THE BIOECONOMY TRANSITION PROCESS: SAILING THROUGH STORMS AND DOLDRUMS IN UNKNOWN WATERS

Andreas Pyka, Ezgi Ari, Ariana Alva-Ferrari, Sophie Urmetzer

De Boeck Supérieur | « Journal of Innovation Economics & Management »

2021/0 Prépublication | pages Ig à XXVII

DOI 10.3917/jie.pr1.0110

The Bioeconomy Transition Process: Sailing through Storms and Doldrums in Unknown Waters

Andreas PYKA
University of Hohenheim
Innovation Economics (520i), Germany
a.pyka@uni-hohenheim.de

Ezgi ARI
University of Hohenheim
Innovation Economics (520i), Germany
e.ari@uni-hohenheim.de

Ariana ALVA-FERRARI
University of Hohenheim
Innovation Economics (520i), Germany
aalvaferrari@gmail.com

Sophie URMETZER
University of Hohenheim
Innovation Economics (520i), Germany
sophie.urmetzer@uni-hohenheim.de

ABSTRACT

A transition toward a sustainable circular bioeconomy requires drastic changes across a broad range of industries and their stakeholders. The current slow pace with which society tries to avert the transgression of critical thresholds of the planetary system is worrying. However, the historical case of the shipping industry in the 19th century shows how suddenly whole industries can change after a long period of low innovation activity and lock-in. We explore how this example might improve the understanding of the transition toward a sustainable circular bioeconomy. For this purpose, we analyze analogies between the processes in the past and the ones we observe today. Our conclusion is that the evolutionary processes shaping the path toward the bioeconomy naturally make use of the knowledge and networks of the fossil era and are characterized by co-existence, mutual learning, and new forms of collaboration.

KEYWORDS: Transformation, Sustainability Transition, Sailing Ship Effect, Bioeconomy, Co-evolution, Innovation

JEL CODES: O12, O14, O32, O33

Scientists and policy makers agree that the bio-based economy or, in short, the bioeconomy, offers a viable response to sustainability challenges such as climate change, natural resource scarcity, and food security. The bioeconomy is also associated with multiple positive socio-economic impacts such as green growth, job creation, rural regeneration, and future-oriented practices of production and consumption (McCormick, Kautto, 2013; Bugge *et al.*, 2016; Meyer, 2017; Pyka, 2017b). At the same time, it is important to keep in mind that an increasing adoption of bio-based technologies and products does not automatically foster sustainable development (Heimann, 2019). If the bioeconomy is meant to contribute to the achievement of the Sustainable Development Goals (SDGs) (United Nations, 2015), thus fulfilling the requirements of a sustainable circular bioeconomy (SCB), its implementation cannot be achieved by markets alone (Fritsche *et al.*, 2020). Safeguarding a socially fair and ecologically sound transition in line with normative perceptions is the obvious duty of politics. In fact, around 50 nation states worldwide, several regional governments, as well as the European Union (EU), have adopted bioeconomy strategies or related policies (Bioökonomierat, 2018) and this number is constantly growing. Through an analysis of twelve of these strategies, De Besi and McCormick (2015) showed that governments across Europe generally focus on the same political priorities to develop the bioeconomy. While these focus areas are oriented predominantly toward supply-side support, at least since the European Commission's commitment to the Green New Deal (European Commission, 2019), with the idea of a 'just transition', a more holistic perspective is called for. This requires cross-departmental policies that integrate environmental, industrial, research, social, energy, and nutrition policies (Fritsche *et al.*, 2020). Such integration, in turn, must be based on a thorough understanding of the mechanisms at work in the incumbent fossil-based industries and their supply networks, the novel bio-based ones, as well as their interactions.

A promising way of analyzing transition processes is to closely examine observations of historical transitions and see what can be learned and transferred to current developments. In the case of the transition to the SCB, the history of the transition of marine propulsion technology from wind (sailing) to coal (steam) promises to provide interesting analogies: just like the sailing ship at that time, fossil-based technologies nowadays dominate not only our industries, but also our daily practices, our lifestyles, and our consumption habits. And even though the steamship promised great advantages, such as velocity, reliability, and carrying capacity, its diffusion was slow due to unsolved problems in the emerging technology and substantial technological improvements in the incumbent technology. After the steamboats appeared, a sudden increase of innovation activities in the incumbent sailing technology was observed with the intention to prevent the fast entry of, and replacement by, steamboats – a transition pathway that has become known as the so-called Sailing Ship Effect (SSE). We suggest that today we can learn from the SSE in two ways: (1) by observing the similarities between the co-evolutionary dynamics between sailing ships and the fossil fuel industry on the one hand, and the steamships and bio-based industries on the other; and (2) by spelling out the differences between the historical case and the current transition, *e.g.* caused by the changed innovation paradigm of our times (Schlaile *et al.*, 2017). Our line of reasoning is guided by the following research question:

In which way can the SSE perspective contribute to an increased understanding of the co-evolutionary dynamics between fossil-fuel and bio-based industries in a transition toward a SCB?

The paper is structured as follows: in Section 2 we introduce general economic theories of change and modern transition theory against the historical case of the SSE. In Section 3 we point out some specific characteristics of the transition to an SCB and draw parallels between the SSE and the SCB transition. Specific examples of bio-based innovations that illustrate our arguments will be presented in Section 4. Section 5 concludes.

