usability of microalgae (more components could be used). Knowledge deficits and uncertainty makes production vulnerable and potentially expensive. Additionally, the workforce dealing with microalgae is highly specialised and therefore costly. Research and development funding is not sufficient to overcome the niche position of microalgae and to foster scaling up processes.

3.2 Main actor groups identified in the microalgae value chain

As a multi-stakeholder group created the material analysed, the stakeholder composition has notably shaped the co-created scenarios. The related framings of roles in the value chain and respective agency and responsibility have emerged as important lens of analysis for further investigation and resulted in three main actor groups:

1. Microalgae farmers and producers, as well as processors and researchers of microalgae-based technologies. We refer to them as 'the inner circle' due to their role as market stakeholders and key stakeholders of the value chain.
2. Actors shaping the larger political and economic conditions of the microalgae value chain, namely policy makers and

respective policies, funding programmes and institutions as well as large, well-established companies. In part, this group comprises market-stakeholders as well as non-market stakeholders. Despite members of this group being present in the workshop, they were largely perceived as external. Based on their role, we refer to this group as 'stakeholders setting the scene.'

3. Consumers, and thus the end-users of the microalgae-based food products. Since no consumer rights organisations were having the resources to join the workshop, this group was not well represented and constructed as 'others'. Due to their role, we refer to them as 'the leverage from outside'.

Since these group framings heavily influence the results drawn from the workshops, reported findings in the following section draw on these positioning and have to be read in the perspective of the group of microalgae farmers and producers, processors and researchers, the inner circle. A summarised version thereof can be found in Figure 2 and will be elaborated in more detail in the following sections.

3.3 The inner circle: Microalgae producers, processors and researchers

Workshop participants identified microalgae farmers, processors and researchers as the main focus point for action, which we called 'the inner circle'. The inner circle has expertise in microalgae and their value chain processes and is key for making the microalgae value chain sustainable. According to this group, consumers and non-market stakeholders should become more aware about the sector and push towards a growing sustainable microalgae value chain. Nevertheless, producers are the ones who are – according to the workshop participants – responsible and supposedly willing to produce in a sustainable way. However, they feel limited without the necessary dialogue along the value chain and the required support from others.

Microalgae producers wish for strong marketing campaigns and enough customers to raise their product from a niche to a commercial product in the first place. The small scale of the sector as well as unsolved technological questions related to the production and unknown health risks related to the consumption of microalgae cause uncertainties in the production process. To cut costs in the immensely expensive production process, producers and processors stress the need for a close collaboration with researchers, focusing on cost effective and energy-sufficient technologies as well as on optimizing techniques involved in purification and processing. More funding is needed to enable this kind of research.

In order to make the microalgae value chain more sustainable, circular economic processes are recommended. Doing so, the use of side streams and by-products from the food industries and other industrial sectors is key to reduce waste and resources to a minimum. For example, instead of using fresh water, microalgae can be cultivated in residual water from other food related industries, which might also decrease the need to use additional nutrients for the cultivation process (Ferreira de Oliveira and Bragotto, 2022; Verdelho Vieira et al., 2022). In order for microalgae value chains to becoming sustainable, the producers, processors and researchers argued for overcoming the currently dominating sectoral perspective, which tends to centre on single sectors, such as the food sector, only. A wider perspective, which pursues collaboration with different food sectors and – even more

