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From Niches to Global Value Chains: The Role of Firms' Collaborative Strategies in the Bioeconomy

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ABSTRACT

The bioeconomy is expected to carry out the transition towards a bio-based economy thanks to the transformation of petrochemical and fossil fuel value chains. Nevertheless, bio-based innovations fail to overcome the hurdle of commercialisation and appropriation. This paper offers a renewed understanding of this problem by combining the niche-to-regime transition literature with the global value chain literature. The article hypothesises that to overcome the challenge of commercialisation and appropriation, bio-based innovations need to break out of their sociotechnical niches and integrate global value chains (GVCs). To achieve this, niche players and lead firms in GVCs need to collaborate together. Using the case of microalgae, we theorise a time-sensitive typology of collaborations according to the three phases mapped around innovation development from emergence to diffusion and commercialisation. This study highlights that the type of collaboration to adopt depends on the level of development of an innovation, suggesting that the study of collaborations as diffusion and commercial strategy deserves further attention in transition studies and GVCs literature.

JEL Classification: O31, O32, F23

1 | Introduction

The use of renewables is a key factor in the ecological transition, enabling us to reduce the use of fossil fuels while stimulating the development of environmental innovations that are conducive to the emergence of new activities. In this context, lead firms must identify how they can either simply change raw materials or transform their offer, and start-ups need to find the right positioning for their innovations (Befort 2021).

From this perspective, the bioeconomy holds the promise of transitioning to a sustainable production system by converting renewable biomass through new technologies into useful products and materials instead of relying on petrochemicals (Vivien et al. 2019). Despite the large investments and the advances in the technological processes, the 2019 European Commission report mentions that only one-third of 107 bio-based innovations are close to full availability on the market, more than 20 products are at the pilot level while the rest remain in the applied research stage (EC 2019). The inexistence of markets to support the development of these bio-based innovations (Befort 2020, 2023; Giurca and Späth 2017; Wydra et al. 2021), the challenges in their appropriation and coordination within value chains due to the rise of new actors and lack of infrastructure incompatibility (Bröring and Vanacker 2022) is trapping bio-based innovation in niches for longer period of times.

This state of 'being stuck' facing bio-based innovation can be explained by a misalignment between sociotechnical niches and the sociotechnical regime. In this article, we use the concept of niche in the sense of *sustainability transition studies*. The niche–regime interaction literature studies the process of formation of innovations and the networks that support them (Köhler, Turnheim, and Hodson 2020; Vihemäki, Toppinen, and Toivonen 2020; Smith and Raven 2012). It assumes a systematic opposition between incumbents and new entrants (Altunay and Bergek 2023) where incumbents are responsible for blocking the emergence of innovations (e.g., bio-based products) (Block, Rennings, and Bröring 2023). However, recent literature shows that incumbents can develop niches and actively engage in market-shaping processes (Berggren, Magnusson, and Sushandoyo 2015; Magnusson and Werner 2023). Moreover, this literature overlooks the business side of the transition from niche to regimes. Finally, it does not deal directly with the selection and adoption of these sustainable innovations within value chains that appropriate and commercialise them, which makes it difficult to use the lens of this literature alone to understand the lack of bio-based innovation commercial development.

To overcome the limitation of niche–regime interaction literature, we mobilise the literature on global value chain (GVC). This concept allows for the exploration of innovation success, meaning its capacity to be selected and appropriated by suppliers and customers within the value chain (Bathelty and Cohendet 2014; Pavitt 1998; Block, Rennings, and Bröring 2023) exiting the niche. The GVC literature studies sustainable innovation as an upgrading process where innovation production and appropriation occur through labour division resulting from complex cooperation strategies to constitute markets and create segments of value chains (Ponte 2014; Hernandez-Aguilera et al. 2018). These collaborations are studied by mobilising the strategic management and innovation studies literature (Langlois 2003). This literature emphasises that to develop innovations in dynamic environments with strong competitive pressure, firms engage in collaborative activities to share and create resources because none of these actors alone has the resources to develop their production. This literature enables us to identify the diversity of forms of cooperation for innovations' development and integration in the division of labour (Pavitt 1998).

We empirically investigate this contribution in the bioeconomy context, using microalgae as a case study. Microalgae constitute a sociotechnical niche with applications in food, feed, agriculture, energy, cosmetics, pharmaceuticals, wastewater treatment and nutraceuticals. We follow two key innovative options giving rise to two contrasted cycles of promises that emerged at the same time (biofuel and high-value-added products). In the two cycles, we explore the various forms of collaborations between incumbents and microalgae firms in the main and adjacent VC at the various phases of transition to help innovation exit the niche and reach the markets.

This paper contributes to the literature by hypothesising that the exit of innovation from the niche 'becoming unstuck' lies in its capacity to integrate GVC through collaborations, linking a horizontal approach of collaborations that form within niches with a vertical approach of entering new collaborations along the value chain (Birch 2008; MacKinnon et al. 2009). The findings indicate that collaborations solve coordination issues around the technical feasibility of a process and its commercial development (Befort 2020; Block, Rennings, and Bröring 2023; Coppola, Vollero, and Siano 2023). The type of collaboration[1] may change over time depending on the actors' position in the value chains, actors' resources and gaps or needs in competencies (Stadtler and Lin 2017) and the development stage of the technology. Finally, these collaborations represent an opportunity for actors to upgrade within their value chain and adjacent value chains or to contribute to new value chain development.

The remainder of the paper is organised as follows. The first section links the transition studies and GVC literature highlighting strategic alliances as a niche exit strategy. In the second section, we focus on the case of microalgae and the methodology used. The third section explores the role of alliances between niches and value chain actors in microalgae technologies. The fourth section discusses the results by theorising the phases of niche exit, the function of collaboration in each phase and the actors involved. Fifth, we conclude.

2 | Conceptual Framework

In this section, we argue that collaboration is an organisational form and a key strategy enabling innovation to exit the niche to contribute to transformative changes. We use the GVC literature to argue that collaboration along the value chains is crucial for making the transition through restructuring production activities by transforming or birthing new value chains and providing both a horizontal and vertical view of actors' interactions. We then mobilise the strategic management and innovation studies literature to identify the functions and types of collaborations firms could conclude to develop new businesses and connect to adjacent value chains.

2.1 | Sociotechnical Niches in Sustainability Transition Literature

Sustainable radical innovations emerge in the periphery of the current sociotechnical system based on the protagonists' expectations of future performance and functionality of the technology to attract sponsorships (Geels and Raven 2006). The acceptance of these promises leads to actual projects (Befort 2020) with protected spaces developed around them to shelter the innovation from selection criteria and mainstream competition (Kemp, Schot, and Hoogma 1998; Raven 2006) where actors try out (Smith and Raven 2012; Turnheim and Geels 2019), shield, nurture and empower their innovation (Smith and Raven 2012).

These innovations are carried out by new entrants and incumbents (Berggren, Magnusson, and Sushandoyo 2015; Turnheim and Geels 2019). To succeed, actors must overcome technological, economic, social, cognitive and regulatory lock-ins and challenges (Geels 2019) around the existing system. Innovation failure can emanate from (1) ambiguous formulation of expectations leading to divergent visions between actors; (2) network fragmentation; (3) narrowed learning processes oriented to the technical aspect of the innovation only (Geels and Raven 2006); (4) uncertainties about user preferences, market development and profitability; and (5) lack of cultural legitimacy and social acceptance (Geels 2019). A niche could face temporal blockage when promises are not satisfied due to commercialisation and demand challenges, resulting in disappointment (Befort 2021; Ruef and Markard 2010), leading to new promise formulation (Geels and Raven 2006).

To overcome the various challenges facing the emergence of radical innovation, actors build networks (Kemp, Schot, and Hoogma 1998; van der Laak, Raven, and Verbong 2007). Moreover, social interaction between actors (inside and outside the niche) contributes to shaping trajectories and links agencies to the enactment of new trajectories or maintenance of existing ones (de Haan and Rotmans 2018; Geels 2004). This focus on social interaction is broad in scope and encompasses different organisational forms of interactions (e.g., collaboration, alliances and coalition strategies) (Geels et al. 2016) and brings together actors from science, policy, civil society and businesses as a governance strategy to facilitate the transition (Köhler et al. 2019). This literature, however, says little about collaboration as a key strategy for bringing about a sociotechnical transition.