Theories of Change

Insights from Modern Innovation Economics and Transition Theory

Standard models applied in neoclassical economics (equilibrium approach, optimization, the *homo economicus*, etc.) show strong limitations concerning the analysis of transition processes and are neither equipped with adequate tools to process complexity nor with interfaces to other disciplines (*e.g.* sociology, ecology, engineering, etc.). For a long time, modern innovation economics has criticized the deficits of mainstream economic theory when it comes to the analysis of innovation. Freeman (1994, p. 463) rightly states: "*one of* *the continuing paradoxes in economic theory has been the contrast between the general consensus that technical change is the most important source of dynamism in capitalist economies and its relative neglect in most mainstream literature*". This paradox now seems to become highly relevant for the attempts to analyze the transition to an SCB.

Discovering patterns in transition processes and disentangling their complexity have been proven to provide guidance in analyzing transition processes in general and might also be conducive to understanding the specifics of bioeconomy transitions. Different strands of theories have taken up this challenge: Scholars of evolutionary economics (Nelson *et al.*, 2018) make use of concepts like innovation networks, knowledge diffusion, system dynamics etc. and connect with other disciplines (complexity science, computer science, transition research, management, etc.). For instance, complexity economics as the formal branch of modern innovation economics offers a bird's eye view to address sustainability challenges such as climate change and the impacts of current consumption levels on resource extraction and waste generation. Complexity economics draws inspiration from a range of approaches including evolutionary economics, institutional economics, and ecological economics to find ways to align the satisfaction of human needs with the limitations of the life-supporting planet. In this line of thought, economies are open, dynamic systems, rarely in equilibrium, and made up of diverse agents who lack perfect foresight but can learn and adapt over time (Foxon *et al.*, 2013). Adding yet another level of complexity, it must be acknowledged that transitions to a SCB cannot be achieved only by market-driven innovation processes (Pyka, Prettner, 2018) but deeply involve normative considerations (Schlaile *et al.*, 2017). A strong normative dedication to the alleviation of the global sustainability challenges needs to be adopted, *e.g.* in terms of sustainability-oriented policies or by the development of innovative business models that diverge from short-run profit-orientation (Urmetzer, 2021). This way, new value creation paradigms can emerge as demonstrated by the example of the circular business model disrupting the linear take-make-dispose economic paradigm (McArthur, 2013).

As an approach to cope with this complexity on a theoretical level, the literature on *sustainability transitions* proposes the adoption of a multi-level perspective (MLP). Socio-technical changes are understood to be the outcome of a certain pressure exerted upon the incumbent dominant technological regime (*i.e.* the meso-level). The pressure originates from two different sides, *i.e.* from the landscape level (*i.e.* the macro-level consisting of a set of deep structural trends) and the technological niche level (*i.e.* the micro-level), where new technologies are developed in a protected environment

(Geels, 2002; Geels, 2005a). According to Köhler *et al.* (2019), the change processes of dominant socio-technical regimes to more sustainable configurations require (co-)evolutionary processes on different levels (*e.g.* technologies, markets, infrastructures, policies, industry structures, and supply and distribution chains) and involve different actors (academia, politics, industry, and civil society). The authors stress that during transitions towards true sustainability phases and areas of relative stability take turns with phases and areas of radical change. These dynamic processes take a lot of time and constantly require the realignment with political and socio-cultural processes, including discourses on values, goals, norms, and regulations.

With view on the particular procedures that run sustainability transitions, Geels and Schot (2007) distinguish between different processes of change within the dominant regime. The authors developed a typology of four transition pathways: *transformation*, *reconfiguration*, *technological substitution*, and *de-alignment and re-alignment* which differ in combinations of timing and nature of multi-level interactions. Geels and Schot (2007) provide several historical examples for each transition pathway. In transitions that follow a *technological substitution pathway*, the regime actors defend themselves and invest in innovation when the innovative potential replacement appears on the horizon. In contrast to the *de-alignment* and *re-alignment path* where the regime actors experience sudden strong landscape pressure and surrender to the obvious major regime problems, in technological substitution pathways established actors keep their faith in the dominant regime and take up the competition challenge to avoid the market entry of the newcomer. As a consequence, the actual transition may be postponed since the fundamental change happens more slowly and incumbent regime actors take the opportunity to gradually adapt to the changing landscape. While both pathways result in the eventual replacement of the initial socio-technical regime by another one, the transition processes differ sharply in duration as well as in the nature of the protagonists and their interactions. In the following, we describe the observed processes that took place during one of the most popular and well-studied historical transitions, which has become a metaphor for the slow substitution of one technology by another: the transition from the era of sailing ships to the era of steam boats.

The Sailing Ship Effect

The introduction of the concept of "sailing ship effect" takes its name from the remarkable persistence of sailing ships in the face of the development of steam-driven ships in the 19th century (Mendonça, 2013). In the own words of New Zealand scientist W. H. Ward, "*the sailing ship made more* *improvements in the 50 years after the introduction of steam ships than they had in the previous 200 years*" (Sushandoyo *et al.*, 2012; Mendonça 2013; Filatrella, Liso 2020a). According to Filatrella and Liso (2020a), this "battle" of the ships lasted about 80 years and resulted in several innovations in the sailing ship industry (*e.g.* became faster, doubled the space for cargo in proportion to tonnage, and reduced their crew needs) (Mendonça, 2013; Filatrella, Liso, 2020a).

In light of this, Geels (2005b) argued that the improved performance of the established sailing ships technology was a mechanism that slowed down the diffusion of the new steamship technology. In other words, the SSE can be interpreted as following a *technological substitution pathway*, where the regime actors defended themselves and invested in innovation when the innovative potential replacement appeared on the horizon. The MLP perspective helps to further illustrate in which ways the changes in the external context and landscape developments supported the co-evolutionary processes at work in the SSE.