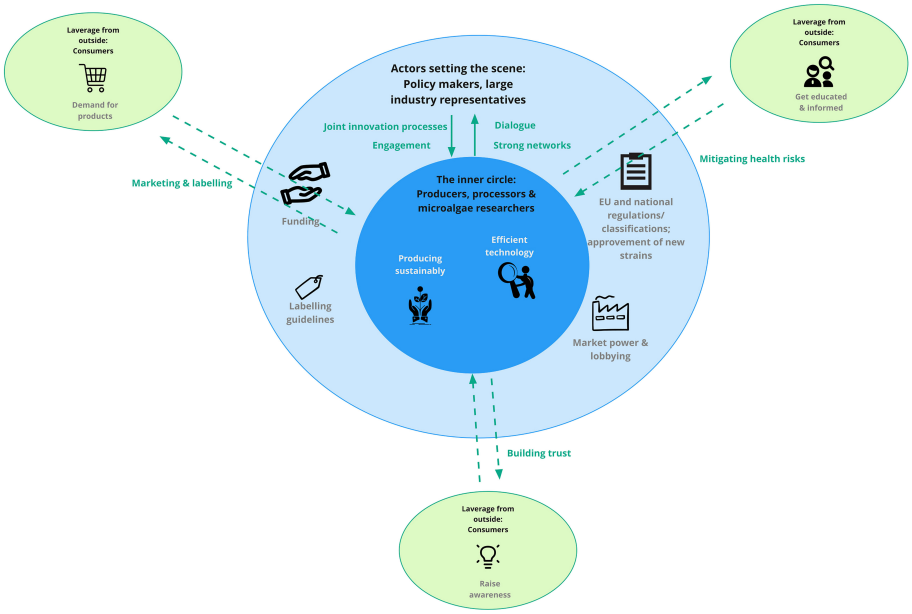

FIGURE 2
Microalgae value chain actor groups and their perceived roles across the scenarios, illustration by the authors using Miro and Iconfnder.

so – with different industrial segments to re-use as many resources and use as many microalgal components as possible, is called for. Thereby, not only proteins or fatty acids of microalgae but for example also other ingredients, such as their pigments or fibre can be used, decreasing the energy and resource input needed per ingredient, reducing the waste streams, and increasing the economic usability and valorisation. The inner circle, however, also opted for short microalgae supply chains, which involve only a limited number of intermediaries, in order to retain more agency over the ongoing production processes. According to the producers and processors, shorter supply chains, involving less steps of processing, decrease the footprint of the final product. In their perspective, short supply chains also render the end-products less expensive and therefore more affordable for a broad public.

In parts, producers and processors seem to see themselves in a rather passive waiting position. Research is considered key to provide the empirical basis to implement a sustainable microalgae value chain. The investment in research by the microalgae producers and processors themselves, however, was not addressed by the workshop participants. Instead, the microalgae researchers themselves consider their opportunities dependent on funding options and policy regulations specifically applying to the microalgae food sector such as the EU's Novel Food Regulation (European Parliament and European Council, 2015) as well as others (e.g. the ban of GMOs or the prohibited use of certain side-streams for food products).

Although microalgae producers and processors do have a lot of agency to shape the value chain and to work in a sustainable way themselves, they depend on a strong network with researchers and policy makers. Access to larger industries is often needed to reach a more relevant critical size of the sector for more security and minimized production risks. The desired collaboration with researchers and policy makers needs to be strengthened from national to European and international level. This cooperation is crucial to drive sustainable joint innovation processes and set the basis for a sustainable production, which can then be implemented by producers and processors.

3.4 Setting the scene: Policy makers and industry representatives

Policy makers responsible for respective policies, funding programmes and institutions as well as large, well-established industries strongly influence the structures, microalgae producers, processors and researchers are working in. At the same time, policy makers do have the power to regulate practices of small and large industrial players, to support profitable, but sustainable production. Most importantly, they are in the powerful position to do so, as they are responsible for the allocation of necessary financial means to make a difference.

While policy makers were present in the workshops, they were largely perceived as external. Discussions about the role of policy makers and large industries were therefore strongly shaped by the perspective of the inner circle.

The inner circle describes themselves as small in scale and short in resources. Therefore, these actors feel dependent on actors that are more powerful to set the scene. In their view, European policies and funding programmes need to acknowledge and support the microalgae industry as sustainable alternative and embrace their – recognized yet not endorsed – role in the realm of the European Green New Deal and its Blue Economy Strategy.

The role of European policy authorities is further seen as crucial when it comes to the approval of new microalgae strains for food use. Microalgae are considered part of the EU's Novel Food Regulation (European Parliament and European Council, 2015), which foresees specific procedures for market entry to guarantee food safety standards corresponding to the precautionary principle. Currently only a few microalgae strains are approved for food-products (Niccolai et al., 2019). New strains might offer potential for decreasing the use of resources needed, have better organolectic properties and higher nutrition values. However, they also bear unknown health risks for consumers. Policy makers are responsible for considering their approval with regard to consumer protection. In this vein, also the prohibition to use genetic modification for food production was discussed. While from a production side the use of genetically modified organisms might support production processes in microalgae cultivation and processing, EU policies follow the precautionary principle and ban the use of GMOs for food consumption. Without approved technologies and strains, producers stick to approved processes, as they are unable to invest the time and large financial resources needed to get new microalgae strains approved.