Exceptions include Hess (2016, 2019), who builds a coalition advocacy framework to explore the coalition's role in building legitimacy, lobbying for resources, engaging in political debates and influencing public opinion. However, the author did not account for innovation production activities and appropriation, as coalitions have a socio-political focus and highlight tensions between niche and regime actors. Altunay and Bergek (2023) explore technology-related, institution-related and network-related interactions between niche and regime by studying collaborations. However, they do not discuss collaboration conceptually as a key organisational form. Instead, they use it as an empirical tool to study niche–regime interaction leading to a limited view of collaborations despite the many types that exist along the innovation trajectory. Finally, they ignore the evolution of these interactions based on the success or the failure of the innovation and their impact on production activities restructuring.

2.2 | Global Value Chain (GVC)

While the analysis of innovation niches focuses mainly on new entrants, the analysis by value chains invites us to consider the dynamics of exiting the niche from the perspective of incumbents or lead firms. More specifically, sustainable innovation is analysed as 'environmental upgrading', which De Marchi et al. (2013, 65) define as 'the process by which economic actors move towards a production system that avoids or reduces environmental damage from their products, processes or managerial systems'.

This definition invites us to consider the organisational processes of appropriating innovations in the international division of labour where lead users play a coordinating role in value chains. Depending on the position of these actors within the value chains, they will induce organisational, product or process improvements. The emblematic case of the furniture value chain shows that actors must combine these three types of improvements to be able to produce environmental innovations (De Marchi, Di Maria, and Ponte 2013). The literature on the upgrading of GVC highlights that firms can innovate either to improve their sustainability within a value chain, to move up or down the value chain or to enter new value chains (Gereffi 2019).

To manage the transformation and greening of their GVC while maintaining control over value creation, lead firms must successfully coordinate activities. The GVC literature (Kano, Tsang, and Yeung 2020) shows that hybrid forms (joint venture [JV], R&D cooperation, international collaborations, etc.) constitute important ways of controlling value chain activities. For instance, vertical (top-down) environmental upgrading processes can be either standard driven or mentor driven (Krishnan, De Marchi, and Ponte 2023). Mentor driven processes are more cooperative and related to the acquisition and exchange of specialised expertise and skills. In these cases, lead firms either co-invest with suppliers in new environmental practices or collaborate with them to develop innovations. More generally, lead firms can contribute to upgrading the GVC by implementing collaborative agreements, long-term formal interactions, and even international JVs with suppliers especially when the creation, transfer, and recombination of specialised knowledge, or complex transactions, are at stake (Kano, Tsang, and Yeung 2020).

While niche players can promise performance levels on their products, studies on promise cycles show that these evolve according to the disappointments that players encounter (Befort 2021). These disappointments result particularly from the encounter between the promised functionalities of products and the product specifications expected by the actors in the value chains. Therefore, after the early stages of development within the niche, the formation of partnerships in complex value chains makes it possible for niche actors to develop learning from the incumbents and for the incumbents to identify how they could appropriate and put into production the innovations developed by the niche actors.

The literature on GVCs highlights the need for niche actors to fit into the division of labour and recognises the role of inter-organisational collaborative arrangements to upgrade GVCs by increasing innovation capabilities along the chain to develop innovations. However, this literature does not specifically address the form of cooperative arrangements needed to develop sustainable innovations and GVCs. Neither does it consider interorganisation collaborations as a flexible means to explore or develop new or adjacent value chains to foster the commercialisation and diffusion of innovations.

2.3 | Roles and Types of Interorganisation Collaboration

The literature in strategic management and innovation studies suggests that innovation is central to most inter-organisation collaborative strategies. It focuses primarily on high-tech firms facing rapid technological change and turbulent environments and aiming at maintain their competitive advantage or leading new markets. More recently, collaborations have been considered as strategies for helping companies to face environmental challenges by developing complex green innovations (De Marchi, Molina-Morales, and Martínez-Cháfer 2022).

Firms establish collaborations to share innovation-related costs and risks (from R&D to commercialisation), achieve economies of scale in R&D, agree on common standards, combine complementary knowledge to create value and explore new technological options (Matt, Robin, and Wolff 2012). The literature distinguishes between different types of collaborations (Belderbos et al. 2018): with universities or public research organisations (PROs), horizontal and vertical collaborations. Each type of collaboration plays a specific role or function for companies and might enable them to upgrade within value chains, integrate new ones or contribute to the development of new ones.

Firms collaborate with universities and PROs to access new and state-of-the-art knowledge to generate new ideas for industrial R&D and innovations (Cohen, Nelson, and Walsh 2002). The link between the type of innovation carried out by firms and their collaboration with universities is unclear. According to Mohnen and Hoareau (2003), the most innovative firms in new products collaborate more with PROs. Others find a positive relationship between process innovation and university cooperation. The extent to which firms collaborate with PROs depends on their size, absorptive capacity and degree of openness (Fontana, Geuna, and Matt 2006). De Marchi, Molina-Morales, and Martínez-Cháfer (2022) show that to develop green innovations, firms should cooperate with universities and PROs because they are generating advanced solutions and knowledge. These authors also stress that collaborating jointly with universities and suppliers has a positive effect on green innovation development that might contribute to the environmental upgrading of the GVC.

Horizontal collaborations take place between competing firms. Horizontal R&D alliances focus on the pre-competitive development of future state-of-the-art technologies. They are better suited to develop innovations in non-core domains, securing future competitive advantage. R&D horizontal cooperation has a positive effect on the generation of new-to-the-market products (Belderbos, Carree, and Lokshin 2004). Coopetition (Corbo et al. 2023) between incumbents aims at the standardisation of existing solutions or the development of innovations. These horizontal collaborations cope with trade-offs between opportunism and justice, free riding and sharing and trust and conflict. Technological coopetition exhibits a high termination rate because of appropriability and protection issues. Coopetition between incumbents and disruptive new entrants enables incumbents to access lacking technological know-how and new entrants to survive and prosper through the access of complementary assets (Corbo et al. 2023). Incumbents tend to cooperate with new entrants when they face a core-knowledge discontinuity and when the appropriability regime of the industry is strong (Cozzolino and Rothaermel 2018). This type of strategy might enable the lead firm to keep its dominant position in the value chain and the new entrants (start-ups or niche actors) to integrate an existing value chain.

Vertical collaborations (Zahoor et al. 2022) can be established with actors located upstream (suppliers) and/or downstream in the value chain (customers and distributors). Collaboration along the value chain facilitates access to knowledge, resources and skills necessary for the successful development of innovation (Birch 2008).

Upstream collaborations are often exploratory, enabling the generation of new ideas to develop new products, processes and services. Downstream alliances are suited for exploiting knowledge in regulatory issues, marketing and production activities. Commercial and marketing agreements facilitate the commercialisation and distribution of products and services and thus their upscaling. Downstream collaboration is crucial to match buyers' needs and expectations and to avoid losing its position in the value chain or abandoning the innovation (De Marchi et al. 2019; De Marchi, Di Maria, and Micelli 2013; Poulsen, Ponte, and Sornn-Friese 2018). For De Marchi, Molina-Morales, and Martínez-Cháfer (2022), the development of highly performant green innovations requires collaborating jointly with suppliers and customers.

From a dynamic perspective, partners that experience successful collaborations generating interactive learning and collective assets might have incentives to continue their relationship. (Matt, Tocco, and Wolff 2013). They might agree upon a higher degree of commitment by co-investing more heavily in R&D (joint research agreement and co-development agreements), in production facilities or by strengthening the governance structure (JV). Figure 1 offers a synthetic view of the theoretical framework of the paper. In this paper, we hypothesise that these different types of collaboration have a role to play in the development of the niche and, more importantly, at the boundary of the niche and beyond it. Their role will evolve along the transition pathway. Some types of collaboration will be relevant for developing the niche (R&D collaboration with universities), while others will be more suited at the boundary and beyond the niche (horizontal and vertical collaborations). We argue that in transition periods, firms (new entrants and incumbents) have incentives to exit their value chains to explore new markets in existing adjacent value chains or by developing new ones. Collaborations constitute a flexible means to explore these new options for value creation.