For instance, the 19th century was characterized by international and colonial trade expansion. Britain's political and economic liberalisation changed the landscape in a way that led to the country's emergence as the world's manufacturing hub (Geels, 2005a). As a result, the shipping regime, in particular the sailing ships' market dimension expanded (Geels, 2005b). At the same time, landscape shocks of political revolutions (1848), the Irish potato famine (1845-1849), and the prospect of obtaining higher wages elsewhere to fight poverty resulted in mass emigration from Europe (Geels, Schot, 2007). Up to those periods of time, steamships were confined to narrow market niches (*e.g.* inland waterways, ports, mail transport) (Geels, Schot, 2007). However, the previously mentioned landscape development resulted in a growing passenger market and provided a window of opportunity for steamships to acquire a wider market niche – the transatlantic transport of passengers (Geels, 2005b). At first, the steamships were able to capture the more affluent emigrants that preferred to travel in steamships because of the speed, regularity, and comfort it offered compared to luxury sailing ship cabins (Geels, 2002; Geels, 2005b). However, steamships quickly captured the entire emigrant market – by 1866, 81% of European emigrants traveled by steamships (Geels, 2002). Additionally, the opening of the Suez Canal in 1869 caused a physical landscape change (Geels, 2005a) that provided a shortcut for ships and thereby giving steamships a major comparative advantage in global trade because strong winds made it unsuitable for sailing ships (Geels, Schot, 2007). Sailing ship companies responded by transferring to other market niches (freight transport in bulk markets) which was supported by the increased diversification of world trade and the demand for imports of raw material (e.g. cotton, metallic ores, meat, wool, guano, and rubber) and luxury products (*e.g.* tea, coffee, sugar) (Geels, 2005a). In this segment, low freight costs were more important than high speed (Geels, 2005b), allowing sailing ships to continue navigating in this market niche.

Geels and Schot (2007) demonstrate how technologies, institutions, behaviors, rules, and values changed during the technological substitution pathway of sailing ships. They observe several seemingly unrelated developments during the 19th century that obviously accelerated diffusion. Some technological innovations improved the functioning of sailing ships although they were not directly related to sailing ships, *e.g.* steam tugs, growing knowledge of oceanography and reliable charts of winds and currents). At the same time, a new steamship regime emerged as three technical trajectories linked up. These were the gradual shifts toward screw propulsion, iron hulls, and compound engines (Geels, 2005a; Geels, Schot, 2007). Furthermore, Geels (2005b) attributed the development of the steamships to landscape developments including changed market dynamics and subsidies, adaptations in ports, the construction of a worldwide coal infrastructure (Geels, Schot, 2007), and the introduction of new ownership statuses which facilitated the acquisition of capital-intensive steamships. All these developments, coupled with the interaction of actors, as stated by Geels (2005a), were part of the "stepwise process of reconfiguration" for the occurrence of the technological transitions from sailing ships to steamships.

The combination of these landscape developments and the measures taken within the sailing ship regime obviously slowed down the diffusion of steamships (Geels, 2005b). The technological improvements in sailing ships countered the competition pressure by steamships in the ocean trade of the 19th century (Geels, 2005b. While such improvements in the incumbent technology when challenged by an emerging one are quite common, Geels (2005b) finds this pattern so obvious with sailing ships and steamships, that the coinage of the sailing ship effect seems justified.

From the very beginning, the metaphorical beauty of the SSE attracted the interest of innovation researchers. By transferring the pattern of the SSE to other occurrences, several authors provide new examples, which shed light to different applications and facets of the SSE. The examples include horse-drawn carriages, motorcycles (Geels, 2005a), chemical processes in the alkali industry, and the iron industry energy transition (Howells, 2002). Sick *et al.* (2016) provide examples of new technologies that eventually displaced old ones like the steam locomotives and diesel-electric powered trains. Filatrella and Liso (2020a) analyze the SSE in a deterministic model (without real innovation) by reproducing the most frequent occurrences of the SSE. They conclude that the old technology survives longer in a SSE situation than without the effect, but eventually the old technology always "loses the battle". Filatrella and Liso (2020a, 2020b) provide examples in which the old technology either continued holding an important niche, or kept the new technology at bay, or that it re-emerged after a while such as the mechanical watches that were threatened by the quartz watches (Filatrella, Liso, 2020a). Lastly, other examples include what Mendonça (2013) call a reverse learning effect or a technology reverse (Sciavone, 2014), where innovations from the old technology are combined with the new technology. Examples of such technological symbioses or hybridization are analog and digital cameras (Sciavone, 2014; Filatrella, Liso, 2020a), steam engines and electric motors, and gas turbines in electricity production (Geels, 2002).

While the existence of the SSE is not unquestioned (Howells, 2002; Liso, Filatrella, 2008; Mendonça, 2013), our main focus is not to historically analyze its existence, but to take it as a basis for the development of a narrative that allows to highlight some of the dynamics observed during socio-technological transitions without ignoring the underlying complexity. We thus offer a basis for understanding the characteristics of the SCB transition.

Is the Bioeconomy the Metaphorical Steamship?

The Complexity of Bioeconomy Transitions

Bioeconomy affects many industrial sectors. Therefore, the transition to a SCB is not as simple as a scaling-up process of an innovative, superior, and substitutive technology that has emerged in a niche (Morone, 2018). It is a transition towards a paradigm shift that affects the whole economy and encompasses highly complex processes (Morone, 2018; Urmetzer, 2020). It is the result of a co-evolution of economic, technological, institutional, cultural, and ecological developments at different scale levels (Bosman, Rotmans, 2016). In the following, we will describe the complexity of the SCB transition by highlighting several questions arising in terms of the current change process.