The inner circle also calls for policies to develop product-labelling guidelines better applicable to the microalgae sector, by e.g. making it compulsory to name included microalgae strains, but also back and visualise their sustainability in a trustworthy way for customers.

Policy makers are hence in the role to support social responsibility, sustainable and joint innovation processes alongside circular economy approaches. European policy frameworks are needed by the inner circle to foster sustainable networks of collaboration amongst the stakeholders of the microalgae value chain, and to ensure long-lasting financial support for the microalgae sector as sustainable market segment, which is unlikely to become the most profitable when only considered from an economic point of view and leaving considerations of sustainability out of sight. In this vein, the scenarios illustrated also the small producers' and processors' demand to regulate the practices of large industrial players, who do not produce in a sustainable way, but are merely interested in producing profitably, putting quantity over quality. Suggested using Miro and Iconfnder.and discussed measures were for example the adaptation of taxation policies.

In the same vein, the small-scale microalgae producers discuss the role of large industrial players active in the food segment ambiguously. Large industries are equally setting the scene for smaller scale producers. On the one hand, workshop participants criticised them for their profit-oriented practices, market power, and advocacy. On the other hand, they considered large industries

as important collaborators for these very aspects. The inner circle expects them to open up to the microalgae sector to help it grow and thereby reduce production costs, but also wanted them to adapt to sustainable standards, which were of high importance for the microalgae value chain stakeholders present in the workshops.

3.5 The leverage from outside: Consumers and end-users

Food and food production is key for society's survival. The way societies shape food systems is crucial for sustainable value chains. The inner circle, however, did not consider society as a large, but rather limited its view of civil society actors to their role of consumers.

Consumers and end-users' perspectives were hardly present in the workshop setting and constructed as 'others' by the workshop participants, who, however, do play a crucial role for sustainable futures of microalgae food-production. While not being directly integrated in the supply chain, consumers and end-users of microalgae food products were regarded as key for shifting microalgae products from a niche sector of healthy, vegan food supplements to mainstream dietary practices. This is why we have called them 'the leverage from outside'.

The inner circle needs responsible and aware consumers, who care about the environmental impact of their consumption practices. In order to reach consumers, and to create the demand necessary for more microalgae-based food products, the small-scale microalgae producers see marketing as key element, which can be used to reach out to end-users.

Workshop participants mainly addressed questions on informing consumers about microalgae and to influencing them to like and to buy the product. They see a need to inform end-users about the advantages of microalgae, their health benefits and their potential for contributing to a better environmental footprint. Advertisement across different media-platforms (TV, mass media & social-media) was equally mentioned alongside product tasting events with microalgae products in public and semi-public spaces such as supermarkets or schools.

Consumers do not only need to be aware about microalgae-based food products, but also recognise them, like them, know where to buy them, be able to afford them and know how and why to use them. In order to become an integral part of dietary practices, microalgae products must not become a product for elites only, but be accessible and affordable for a broad public. This, however, also requires that currently existing bottlenecks in the production processes are successfully addressed and overcome.

Consumers further need to be able to trust in microalgae products, their food safety and nutritional and environmental benefits. This trust cannot be created through marketing alone, but also needs to be sustained during the production process. EU food safety policies as well as labelling policies do equally play an important role here, as they need to provide the ground for trustworthy consumable and sustainable end products. In case these processes do not work out, microalgae producers risk losing vital actors – consumers as leverage from outside.

4 Discussion

Microalgae are an evolving field to produce sustainable macro- and micronutrients for food products in Europe with low environmental impact. A sustainable product, however, also relies on the sustainability of its value chain. Based on a multi-stakeholder process, we have analysed four scenarios on sustainable microalgae value chains for food products in Europe. Thereby, we have identified three distinctive actor groups with different agency for shaping the value chain. **The inner circle,** consisting of microalgae producers, processors and those researching microalgae technologies and applications, is responsible for shaping microalgae value chains in a sustainable way. This is a position unequivocally shared by all of the actor groups analysed in this paper. However, the inner circle cannot operate autonomously, but is dependent from **actors setting the scene**. Policy makers need to implement policies as well as standards in support of the sector. Large, well established industries do play an important double-edged role here, as their market power renders them to gatekeepers and needed allies. **Consumers** are crucial leverage points for the inner circle as their involvement, interest and demand can notably support the inner circle with their activities.