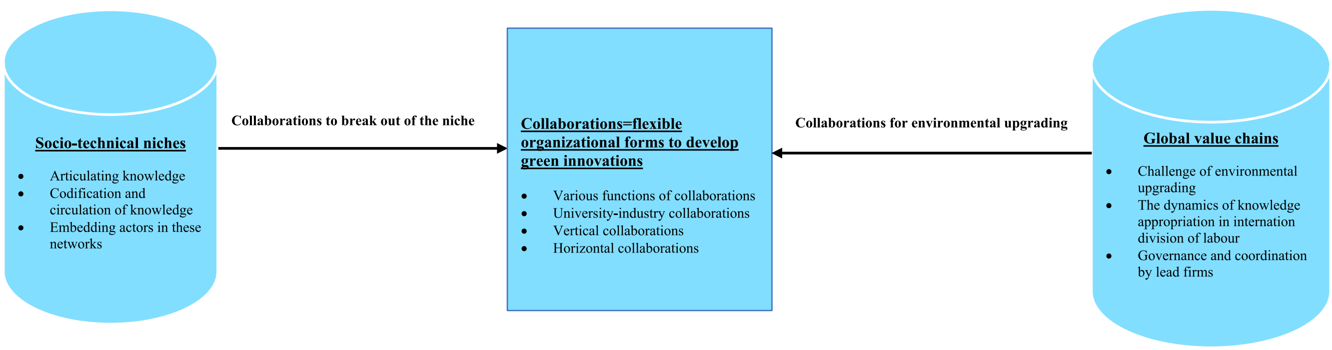

FIGURE 1 | Summary of the theoretical framework.

3 | Methodology

3.1 | Case Study Selection

We choose microalgae as a case study to answer our question: How do niche actors in the bioeconomy sectors mobilise value chain links to exit the microalgae niche? Bioeconomy is driven by the growing necessity to change existing production systems (Staffas, Gustavsson, and Mccormick 2013) by searching for and using new biomass and technologies to substitute non-renewable resources and develop products with the same or new functionalities as their oil-based counterparts (Befort 2021). Two strains of microalgae (Spirulina and Chlorella) represent 72% of the market in 2021 as illustrated by Figure 2. The global microalgae market is expected to increase from 1389.06 million in 2020 to 2299.18 million USD in 2028 (Data Bridge Market Research 2021). Figure 3 shows the most prominent actors in the microalgae sector as of 2021. This information provides an understanding of the considerable size and main players of microalgae market in 2021.

We consider the production and use of microalgae as a niche, that is, as a protected space that enables the exploration of technological opportunities and innovation options. Microalgae are a promising biomass used in its entirety, limiting waste and promoting circularity in the production systems to develop biofuels, biochemicals and high-value-added products in biorefineries using various conversion technologies, closing the production loop (Bauer 2018; Ubando, Felix, and Chen 2020). They are also being explored for bioremediation and biomonitoring activities (Araújo et al. 2021), wastewater treatment and clean-up of flue gases (Vieira de Mendonça et al. 2021).

This multiplicity of products developed links various sectors, industries and production systems previously distinct such as food, feed, agriculture, energy, cosmetics, pharmaceuticals and

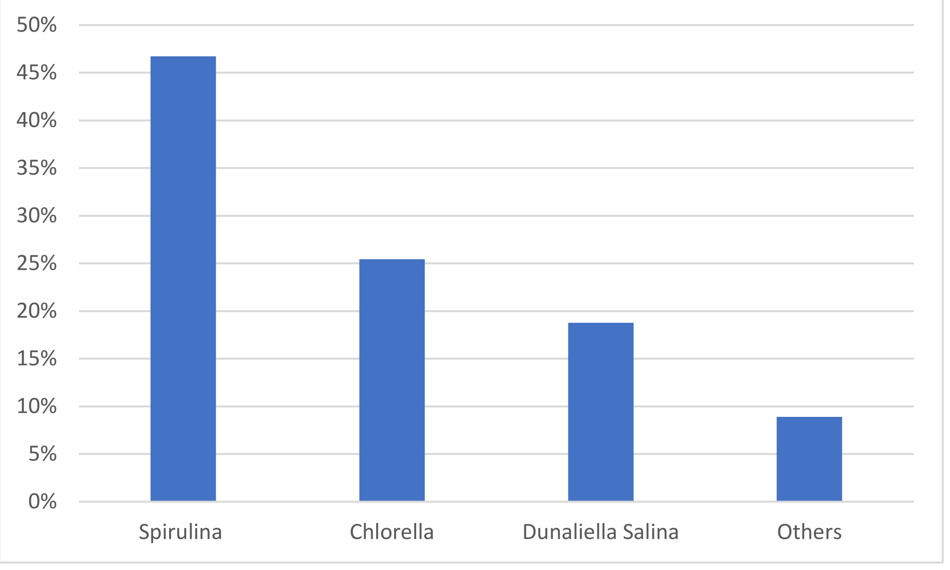

FIGURE 2 | Microalgae market share in percentage based on strain in 2021. *Source:* Data Bridge Market Research (2021).

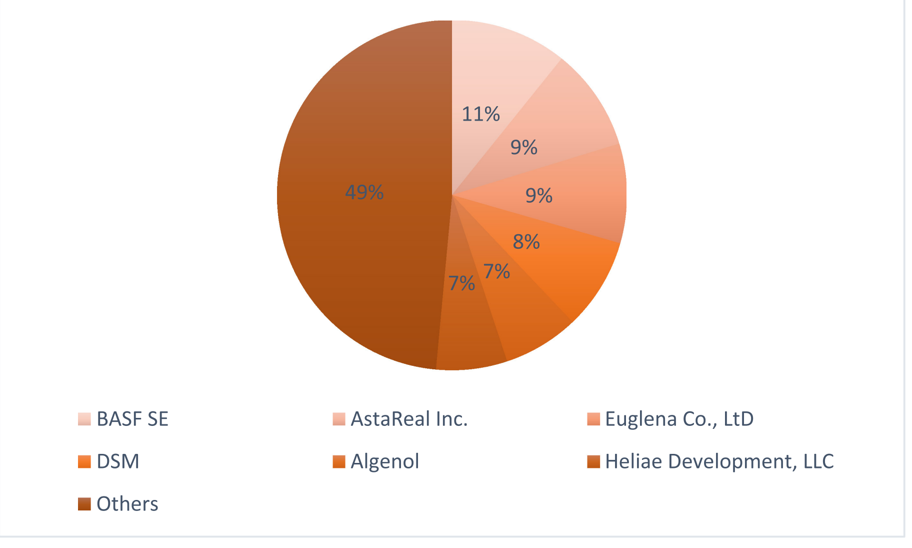

FIGURE 3 | The market share distribution among microalgae firms in 2021. *Source:* Data Bridge Market Research (2021).

nutraceuticals (Fernández et al. 2021), in a new way, they rely on the same biomass (Carraresi, Berg, and Bröring 2018). Thanks to versatility in applications (Rhee et al. 2021) and suitability to grow in different conditions, it became a promising avenue for developing new processes and products to mitigate, in an integrated manner, different environmental issues (Vieira de Mendonça et al. 2021) (see Figure 4 for a representation of the microalgae value chain).

3.2 | Data Collection

To gather information about the timeline of the promise cycle and important dates and trends, we first start by compiling the data from the publication collected from SCOPUS and patents from PATSTAT. We complement this data with information collected from market research, project data, firms' reports and academic publications where the purpose is to identify actors and gain information about their date of entry, market segments, products developed, their projects and collaborations with other actors and positions in the value chain. We break down the data collection strategy by the different chronological phases of the promise cycle: (1) knowledge accumulation and niche emergence, (2) the hype with the promise formation and (3) disappointment and survival. First, we gather data from secondary literature and from patent datasets for the period (nineteenth century to 2000) through an online search and from PATSTAT to learn about the early initiative of niche formation and knowledge accumulation, the first attempts of industrial exploration and the most active and innovative actors in this period and their collaborative activities. Second, we use market research, project datasets such as the CORDIS data for European firms, firms' reports and academic publications for the period 2002–2015 to study the promise formulation process and to identify the type of collaboration implemented between actors in different market segment and different position along the value chain. Finally, for the period 2011–2021, we use the data collected in Stages 1 and 2 to investigate whether or not firms are still on the market during the third period. The purpose is to explore the outcomes of cooperation established in the previous period marking the disappointment and survival stage and the development of new collaborations in the survival phase. Table 1 and Figure 7 summarise the data mobilised for this study and the data analysis process.