What is "Bio"?

To begin with, *monitoring* the bioeconomy is hampered by a lack of statistics on emergent and partially bio-based sectors *i.e.* those sectors where bio-based products are produced along with non-bio-based products (Morone, 2018). Additionally, deciding on the most appropriate socio-economic indicator framework or economic performance indicators is an intricate ordeal. For instance, some countries focus on the contribution of the bioeconomy sectors to gross domestic product (GDP), turnover, and employment. However, this approach only provides an incomplete picture when environmental and social aspects are not included (Morone, 2018). Additionally, the current status of sustainability certification and standardization of bio-based products is faced with the challenge that there are no homogenous criteria, or the practical implementation of criteria in certification processes is inadequate (Heimann, 2019). Similarly, legislative frameworks, recycling schemes, and necessary standardization activities are lacking implementation (Morone, 2018). Understanding interactions, transition costs, and friction among the various processes and stakeholders within bioeconomy value chains remains a challenge.

How many Bioeconomies are there?

There is no single bioeconomy but rather *many bioeconomies* (Urmetzer, Pyka, 2017; Fritsche *et al.*, 2020). Given that there is no agreed definition of bioeconomy around the globe, worldwide comparisons are hard to make. Countries' different priorities are illustrated in their nation-wide strategies and their respective comparative advantages (*e.g.* availability of natural resources) (Morone, 2018). Thus, measurement, monitoring, and reporting of the SCB is a challenge. A bioeconomy agenda-setting must consider the respective national and regional circumstances. According to Jander and Grundmann (2019), the transition from a fossil-based to a bio-based economy requires to chart the status quo and the developments in fossil resource consumption within an economy, to record developments in the availability of substitute goods from bio-based resources, and to involve those sectors that are currently or potentially part of the SCB. Only then can visible targets for policy interventions be enacted and achieved.

What Do We Mean by "Bioeconomy"?

Due to the fact that the bioeconomy "*sits at the intersection*" (Morone, 2018, p. 2631) of many overlapping concepts such as sustainable development, circular economy, and green technology (D'Amato *et al.*, 2017; Morone, 2018), some *conceptual inconsistencies* can be diagnosed. Vivien *et al.* (2019), for instance, described the historical development of three different narratives of the bioeconomy, each one of them selectively supporting a certain group of stakeholders in their specific agendas, be it nature conservation, technological development, or the full substitution of fossil resources. Without doubt, the increase in biomass resource demand has strong implications for global sustainability concerns. This includes issues such as paying attention to workers' conditions, ensuring sustainable and effective use of water and land to produce biomass for food, feed, fiber, materials and energy, and impacts on the ecosystem quality and biological diversity (Pfau *et al.*, 2014; Dietz *et al.*, 2018; Morone, 2018; Gawel *et al.*, 2019). In the wake of such concerns, especially in the EU, the bioeconomy has recently undergone a shift from a technology- to a more society-focused concept although Gawel *et al.* (2019) still make out a policy focus on an input substitution concept with an emphasis on high-tech innovations in biotechnology (see also Zinke *et al.*, 2016) This ambiguity between a biotechnology-centered vision *versus* a biomass and sustainability centered vision of the bioeconomy still seems to prevail across and within nation states thus contributing to inefficiencies in the formulation and implementation of bioeconomy policies (Vivien *et al.*, 2019; Befort, 2020). Nevertheless, the European Commission's Knowledge Centre for Bioeconomy is promoting bioeconomy as a core instrument to foster economic resilience in the post-COVID-19 era and providing a new perspective along with a new term "BioWEconomy" in which social aspects are of high importance with a transformative focus towards an inclusive, sustainable, circular bioeconomy (Fritsche *et al.*, 2020).

Who Buys "Bio"?

Consumer dynamics within a SCB are complex and play a key role in supporting the transition (Pyka, 2017a). Consumption patterns and the willingness to pay for bio-based products influence demand and innovation activities (Hagemann *et al.*, 2016). Factors such as new lifestyles, price, quality, and changing preferences will determine the success of new technologies and products. In addition to their mere acceptance of novelties, consumers have been seen as economic agents who share responsibility with industry, politics, and science for actively contributing to the structural transition towards a SCB (Wilke *et al.*, 2021). Thus, consumers' roles in the ongoing process of market uptake of bio-based products need to be exploited (Morone, 2018). As consumption trends such as responsible consumption, ecological footprint, etc. continue to reach a growing number of consumers, it is important that sustainability issues are made transparent and are openly discussed with stakeholders (Hagemann *et al.*, 2016).

A Long Way to Change?

In a complex transition process already modest progress towards a higher share of bio-based products might have the potential to radically transform production and consumption once it reaches a *tipping point*. Bioeconomic opportunities are still mostly unexplored and require long periods to be discovered, researched, and introduced as innovation (*e.g.* synthetic chemistry, biochemistry, microbiology, molecular biology, process technology). However, transitions rarely follow linear developments. The more the advantages of bio-based solutions become known, the faster novel products, technologies, and practices of the SCB will diffuse. Therefore, integrating bioeconomy in curricula (Urmetzer *et al.*, 2020) and a continued support of bioeconomy entrepreneurship and start-up activities will be decisive in supporting SCB transitions (Kuckertz *et al.*, 2020).