Our analysis unveiled a dominance of a supply chain perspective amongst the workshop participants, which does not consider customers being an active part of the chain. This perspective contrasts the literature arguing for the necessary involvement and participation of consumers for moulding a food value chain in a sustainable way (Petit et al., 2018; Lewandowski et al., 2019; Toussaint et al., 2022). According to these authors' perspective, all actor groups bear responsibility to shape the value chain in a sustainable manner. Similarly, also the global value chain framework urges to focus on the interlinkages between all actors of the value chain and points to the role of knowledgeable consumers and their significant agency for determining innovative trajectories for products (Gereffi et al., 2005). In the same vein, 'thickening' processes, and hence a strengthened integration of the involved firms in the value chain are the suggested policy to deepen the value added in the sector for thriving in a sustainable way (Kaplinsky and Morris, 2016). As most of the current shortcomings and limitations of the European microalgae sector are financial in nature, efforts to increase also the economic sustainability of the microalgae value chain are required (Grossmann et al., 2020). The uncertainties and risks related to the production and processing of microalgae need to be addressed in order for microalgae truly having the potential to support the food supply of the future in a sustainable manner (Kiesenhofer and Fluch, 2018).

Interestingly, corporate social responsibility (CSR) was not addressed in our workshops, even though many consider global supply and value chain research as a part of corporate social responsibility (Carter and Jennings, 2002; Kaplinsky and Morris, 2016). This lack might be related to the specific workshop focus on sustainable value chains and the emphasised inter-stakeholder dialogue, which might have shifted attention from company-internal to systemic dimensions. However, also internal processes and strategies firms employ to act in a responsible and sustainable

way might positively influence value chains as a whole (Kaplinsky and Morris, 2016; Gereffi, 2019). Similarly, stakeholders setting the scene, i.e. policy makers, responsible for funding and regulations and large industry representatives, bear responsibilities to shape market structures in a responsible and just way to enable holistically sustainable value chains. Literate consumers making conscious choices and demanding sustainable products are crucial for supporting a sustainable microalgae value chain in Europe. All of these processes can be regarded as co-depended, mutually enriching and possibly re-enforcing (Gereffi et al., 2005; Verdelho Vieira et al., 2022).

A dimension, which remained largely unaddressed in our scenarios, is social sustainability. Elements of sustainability relating to social aspects, such as for example, human rights and basic needs, anti-discrimination policies, access to education, employment conditions or labour rights were hardly integrated in any of the scenarios. While the workshop methodology was specifically designed to consider these social aspects (see Step 2 of Materials and Methods), participants did not seem to relate them to sustainability and as part of their responsibility for implementation. All of these aspects, however, require a 'joint and coordinated effort of all actors […] directly or indirectly involved along the value chain.' (Toussaint et al., 2022, 2493).

With this paper, we have delved into the roles of different actor groups for shaping the European microalgae value chain based on relevant literature and qualitative empirical results. Our findings suggest that it is key to identify all stakeholders and actors along the value chain and to strengthen the dialogue and collaboration among them. The niche sector of microalgae food products needs political support to get the necessary funding and build up the required networks. For making existing processes more sustainable, and to enable survival in capitalist market structures, companies need to be rooted in the food sector. Financial and technical uncertainties have to be minimized by the support of policy makers and funding agencies. Collaboration with large well-established industries can assist the rooting processes. At the current stage, the agency consumers and – even more so – civil society holds is underestimated in the microalgae-based food value chain. Their engagement and demand is key to render microalgae food products relevant and sustainable alternatives in the future. The collaboration of all actor groups is crucial to achieve socially and ecologically sustainable microalgal food value chains in Europe from the outset.

Data availability statement

The raw data supporting the conclusions of this article will be made available upon request, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Centre for Social Innovation Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

Author contributions

All authors contributed to data collection, analysis, the literature review as well as drafting the article. All authors approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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