3.3 | Data Analysis

We adopt a single case study approach to conduct an in-depth analysis of the microalgae case (Thomas 2021; Yin 2008). We reconstruct the long-term development trajectory of the microalgae by intertwining our theoretical approach with the empirical evidence (Eisenhardt and Graebner 2007). To analyse the data, we

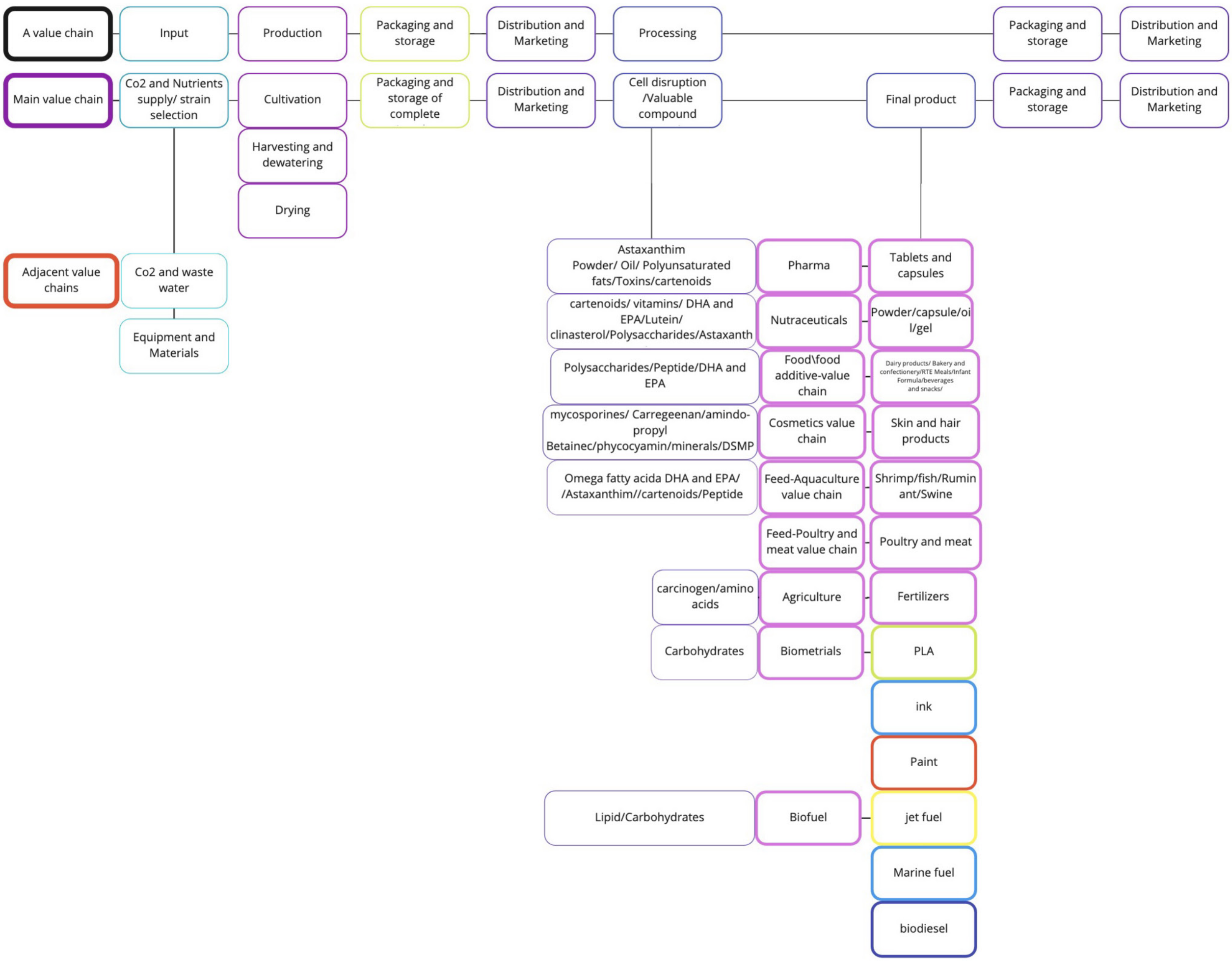

FIGURE 4 | The microalgae value chain.

TABLE 1 | Data sources and type.

Data type	Period	Source and purpose
Patent data	1950–1995	• Internet research to identify the patent application by scientists and the patent filed by industrial actors. • The online search yielded 35 patents. These patents are used to identify the first actors and their first concrete contribution to the field.
	1995–2016	• Using data from PATSTAT and secondary literature and reports. • The number of patents filed identified in this period is 8118. • The purpose is to identify the general trend in patent filing in microalgae. This analysis will also enable us to determine the important dates in the promise cycle and identify the main promises constructed during this cycle. • The PATSTAT data used are illustrated in Figure 5, which shows the trend of patent applications accelerating from 2002 and slowdown from 2015. Information about patents from 2017 forward is collected from secondary literature.
	2017–2021	• We rely on information from secondary literature (research papers and reports). • The aim is to identify the current state of the microalgae after the end of the promise cycle and identify if actors are formulating a new promise and a new cycle, the main applications of this new promise and actors actively engaged in generating knowledge for the new promise.
Firms	1970–2020	• To identify firms using (1) a market analysis report of the microalgae sector, (2) patent data by choosing the top 20 firms with the most patents filed and (3) online reports by organisations such as WIPO. • The total number of firms studied is 75 firms. We took a deep dive into their business strategy, their targeted market segment and product development. We also based the analysis on the reports and newsletters published by the firms. • We also traced firms from the date of entry to 2021 to explore if firms survived or were shut down as a result of the promise disappointment. • The analysis is also interested in the collaboration and the alliances built between the different firms and how the actors constructed links along different value chains.
Publication	1995–2017	• We compile data from Scopus. • To trace the promise cycle by following the general trend of publications. • The data collected from Scopus are mapped to trace the trend of publication in Figure 6.
Projects	1980–2021	• We access the online CORDIS EU database and online reports published by the US Department of Energy • We collected 833 projects funded by the European Commission to map the different types of alliances built between the different types of firms based on their position in the value chain. • For the United States, we find the information in reports, grey literature and firms' newsletters. • This was also complemented by an internet search to identify additional collaborations between firms. • We compile our list of collaborations based on the previous data where we also follow the outcome of the collaboration (failed or succeeded).

develop a multilayered analysis. First, patents, publications and project data are classified to build a timeline of microalgae niche emergence, niche expansion by promise formulation and consolidation, disappointments and recovery phase. Then, we build a second layer where we identify the political, economic and societal factors contributing to the emergence of the niche to investigate the enabling factors and the lock-ins that might trap the innovation inside its protected space. In the two first layers, we rely on historical events analysis as a method, which is a fine-grained analysis that dives into details to gauge theoretical implications from empirical observations (Langley 1999). The historical event analysis equips us to characterise the promises cycle.

In the third layer, we mobilise a dynamic value chain analysis to differentiate between the value chain segments targeted by niche actors using the value added by firms to the product development process (Gereffi and Fernandez-Stark 2011). In this layer, we privilege project and firm data to explore firms' business strategies and positions in the value chain to understand how firms' positions in the value chain evolve and change over time following changes on the niche level. We do so by matching firms' supply with existing or future demand for their product. The value chain lens adds to the historical analysis by focusing on the linkages developed by actors to diffuse and mass market their innovations.

The final layer of the analysis mobilises all information collected on previous layers to study the implication of niche emergence and evolution on the overall value chain structure. This enables us to identify the different strategies that a niche can follow to surpass the boundaries and to shed light on the complex process by which innovation comes to exit the niche. The combination of these four layers makes it possible to restore the richness of the case studied, while guaranteeing triangulation between the data (Yin 2008).