The above paragraphs illustrate that a transition to the SCB is a truly complex process and that the attempts to reduce its complexity are likely to assume away the essence of the transition. The drivers of the bioeconomy are multi-faceted and involve a variety of domains and stakeholders, encapsulating economic, environmental, societal, and political objectives. A transition to a SCB involves the emergence of a new and complex set of relations among stakeholders acting at the production level, as much as at the consumption level. These intersect with institutional actors playing a fundamental role in steering the transition altogether (Morone, 2018) and attempt to mitigate the social distortions that may occur (*e.g.* affecting urban and periphery regions differently, producing winners as well as losers).

Sailing Ship Effect Dynamics in the Transition to a Sustainable Circular Bioeconomy

The fundamental dynamics of the SSE illustrate how the advent of a new technology stimulates an innovation response of the incumbent in order to survive (Nainwal, 2018). In the previous sections, we shed light on the complexity and the characteristics of sustainability transitions in general and of a SCB transition, in particular. Obviously, many bioeconomy innovations (*e.g.* biofuels, bioplastics, and biopharmaceuticals) are designed to compete with existing fossil-based alternatives within the existing value chains (Hermans, 2018). A relatively long interim phase can be expected to be characterized by a *co-existence* of both a fossil-based economy and a bio-based economy. The processes of *cooperation* and *imitation* across niche and regime industry actors can be expected to trigger specific intra-subsystem changes of co-evolutionary nature (Almudi, Fatas-Villafranca, 2018).

With the aim of assessing the co-evolutionary dynamics between the fossil industry (established technologies) and the bio-based industry (novel technologies) we will, in the following, explore in which way the SSE perspective can be applied to improve our understanding of these dynamics. Therefore, we develop a narrative analogy on the innovative response of the fossil-based industries in reaction to the appearance of bio-based products. The similarities include:

– *Technology lock-in:* The emergence of the bio-based trend is occurring during a time characterized by a state of lock-in to carbon intensive, fossil-based systems for the past sixty years. All networks and actors along the supply chains, from extraction to use and disposal are established and have been more or less uncontested for the past sixty years. Thus, bio-based efforts began in a "red ocean market" filled with many uncertainties and fierce competition, just like steamships did in the 19th century when contesting the vintage sailing ship.

– *Changing regulatory settings:* Changes taking place in the institutional framework during the 19th century influenced sailing ship design. For instance, the amount of freight a ship could carry was taxed with a new Tonnage Law (Mendonça, 2013; Geels 2002). As a consequence, shipbuilders started innovating in materials (*e.g.* iron was first used as an add-on to strengthen wooden constructions) (Geels, 2002) and in the design, to remain competitive, and began to build clipper ships that were heavier, stronger and narrower (Geels, 2002). Additionally, a new subsidized market niche for mail steamers in the UK supported the emergence of the new steamship technology (Geels, Schot, 2007). Today, the increasing amount of environmental regulations and standards towards a more sustainable circular economy is influencing the way, how we produce, consume, and dispose, and is paving the way to turn to a bio-based economy.

– *Innovations:* As steamships did when improvements in ship design and materials took place, the bioeconomy solutions benefit from innovation efforts in other industries, including innovative efforts in the fossil-based industries (*e.g.* attempts of the conventional plastic industries to increase the resource-efficiency by introducing recycling and the circular economy), combining products (*e.g.* a computer with a bioplastic casing), or bioeconomy solutions also form new combinations with established products (*e.g.* a certain share of biofuels in fuels, drop-in bioplastics).

– *Co-existence:* Throughout the 19th century, sail and steam technologies co-existed and together met the growing demand for maritime traffic (Mendonça, 2013). Similarly, the 21st century will be characterized by an increasing fossil- and bio-based production and consumption. The co-existence of the fossil economy and the emerging bioeconomy is likely to last for a long period in which the relative share of bio-based products needs to grow continuously.

– *Co-evolution and complementarities:* Mendonça (2013) illustrates the complementarities or reverse-learning effects that took place between steam and sailing ships. For instance, sailing ships incorporated a "steam tug" into its design for better maneuvering, and steamships incorporated "sails" into their early designs to complete long voyages when the winds were favorable (Mendonça, 2013). Today, bioeconomic knowledge is combined with other knowledge fields (*e.g.* from digitalization) and new applications are generated (*e.g.* food waste reduction and digital food sharing). Similarly, new concepts are introduced (*e.g.* recycling) which were adopted first by fossil-based industries, namely, plastic recycling. Only recently, bio-based industries began to also *imitate* this concept (*e.g.* Bio PE and Bio PET) which allows for recycling as well.

The parallels between the two transition processes then and today stress how in both cases incumbent industries challenged by new technologies tend to safeguard their established dominance and vested interests. Novelties in products, services, and business models (*e.g.* steamships and bio-based products) contribute to the formation of markets and new industries (Berggren *et al.*, 2015; Planko *et al.*, 2016). At the same time, existing industries (*e.g.* sailing ships and fossil-based products) transform (Turnheim, Geels, 2013), industry associations facilitate institutional change and shape societal discourses, lobby for efficacious policy and regulations, develop new industry standards, and create (or undermine) legitimacy for new technologies, practices, and visions (Geels, Verhees, 2011; Rosenbloom *et al.*, 2016).

Also, in the case of the bioeconomy transition, newcomers are associated with radical niche innovations, that may motivate incumbents to align their innovation strategies to the aims of the developing market. This may involve a re-orientation of industries by developing and pushing green technologies (Planko *et al.*, 2016). Such re-orientation will not happen overnight but requires longer transition periods, which, in turn, offers opportunities for mutual learning.