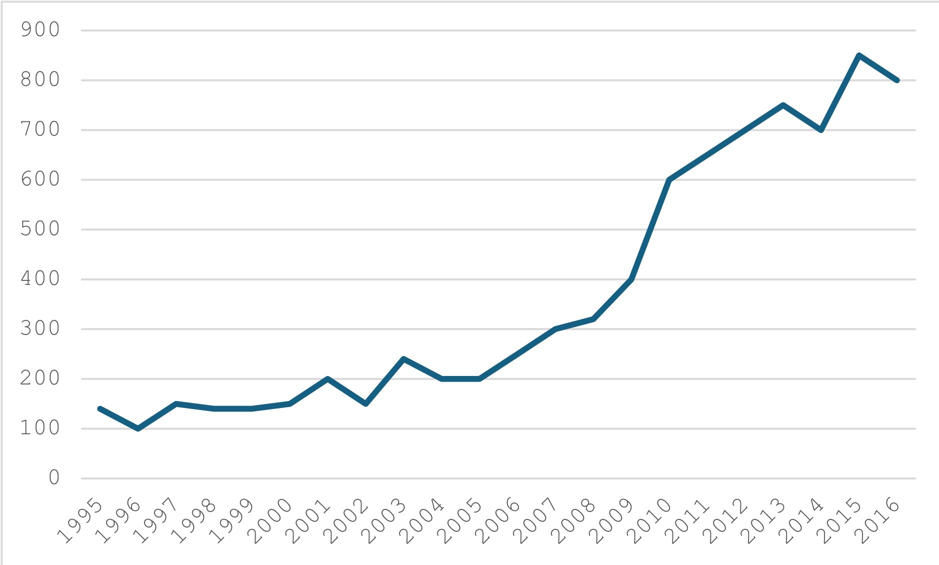

FIGURE 5 | Numbers of patent applications from PATSTAT between 1995 and 2016.

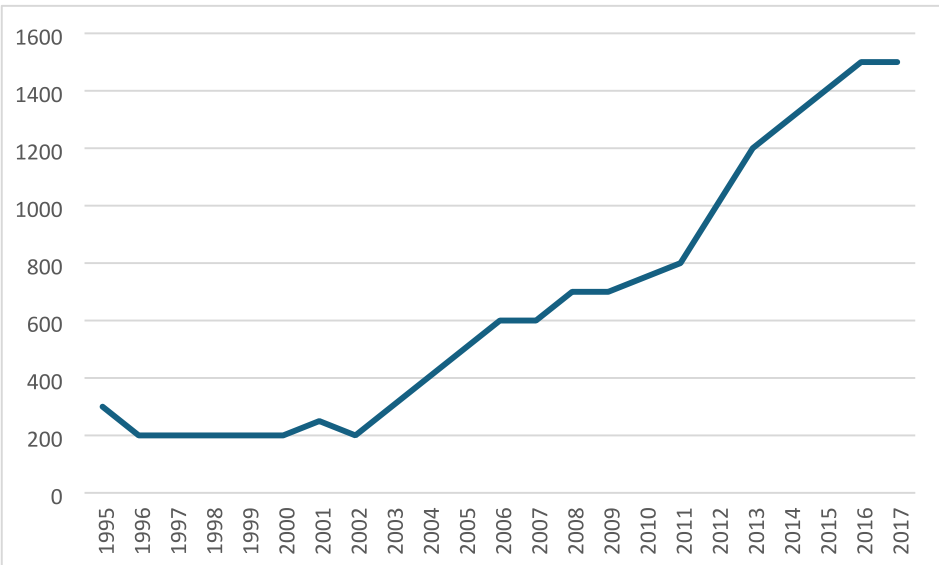

FIGURE 6 | Number of scientific publications about microalgae from Scopus between 1995 and 2017.

4 | Results

This section presents the results by historical period. A summary diagram (Figure 8) provides an overview.

4.1 | From the 19th Century to 1975

4.1.1 | Discovery of Algae and Niche Formation (1889–1950)

Algal research started in Japan in 1889 and crystallised in the 1920s (Coaldrake 2021). The Second World War was the catalyst for research in microalgae to secure lipid sources for fuel and food (Burlew 1953; Coaldrake 2021). In parallel, algal research in the 1940s gained momentum in the United States thanks to scientists at the Carnegie Institution of Washington (Burlew 1953). In 1943, Carnegie scientists focused on producing an antibiotic, chlorellin, from *Chlorella*, but the results were inconclusive. After the war, algal research was oriented to fuel and food security as a post-war priority leading to the first patent filled in 1950 and granted in 1953 about the cultivation methods of microalgae (Carnegie Institution of Washington 1950) and its commercial value. This patent (cf. Figure 8) marks the start of microalgae trajectory and niche construction. It led to the cultivation pilot for chlorella between 1948 and 1950 in collaboration between Japanese researchers and the Stanford Research Institute.

4.1.2 | Knowledge Base Expansion (1950–1975)

In the 1950s, disconnected efforts established their first connection in the Algal Mass Culture Symposium in 1952

FIGURE 7 | A schematic illustration of the research procedure for the case study of microalgae niche.

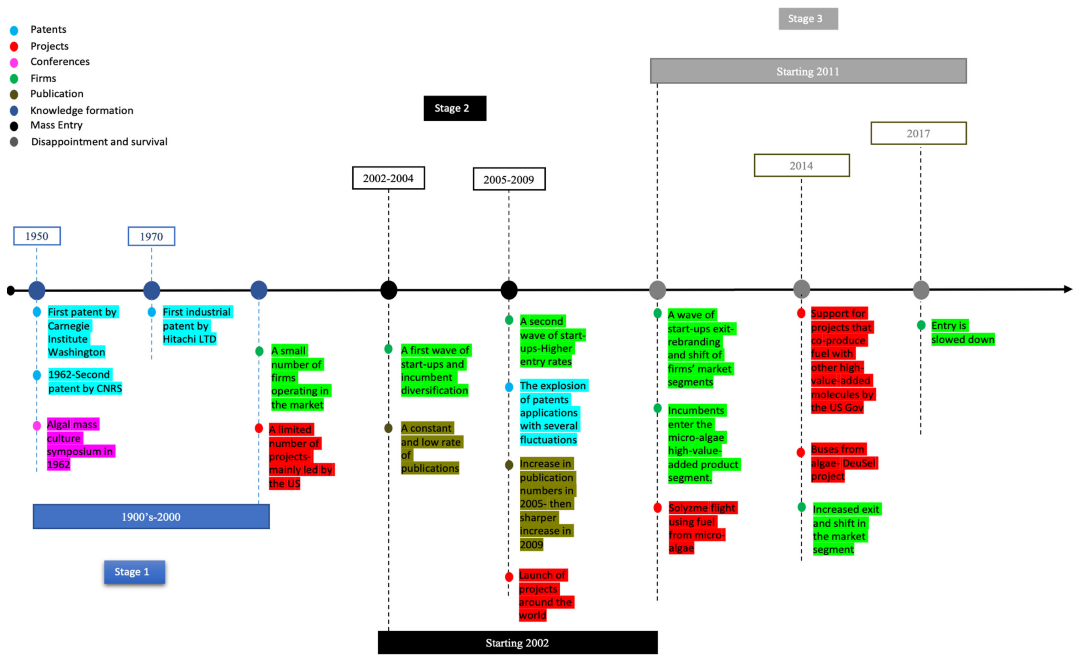

FIGURE 8 | Microalgae development timeline.

(Borowitzka 2013) (cf. Figure 8), leading to the development of various technologies of microalgae mass cultivation (e.g., open ponds and photobioreactors). The interest in microalgae as an energy source was also recorded in the 1950s (Sheehan et al. 1978) by Meier, who proposed the production of methane gas from the carbohydrate fraction cells in algae. Oswald and Golueke (1960) developed this idea by conducting a techno-economic engineering analysis of microalgae to produce methane gas.

A few years later, algae received international attention. The International Association of Applied Microbiology claimed Spirulina as a 'wonderful future food source' (Habib and Ahsan 2008). In 1974, the United Nations World Food Conference considered Spirulina as the new weapon to fight malnutrition (García, de Vicente, and Galán 2017). In 1973, the oil embargo and the slowed innovation efforts in chemistry motivated the search for alternative energy sources, especially from algal lipids. Also, 1970 and 1975 mark the two patents filed by Hitachi Ltd. and Chlorella Industry Co. Ltd., respectively, an important step to include industrial actors (cf. Figure 8).

4.1.3 | Industrial Exploration (1976–2001)

4.1.3.1 | Exploration by Chemical Industry Giants (1976–1990). The increase in fossil fuel prices, President Carter's famous energy speech about the decreased fossil fuel reserves and the progress in plant genetic engineering were some triggers to the industrial exploration of microalgae. Additionally, in 1978, the Department of Energy (DoE) in the United States launched the Aquatic Species Program, with a 25MUS$ budget, yielding scientific advances in algal strain isolation, characterisation, genetic engineering, biochemistry, physiology and culture (Hu et al. 2008). The European Framework Programmes also dedicated projects to microalgae as early as 1984. Moreover, many chemistry firms were looking for new biomass rich in carbon compounds to recover the glorious years of the chemical industry after the slowdown in innovation mid-1970s to produce bioproducts such as polysaccharides, lipids, pigments, vitamins, antioxidants and high-value-added molecules. Companies like Bayer AG, DSM, Du Pont and BASF started filling patents in microalgae in the second half of the 1970s and the 1980s. Firms positioned themselves strategically in different market segments. The first patent filed by DSM explored algal strains with high concentrations of omega-3 for the production of docosahexaenoic acid (DHA), an omega-3 fatty acid. At the same time, BASF and Dupont used microalgae for biofuel and substitution of petrochemical-based products.

4.1.3.2 | Materialisation of Incumbents' Efforts and New Entrants (1990–2001). The multitude of applications that microalgae were promising paved the way for new entrants. Incumbents' interests led to the creation of subsidiaries devoted to microalgae, such as EID Parry with Parry nutraceuticals; Fuji chemicals created AstaReal. Simultaneously, new biotech firms emerged in the 1990s, centring their business strategy around specific algal strains that can be mobilised to develop particular applications. These differentiated business decisions indicate that firms think about which market segment and value chain to target by deciding the type of product produced (e.g., algal strain, equipment, extracted molecules and final products).

Some firms focused on cultivating microalgae, drying and extracting molecules sold for applications in nutraceuticals, skincare and others. They also produce ready-to-use products. Examples include AstaReal, which specialises in astaxanthin from *Haematococcus pluvialis*, for pet feed, livestock, aquaculture and horses. The astaxanthin is also sold to external firms (such as Now) for applications in health and skin care. Other firms only cultivate and sell microalgae for direct consumers. Australian Spirulina cultivates Spirulina and produces powder and tablets for human consumption, while a different group of firms supply equipment and machinery for algae cultivation, such as Subitec, a producer of photobioreactors. The last group of firms grows for fuel, such as green fuel technology. This phase concludes the first stage of the microalgae trajectory of knowledge formation and the early effort of niche construction (Figure 8).

4.2 | From 2002 to 2015—The Formation of a Strong Promise

4.2.1 | Biofuel Promise Network (2002–2015)

In the 2002–2015 period, microalgae for biofuel received substantial attention triggering the hype stage in the promise cycle. Algal fuel was supposed to be a third-generation alternative biofuel. Firms were built on a bundle of promises. The first is finding the right strain and cheaply mass-producing it. The second is developing the right conversion techniques to scale up algal fuel quickly at prices competitive with fossil fuel. The third is using nonarable land, wastewater and CO_2 emissions (Bošnjaković and Sinaga 2020; Pienkos, Laurens, and Aden 2011).

An extensive network was constructed around algal fuel. Associations advocated for algal fuel, such as the International Air Transport Association, which led discussions, published reports and organised conferences about aviation algal fuels. The purpose of conferences, such as Alga Europe and AlgalBBB2023, was to catalyse and foster alliance-building between actors to facilitate knowledge exchange and project implementation.

Microalgae received public stimulus funding from the European Commission and DoE where industrials and academics carried out projects to develop the technology needed to increase algal lipid production for fuel achieving climate and energy targets by 2020. Famous examples include the Framework Programmes and Horizon 2020. In the context of the Security Act of 2007 in the United States (IEA Bioenergy 2017) and the DoE 'top 10' chemical opportunities published in 2004 (Bozell and Petersen 2010), the DoE (Pienkos and Darzins 2009) financed a multi-year programme to reach an economically viable algal biorefinery industry. This yielded the funding of three biorefinery demonstration plants with a budget of $97M. The DoE also financed firms like Solazyme, Algenol Biotech LLC and Sapphire Energy Inc. to develop demonstration pilots (Menetrez 2012). In other countries, such as Japan, the focus was on producing commercially viable jet fuel; the Kyoto Protocol included a programme focusing on second and third-generation biofuel (Herrador 2016).

Private investments played a crucial role in expanding microalgae through collaboration with actors along the main and adjacent value chains. Collaborations can be between actors situated upstream looking for inputs (CO_2, wastewater, equipment and machinery) and firms situated at the end of an adjacent value chain producing these inputs, creating a link between two previously distinct value chains. SCHOTT, the supplier of glass tubes, enters an R&D agreement with Algatech and another partnership with Heliae. These two collaborations enable SCHOTT to enter a new value chain and Heliae and Algatech to reinforce their place in the microalgae value chain by linking with suppliers from various value chains. The purpose of the partnership is to codevelop inputs tailored for microalgae production for biofuel and high-value-added products.

Collaborations between algal fuel firms and energy incumbents were recurrent. The agreement between Chevron and Solazyme and the partnership between Algenol Biofuels Inc. and Valero Energy focused on demonstrations to grow and convert microalgae into fuel and assess their commercial viability. The scalability expectations of algal fuel led firms to draw commercial agreements and JVs. Cellena is a JV between Shell and HR BioPetroleum Inc. (HRBP). These linkages illustrate niche actors' attempts to achieve mass production and scalability.

Actors also tested the compatibility of algal fuel with engines and motors through different partnerships. Euglena partnered with Isuzu in a research agreement to develop biodiesel and vehicles compatible with the invented biodiesel. Sapphire Energy collaborated with Toyota Prius to test algal fuel on a hybrid car built specifically for that purpose called the 'Algaeus car'. Sapphire Energy also partnered with Boeing to develop jet fuel, which was used for a test flight. A similar partnership was also between Boeing and SkyNRG (Menetrez 2012). Algal firms invested in each other, pooling their resources and knowledge together through technology licensing, direct investment, acquisition and collaboration on demonstrations and pilot plants. These alliances enhanced the new technology. Algenol Biofuels licensed its 'DIRECT ETHANOL' technology to Biofields SAPI and the license between Heliae and Evodos B.V.

4.2.2 | High-Value-Added Product Promise (2002–2015)

Concurrently to fuel promise, medium- and high-value-added products from microalgae emerged in parallel. Microalgae offers a natural alternative, sustainable and plant-based substitute to chemically synthesised products with applications in nutraceuticals, pharmaceuticals, cosmetics, food and feed. The microalgae bioproduct market growth was anticipated to reach 53.43 billion USD by 2026. The commercial potential of high-value-added molecules attracted many start-ups (e.g., Microphyt, AstaReal, AlgiSys LLC, BioProcess Alga and Fermentalg SAS). Some incumbents invested in these sectors since the mid-1970s, such as DSM and BASF, while others joined during the hype period, such as Roquette Frères, which started their algal research in 2006.

The FDA published and reviewed the Generally Recognized as Safe (GRAS) list in the United States between 1998 and 2012, including seven algae food-based ingredients (Enzing et al. 2014). It encouraged novel food production from microalgae, driving the sector expansion, which was driven by partnerships along the value chain. Partnerships existed between upstream (e.g., microalgae suppliers) and downstream actors (e.g., cosmetics, nutraceuticals, food and feed). Algatech signed a supply and a long-term partnership to sell its natural astaxanthin to Fujifilm Corp, which distributes and uses astaxanthin in cosmetics and dietary supplement products.

Actors developed JVs in different steps of the value chain. Roquette Frères and Solazyme joined forces to produce and commercialise nutritional and dietary products from microalgae for speedy market entry, access to large agri-food firms and financial support. Other JVs emerged to commercialise cultivation technologies. IGV GmbH, an expert in the closed cultivation system of microalgae, and Bioalgostral, an engineering and consulting firm specialising in producing microalgae, established a JV to produce microalgae for various applications. Actors also acquired firms cultivating and producing high-value-added products (e.g., DSM, a life sciences and material sciences company, acquired Martek, a microalgae company, in 2011). These partnerships illustrate the orientation of actors to production and commercialisation by integrating and positioning their business strategy in different steps of the value chain. Moreover, it shows that collaboration facilitates market access and knowledge transfer.

4.3 | From 2011 to 2021—The Disappointment and Rebound

4.3.1 | Biofuel Disappointment 2011–2015

Decades of research about algal fuel revealed that scalability and competitiveness are not possible. This disappointment was limited to fuel and materialised in firms' exit and bankruptcy from the algal fuel market as in Figure 8 (e.g., SBAE Industries NV, Algaestream, A2BE Carbon Capture LLC, Aquavirids Inc., Sapphire Energy Inc. and Aurora Biofuels). Many projects stopped. Many conferences and NGOs were dissolved, such as the EABA Expo, the International Algae Conference and Trimatec.