Compared to sustainable niche innovations by bio-based start-ups, the adaptations in incumbent routines and practices can have tremendous positive effects on sustainability in the short run. Due to their sheer proportion of industrial activity, incumbent firms can contribute much more to sustainable economic outcomes, for example, by investments in circular production processes (*e.g.* making progress on recycling systems). Conventional industries can also contribute to SCB transitions by either offering complementary or auxiliary technologies (*e.g.* combustion engines in hybrid cars), or providing the technological knowhow for substitutive solutions (*e.g.* drop-in bioplastics). Such blended technologies provide additional time for the bio-based technologies to develop further. Finally, incumbent industries have accumulated important competences and established networks which cannot easily be replaced by innovative start-ups, *e.g.* concerning the organization of production, international distribution, as well as competences on varying national regulation required for market access and entry. This offers promising opportunities for cooperation between established actors in incumbent fossil industries and emerging start-ups in bioeconomy industries. The cooperation in vaccine production between Pfizer and BioNTech is a striking example for prolific cooperation.

Examples from Selected Bioeconomy Industries

One of the key features of the SSE is a sudden increase in innovative activity by incumbents in the face of the advent of a new technology. In this section, we focus on realignments, connections, and relationships in business networks within the chemical and bioplastics industries, on policies supporting the transition and on technological complementarities as well as changing consumption patterns. New sustainable value propositions emerge as an adaptation either to new environmental regulation and climate change mitigation policies or to changing consumer preferences increasingly considering negative environmental impacts of conventional products. A few examples from the SCB transition are selected to work out the similarities and differences with the SSE effect in order to develop a better understanding of the dynamics despite the extraordinary complexity of an innovation driven transition.

Incumbents' and Start-ups' Strategies in the Transition

The bioeconomy change going on in the chemical industry may serve as an example for both types of the bioeconomy, as described by Vivien *et al.* (2019) and Befort (2020), the biotech- and the biomass-bioeconomy. In the former case the complementarities and interrelated processes between incumbent and start-up actors concerning industrial structures and networks are relevant. In the latter case, the substitution to manage sustainability and reduce dependence on non-renewable resources is important.

On the firm level, the emerging bioplastics sector is currently struggling with competing against traditional business models. To understand the reason for this, we need to look closer at both, the large chemical and the innovative dedicated bioplastic start-up companies and their cooperation strategies. Because of their focus on mass production, economies-of-scale, and the prevailing idea of product durability, the established actors conceive the emerging bioplastics sector as a challenge, which, on the one hand, allows for business opportunities, but on the other hand, represents a costly learning process with uncertain results. Established chemical companies need to decide whether to substitute profitable conventional products with bioplastics, thereby replacing their own established position, or more cautiously, to produce bioplastics alongside conventional plastics (Iles, Martin, 2013). This motivates the companies not only to innovate in new technologies, but also to develop new business models (Demil, Lecocq, 2010). Because of the uncertainty about how biomass feed-stock can add value to them as well as to their customers, they either adapt their existing business models and invest in building in-house biotechnology capabilities, or they choose to partner with agriculture or biotechnology start-ups (Iles, Martin, 2013).

The start-up firms instead need to evaluate whether it is possible to compete with incumbent technologies or to cooperate with incumbent firms by exploiting their specific industrial knowledge and tapping into established supply chains to enter markets and to overcome missing process engineering abilities as well as resources needed for large-scale polymer production. In most cases, the cooperative strategy is chosen.

The Biochemical Industry

The first example illustrates how the emerging bioplastics industry can learn from imitation of the established conventional plastics industry. Not all of the bio-based plastics are also biodegradable. Furthermore, there have been other ongoing debates related to certification issues, ecological footprint, and competition for land use. Because of such sustainability concerns in the potentially superior bioplastics domain, the bioplastics industry is strongly interested in the imitation of circularity concepts developed in conventional plastics. Referring to the SSE example, the bioplastics industry takes the role of steamships imitating an innovation of the sailing ship industry. This way, the introduction of circularity ideas is accelerated and the innovation process in bioplastics avoids *re-inventing the wheel*, making the whole knowledge-generation more efficient.

It has to be mentioned that besides imitation, the implementation of ideas of the circular economy also leads to new cooperation strategies. Today, large chemical companies undertake enormous efforts in collaboration with dedicated start-ups to develop either recyclable and/or biodegradable bioplastic products (*e.g.* BASF's Ecovio, DuPont's PTT and Braskem's Green PE (Gautam *et al.*, 2007; Iles, Martin, 2013)). It can be expected that this cooperation trend will be maintained in future and includes efficient waste management system in the value chain of bioplastics in order to achieve a more sustainable circular bio-based plastic industry (Iles, Martin, 2013).

Looking at the largest players in the global bio-based chemicals market today shows that most of the players originate in petro-chemistry and successfully implemented bioeconomy competences. The key players include Dow Inc. (USA), BASF SE (Germany), DuPont (USA), Braskem (Brazil), BioAmber Inc (USA) and Evonik Industries (Germany) (Market Research Future, 2021). Except for BioAmber, which was founded in 2008 as a renewable chemicals company, the big players all have a long tradition in petrochemistry. These companies follow mixed strategies that entail expansion by building-up own competences, acquisitions to acquire external competences, joint ventures to develop jointly new competences, and technology transfer on the global level to gain market shares. It is remarkable that despite their long experience, most large established companies with huge R&D departments, rely on cooperation with innovative start-ups in bioplastics.