Algal fuel faced many technical issues (Saad et al. 2019), including the identification of a strain with high oil content, cost-effective, easy and cheap to harvest. The compounds (e.g., NOx and SOx) in CO_2 from power plants are used to cultivate microalgae but lead to toxicity. Open pond cultivation has low productivity, a high cost of harvesting and contaminations compared to photobioreactors. Microalgae cultivation needs flat terrains for pond systems (Leite, Abdelaziz, and Hallenbeck 2013). The production process from collection, concentration and drying is energy intensive.

These challenges entail that the production cost is substantially higher than fossil fuel. To mass produce algal fuel, cultivation requires more water, fertilisers, pesticides and energy than lignocellulosic raw materials (Bošnjaković and Sinaga 2020; Singh, Nigam, and Murphy 2011). Moreover, the competition with electric vehicles, coupled with the decline of fossil fuel prices between 2008 and 2011, challenged algal fuel survival in the transport sector (Bošnjaković and Sinaga 2020). Additionally, governmental directives on the European and global levels facilitated the diffusion of electric cars.

4.3.2 | Survival 2015–2021

Some algal fuel firms shifted their business strategy and rebranded to high-value-added products. Only ExxonMobil continues collaborating with Viridos (formerly Synthetic Genomics Inc.), using the CRISPR gene-editing technology to develop algal strains for fuel. In 2021, Total Energies cooperated with Veolia to cultivate microalgae using CO_2 in la Mède biorefinery to produce biofuel.

Moreover, the use of microalgae to produce different products (high-value-added and oil) simultaneously was reinforced to offset the high costs of algal fuel (Vanthoor-Koopmans et al. 2013). Biorefineries transform microalgae into fuel, cosmetics, chemicals, food and feed (Chew et al. 2017), linking algal fuel to high- and medium-value-added product value chains. It attracted new start-ups, but entry is slowed. The DoE financed 11 projects in 2021 to produce drop-in biopower and bioproducts for sectors where electrification is not possible, like aviation and marine. The Japanese actors (e.g., Euglena Co. Ltd.) also adopted a similar strategy for jet fuel.

Moreover, the shift included using microalgae in agriculture. From 2015, agriculture-related patents filed increased significantly, focusing on plant growth, biofertilisers, resistance elicitors, weed management and post-harvest (Murata et al. 2021). Other novel applications are wastewater treatment, bioabsorption and nutrient recovery (Yap et al. 2021).

In this period, large retailers (e.g., Carrefour and Amazon) started selling high-value-added algal products to end consumers (e.g., capsules and tablets) made by actors such as True Nature and Nature Love. Retailers also forced specification agreements. Super U Marché and Cora, retailers, sell salmon fed on microalgae mobilising their position in the value chain. Besides these agreements, AlgaEnergy signed a distribution agreement with Laboratoire M2 Inc. It gave AlgaEnergy exclusive distribution rights to 'Thymox Control', a fungicide made from microalgae.

Many firms were acquired. Solabia Group, a biotech company, acquired Algatech Ltd.; Corbion acquired TerraVia; and NextStage AM acquired stakes in Fermentalg. Other actors established JVs. Parry Limited signed a JV with Synthite Industries Ltd. DSM established a JV with Evonik.

Fermentalg SA signed a commercial, development and marketing agreement with DDW to collaborate in R&D, manufacturing, marketing and sales to develop colours based on microalgae. These partnerships indicate actors' orientation to exploitation activities influencing the structure of petrochemicals' value chains by linking different products into one system (Bröring 2010). In this case, many value chains are meshed together, forming value webs.

5 | Discussion

5.1 | Collaboration 'The Missing Link'

Combining the value chain approach with niche analysis, in the case of multipurpose innovations, highlights the complexity of dynamics resulting from the emergence of an innovation linking different sectors. In Figure 4, we illustrate the interdependencies between the main and adjacent value chains. The value chain analysis, first, enables us to survey all actors involved in the niche through the study of the upstream of the main value chain and the adjacent sectors supplying inputs and services needed for the production upstream of the main value chain. Simultaneously, we study the downstream sectors (main and adjacent) using innovation to create different products or services. Therefore, this framework underlines that innovation relies on the combinations of new and existing knowledge and is used and produced by various actors.

Second, the framework shows the multiple interactions between the niche actors and incumbents in the main and adjacent value chains (Table 2). Actors collaborate at the different phases of transition: development of the niche, at the boundaries of the niche and beyond the niche. In the development phase of the niche, partnerships are mainly characterised by R&D collaboration to explore new technological options and navigate expectations to develop biofuels and high-value-added products. These exploration-focused partnerships are centred around risk-taking, discovery, innovation development and flexibility (March 1991). These partnerships can include various actors (new entrants, incumbents, universities, NGOs, etc.) working collectively to develop and test new technologies, sharing risks through collaborative R&D, exploring innovation viability and testing the innovation against complementary knowledge and technology (De Faria, Lima, and Santos 2010; Hall et al. 2001).

At the boundaries of the niche, strategic partnerships include demonstrators, technology licensing and development agreements up to JVs. Their objective is to analyse the scalability of the production process of microalgae and biofuels. This phase shows the first attempt to exist the niche and diffuse the innovation at a larger scale. These partnerships are the first steps of an exploitation phase. Exploitation activities are meant to embed innovation into production processes, refine it to increase efficiency and massively produce it (March 1991). The niche actors seek these collaborations to develop the market demand for their products by cooperating with actors operating in existing markets. Incumbent actors especially oil, gas and petrochemical companies enter these collaborations to benefit from first mover advantage (Morgunova and Shaton 2022). This enables them to shift to a 'greener' value chain that they contributed to creating if the market conditions change due to external pressures or due to the innovation success in terms of scalability and cost reduction potential.

The exploitation or upscaling-focused agreements are located in the phase beyond the niche. In this phase, the agreements

TABLE 2 | A typology of collaborations.

Phase	Promise Cycle	Collaboration type	Actors	Role/Function	Example	Firm 1 GVC position	Firm 2 GVC position
Development of the niche	Biofuel and HVA	Research collaboration	Universities and niche actors	Exploration	US-Japanese researchers about chlorella cultivation (1950s)	-	-
Development of the niche	Biofuel and HVA	R&D collaboration	Universities and niche actors	Exploration	EU Framework Programme & Horizon Europe (from 1984 onwards)	-	-
Development of the niche	Biofuel and HVA	Co-development of equipment to improve algae production	Algae producers & equipment suppliers	Exploration - navigating expectations (improving algae production)	Schott-Algatech (2014) Schott-Heliae (2010)	Lead firm in glass industry GVC but supplier for the microalgae GVC	Microalgae producer and processor in the main GVC
Development of the niche	Biofuel	Co-investment (from agreements to JV) to improve algae and biofuel production	Algae producers & input producers (CO2, wastewater)	Exploration - navigating expectations (improving biofuel production)	Biofields S.A.P.I and Alganol Biofuel (2009	Microalgae producer, processor into biofuel in the main GVC. Suppliers of biofuel in adjacent VC	Microalgae producer, processor of microalgae to biofuel in the main GVC. Suppliers of biofuel in adjacent VC
Development of the niche	Biofuel	Joint research agreement – partnerships (biofuel - vehicle compatibility)	Algal fuel firms & transport firms	Exploration - navigating expectations (testing out algae-based fuels in cars, buses, and jets)	Euglena & Isuzu (2015) Sapphire – Toyota Prius (2009) Sapphire-Boieng (2009)	Microalgae producer, processor into biofuel in the main GVC. Supplier of Biofuel in adjacent VC.	Producers/lead firms of transportation vehicles of aircrafts and buyers of fuel
Development of the niche	Biofuel	R&D collaboration	Algal firms & Fuel firms	Exploration of new generation of biofuels	Veolia & Total (2021)	Producer/Lead Firm of energy and wastewater treatment in the Energy adjacent VC	Producer/Lead Firm of energy in the Fuel/Energy adjacent VC
Development of the niche	Biofuel and HVA	R&D collaboration	University-firms (algae sector and others)	Exploration of new drop-in biofuels and bioproducts	DoE (2021)	-	-
At the boundaries of the niche	Biofuel	From demonstrators to commercial agreements and JV	Algal fuel firms & petrochemical firms	Scalability expectations - biodiesel production and commercialisati on	Solazyme and Chevron (2008) Algenol Biofuels Inc and Valero Energy (2010) HR biopetroleum and Shell created Cellena (2011)	Microalgae producer, processor into biofuel in the main GVC. Supplier of Biofuel in adjacent VC	Producer and retailer /Lead firms of petrochemical and energy refinery in the Energy adjacent VC.
At the boundaries of the niche	Biofuel and HVA	From technology license to co-development & JV (demonstration plants, production, commercializatio n)	Algal firms	Scalability expectations- producing algae for various applications	Bioalgostral & IGV (2011)	Microalgae producer, processor into biofuel and HVA in the main GVC. Supplier of Biofuel & HVA in adjacent VC	Supplier of cultivation process in the main GVC
At the boundaries of the niche	Biofuel	Development agreement	Algal firms & Fuel firms	Scalability expectations- economies of scale	Viridos and Exxon Mobile R&E (2021) follow up of strategic R&D alliance formed in 2009	Microalgae producer, processor into biofuel in the main GVC. Supplier of Biofuel in adjacent VC	Producer and retailer/Lead Firm of energy in the Fuel/Energy adjacent VC
Beyond the niche	HVA	From long term supply agreements via JV	Algal firms or integrated algal firms & downstream adjacent value chain lead actors	Upscaling	Algatech and FujiFilm Corp (2015) Solazyme and Roquette Frères JV (2010-2013)	Microalgae producer, processor into HVA products in the main GVC. Suppliers of HVA in adjacent VC.	Producer and distributor of products made of HVA algal products in cosmetics and nutraceuticals VC. Supplier of food by-products and ingredients to food and beverages VC.
Beyond the niche	HVA	Distribution agreements Product development agreement	Retailers & HVA or algal firm	Upscaling	AlgaEnergy and Laboratoire M2 Inc.(2021)	Microalgae producer, processor into HVA products in the main GVC. Suppliers of HVA in adjacent VC.	Suppliers of by products in the feed and agriculture VC.
Beyond the niche	HVA	Acquisition and JV	Algal companies in different steps of the value chain	Upscaling	Algatech LTD was acquired by Solabia Group, (2019) TerraVia was acquired by Corbion (2017) EID Parry and Synthite Industries JV (2018) Evonik and DSM JV (2015)	Microalgae producer, processor into HVA products in the main GVC. Suppliers of HVA in adjacent VC.	Producers of HVA end and by-products in adjacent VC
Beyond the niche	HVA	Commercial and marketing agreements	HVA producers and downstream adjacent VC lead actors	Upscaling	Fermentalg and DDW (2021)	Microalgae producer, processor into HVA products in the main GVC and supplies them to adjacent VC	Supplier of colour solution to Food and Beverage VC

mainly concern production, distribution, commercialisation and marketing, with increasing and binding commitments such as JVs, acquisitions and long-term agreements. The objective of these partnerships is for niche actors to integrate into existing markets by offering a substitute for other ingredients and create new markets where microalgae lead the development of new products diffusing the HVA products largely in different sectors (pharmaceutical, food, beverages, feed, cosmetics, agriculture and chemistry). For incumbent firms, these partnerships are an opportunity to upgrade, green their value chain and create new market segments. These increasing commitments between companies only took place in the HVA-based products and not in the biofuel sector.

Third, this approach reveals the repercussions of innovation emergence and diffusion on the value chain links. The collaborations allow actors to subscribe to the labour division, integrate existing value chains or develop new ones by governing the flow of knowledge and products. In our case, innovation can change and restructure industries that were once considered mature such as petrochemical value chains. Innovations in the upstream value chain generate opportunities downstream while introducing innovation downstream will affect the upstream. Therefore, the final form of the value chain is a value web. The new technologies connect various value chains by using by-products or new biomass as a source of novel applications to substitute synthetics and petrochemicals. The newly established linkages are between specific steps of value chains. Therefore, the structure that emerges is a value web where many value chains mesh.

5.2 | A Dynamics Lens of Collaborations

Analysing the niche evolution through the promise cycle enables us to study the collaboration dynamics in biofuel and HVA products. The niche starts with the revelation period, where knowledge is discovered in a controlled environment or through serendipity, triggering a knowledge formulation and expansion period. At the beginning of this phase, actors are disconnected, working separately on advancing the knowledge.

The initial attempts at network formation happened through conferences, collaboration in academic publications and research projects encouraged by public, private (e.g., early incumbents) and academic entities. Early exploration activities were between academics, scientists and incumbents, emphasising the role of incumbents as early explorers of innovations. These later diversify, moving from one sector to another, bringing along resources and knowledge crucial for technology development.

The hype period is characterised by (1) the entry of new actors (start-ups and incumbents) and (2) the mobilisation of funds and resources in the form of private and public partnerships to conduct exploration and preliminary scalability activities. This hype period reflects intensive exploration activities and the first efforts in exploitation activities. The disparities in partnership strategies depend on the application, the actors' position in the value chain and the degree of maturity of the innovation in a given sector.

The disappointment phase of the biofuel case is expressed through exits and cessation of firms and projects. Collaborations are ceased. The contributing factor to disappointment triggered new promises in biofuel. These new promises are characterised by a series of new exploration-focused partnerships around the 2020s (cf. Total and Veolia and the new DOE initiatives). These partnerships mark the survival phase of the promise, where actors refurbish and reorient their expectations targeting new directions leading to the survival of the innovation. This might lead to a second hype period in the future in the biofuel promise cycle. In the high-value-added field, there was no disappointment, and we observed exploitation or scale-up–based agreements that enable the diffusion of new HVA products. The diffusion of innovation can lead to the restructuration of the value chain, as it creates linkages between the different steps of several value chains simultaneously. This results in a web of value as multiple value chains mesh. However, this is not the only form that could emerge; innovation can cause the emergence of a substitute value chain that replaces an existing one (Bröring and Cloutier 2008). Innovation can also result in a complementary value chain (Bröring 2010) that complements an existing value chain or can simply integrate it without leading to a major change in its structure.

6 | Conclusion

This paper assumes that commercial development and innovation diffusion transpire through integration into the labour division and the GVC. This integration is attained through collaborations along and between value chains. We use microalgae as a case study to support this assumption in the development of the bioeconomy because the underlying innovation dynamics involve transforming the existing petrochemical value chains to develop sustainable bioproducts to substitute fossil products.

From a managerial perspective, we identify two main strategic recommendations. On the one hand, our article shows that innovation strategies for the development of microalgae are mainly process innovations, aimed at substituting fossil-based processes with bio-based processes while retaining identical products. As illustrated with the case of biofuels, the competition is based on the ability to achieve economies of scale enabling algae to partially replace fossil fuels. However, as the results on the bioeconomy show (Befort 2020), this strategy arises from companies starting with algae to identify potential markets and focus above all on existing markets rather than on creating new ones. From this point of view, successful innovations have been driven by new uses, as illustrated by the marketing of seaweed feed. On the other hand, paradoxically, periods of disappointment with technological expectations are also periods of learning about the possibilities and the limitations of emerging technologies (Befort 2023). A company could therefore choose to exploit the the value web formed through technological exploration around microalgae, treating it as a *general-purpose technology*. Following this strategic choice, the firm should act as an intermediation platform between alliances enabling it to accumulate knowledge and apply these processes within relevant value chains (Blackburn, Ritala, and Keränen 2023; Teece 2018).

Our study paves the way for an in-depth examination of the role of innovation strategies in the greening of GVCs in three directions. First, the results could be confirmed by an extension of the approach to other cases, particularly in the context of developing the circular economy. Second, bioeconomy innovations rely on by-products to develop new solutions, linking new segments of the value chain where by-products and waste become products produced, transported, distributed and sold on markets. Thus, our study invites us to examine in detail the positioning of firms at the crossroads of several GVCs. Third, new questions arise about the circularity of the value chain and to what extent geographical aspects, due to the potential difficulty of waste relocalisation, drive the development of clusters.

Conflicts of Interest

The authors declare no conflicts of interest.

Endnotes

[1] We use the notion of collaboration, cooperation and partnerships interchangeably.

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