This development illustrates an innovative reaction of the established chemical industry triggered by the advent of the new supposedly more sustainable bioplastics industry. The improvement thrust in recycled plastics market to capture value in the circular economy can be considered as a defense by the chemical industry against developing bio-based markets. Thriving toward a more sustainable circular economy, whether driven by consumer activism or government policy and regulations, has led to a distinct merger and acquisition activity in the form of new alliances, partnerships, and joint ventures (Keas, Forster, 2020). Examples are Quality Circular Polymers, the LyondellBasell and SUEZ joint venture to recycle post-consumer plastic into a high-quality polypropylene (*LyondellBasell*, 2019) and Eastman Chemical's partnership with Circular Polymers to collect discarded post-consumer carpeting and recycle it into feedstocks for use in Eastman's products (*Eastman*, 2019). Whether intended or not – with respect to the changes in the plastics industry landscape (Keas, Forster, 2020) - there is a US$120-billion market opportunity in North America alone for plastics and petrochemicals stemming from recycled waste plastics (Deloitte, 2019). According to the Infoholic Research LLP (2019) report, it is expected that the recycled plastics market will grow globally with annually 6.8% by 2025. This reveals the strong economic incentive provided by the circular economy and can be interpreted as a precursor of changing mergers and acquisitions practices in the chemical industry. The new alliances and business ecosystems potentially drive innovation in a direction that will positively affect the sustainable development of the sector while at the same time allowing the bio-based industries more time to develop. Like in the SSE the established chemical companies exploit existing opportunities to improve the sustainability of established production processes and products. As described a paragraph above, the bioplastics industry benefits twofold: By imitating the circularity processes and gaining time to develop their own products towards market readiness.

The Bioplastics Industry

An example for the emerging bioplastic cooperation business model is provided by the case of polylactic acid (PLA), a compostable biopolymer. The established firm Dow Chemical, not familiar with using biotechnology and agricultural feedstocks in chemical production and the dedicated bioplastics company Cargill with competences in PLA production from corn started a joint venture in 2000, the DoweCargill LLC, to produce PLA from corn (Castilla-Archilla *et al.*, 2019). A business model was developed to combine Cargill's technology with Dow's expertise in polymer production and marketing. The collaboration offered an opportunity for both companies to mutually benefit from the partner's capability for the emerging biopolymer market (Iles, Martin, 2013). However, the joint venture failed due to PLA's costliness compared to conventional polymers and due to the difficulties to convince customers of the superiority of the corn-based PLA compared to conventional material such as PET, in both environmental and performance terms. This failure in a market-relevant application of a renewable material increased skepticism (Iles, Martin, 2013) but was only one step in a learning process. Later, in 2005, Cargill bought out Dow's share (Tullo, 2005; Castilla-Archilla *et al.*, 2019) and in 2007, Cargill and Teijin Corporation, a large Japanese chemical company, built a new partnership to found NatureWorks LLC and created the brand "Ingeo" for their PLA (Larson *et al.*, 2012). This company finally managed marketing the product as compostable material which is ideal for packaging and beverage applications, and also obtained a cost reduction by expanding its scale of production (Iles, Martin, 2013).

Figure 1 **– Illustration of an example business model established for the production of a bio-based chemical PLA**

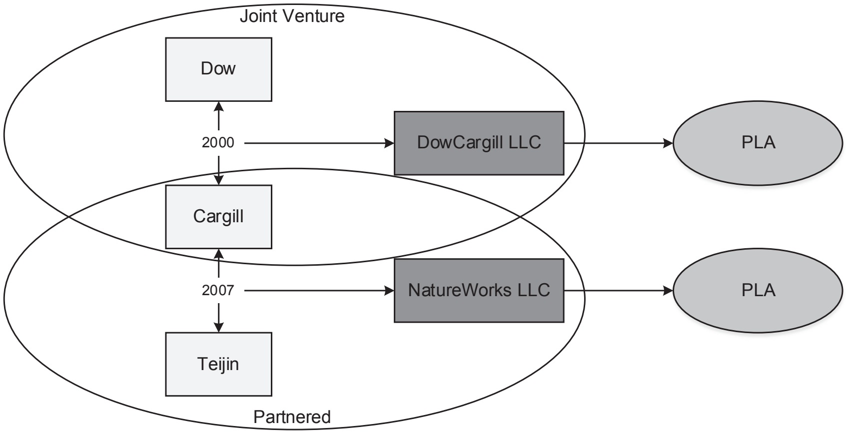

Figure 1 illustrates the case of PLA and shows how a business strategy evolved for an early biopolymer production by combining competences in innovation cooperation to form a business model that suits bio-based chemicals. Obviously, the DoweCargill joint venture failed to engage business stakeholders, and customers continued to have concerns about the PLA's performance and its sustainability as a starch-based product. With this experience in mind, Cargill took the chance again seven years later. With its new joint venture, NatureWorks, they managed to actively shape the bioplastics ecosystem while staying attentive to market needs. The example illustrates the justification and the benefit of a co-existence of large established and small dedicated companies now and in the future. Clearly, the specific technological competences are not easily developed in established companies nor can dedicated bioplastic companies easily develop the complementary capabilities of large-scale production and distribution.

A further example highlighting the importance of suitable cooperation strategies for the established chemical companies is presented by DuPont. Their development of bioplastics was a response to a competitive threat to its polymer division. Shell Chemical commercialized a new way to manufacture polytrimethylene terephthalate (PTT) polymers. Shell's competitive advantage was based on their ability to economically produce large quantities of the fossil fuel-based monomer 1, 3 propanediol (PDO). To protect the market share it had acquired through its established nylon business, DuPont sought to develop a PTT business model by researching other economical routes of PDO production. As early as 1995, DuPont created an R&D partnership with Genecor, an industrial enzyme producer to investigate a sugar-based route to

PDO. Because of the envisaged opportunities, DuPont re-calibrated its business model to focus on bio-PDO as the foundation for new product lines that could be marketed as renewable resources. Today, DuPont has set corporate sustainability goals, continues making new dedicated acquisitions, and is also focusing internally on bio-based initiatives. DuPont also created a bio-based materials unit that unifies scientific expertise in bioconversion and complementary partnerships with agri-food companies such as Tate & Lyle and the acquisition of biotechnology firms such as Genencor (Iles, Martin, 2013). This example illustrates that despite a long-term engagement in bioplastics, DuPont still relies on the cooperation with dedicated bioplastic companies which explains the co-existence of these different types of firms in one narrowly defined industry.

The examples of Cargill and Dupont are not rare exceptions. Today there are various types of business collaborations between established industry companies and new firms or start-ups to produce bio-based products. Castilla-Archilla *et al.* (2019) describe in detail two further examples for acrylic acid (used in plastic manufacture) from renewable feedstock (sugars dextrose or sucrose) and for biosuccinic acid (used in certain biodegradable polymer production) from corn mainly as feedstock (Castilla-Archilla *et al.*, 2019).

The above examples illustrate how, like in the 19th century case of the SSE, the appearance of potential competitors introducing bio-based solutions triggered innovation in the established fossil-based industry with a motivation to prolong their dominance in the market. In contrast to the sailing ship industry 150 years ago, the chemical industry today is adopting, at least partly, a cooperation strategy to internalize the new knowledge, to enlarge their product portfolio and to improve their ecological footprints.

Other Actors Influencing the Transition: Policies and Consumers

As mentioned in the previous section, Geels and Schot (2007) proposed the concept of transition pathways which Imbert *et al.* (2017) apply to relate the bioeconomy policy strategies to the transition dynamics taking place in the bioplastics sector. The authors illustrate the broader dynamics of transition towards bio-based feedstock within the chemical sector, where the waste management regime plays a key role, either for enabling or constraining the market uptake of bioplastics.

In Germany, the established regime together with a top-down policy strategy aims for incremental improvements along the well-established paths and prevents a rapid and disruptive change. Imbert *et al.* (2017) argue that the bioeconomy transition process in Germany follows a gradual and incumbents-friendly regime adjustment transformation pathway. This enduring reliance on the established industry prevents more ambitious measures to promote markets for bioplastics. Consequently, the transition efforts remain restricted to the establishment of more advanced recycling systems for conventional plastics (Umweltbundesamt, 2013).

In contrast, in Italy – meanwhile leading in bioplastics – the bioeconomy transition policy resembles a *reconfiguration pathway*, which is favored by environmental concerns, a struggling chemical sector, and an insufficient waste management regime. Thus, the Italian bioplastics sector is promoted as an alternative to conventional plastics by environmental NGOs along with Italy's policy in favor of the emergence of new actors and alliances (Imbert *et al.*, 2017).

Ari (2020) and Pannicke *et al.* (2015) confirm the shortcomings of innovation policy approaches such as the German one with regards to their capacity to overcoming lock-in and path dependency effects because of the strong weight attached to established actors. European bioeconomy strategies often fail in developing a real path transition towards a sustainable bioeconomy, because existing policies generally support more of R&D and pilot projects, such as clusters of excellence in the Bioeconomy while neglecting engagement with other actors than the established ones.

In the transition to the SCB – maybe to a larger extent than in the steam ship transition – old technologies are also challenged by new consumer behavior and expectations, as well as changed regulations. In analogy with the MLP, these combined effects can be perceived as landscape changes arising from megatrends, such as sustainability (Prothero, McDonagh, 2015) or digitalization (Haefner, Sternberg, 2020). The imminent climate change, changing consumer preferences, and the new digital opportunities provide extra motivation for incumbents to innovate in addition to the pressure exerted by new market entrants. In many cases, this demand-side pressure contributes to a growing SCB to a much higher degree than it did in the case of the emerging steam ship regime. Therefore, incorporating the consumer realm and its co-evolution along with the industry by identifying the specific feedback mechanisms (Almudi, Fatas-Villafranca, 2018) can provide more insights on how such co-evolution engenders the change towards the SCB.

The current co-existence of fossil-based and bio-based technologies resembles the phase in the SSE before the socio-technological change was completed and sailing ships co-exist with steamboats. But in contrast to the SSE, we do not know the outcome, and the transition to a SCB might not directly terminate the fossil era. While the disappearance of old technologies themselves will eventually come true (observed, for instance, in the decline of diesel and gasoline-powered vehicles, single-use plastics, plastic carrier bags etc.), some of the dominant actors might survive by adapting to the transition or becoming part of the transition. In many cases, a continuation of the current co-evolutionary developments of both old and new technologies will be observed, in which complementarities, cross-fertilizations, knowledge exchange, and reciprocal dissemination take place and large established firms as well as dedicated start-up companies co-exist. They will enter new forms of cooperation and mutually develop new knowledge. The business examples do not suggest the existence of a strong substitutive competition but rather highlight the opportunities of cooperation to jointly develop from the exchange of heterogeneous and highly specialized knowledge as well as from sharing competences in complementary activities.

Conclusions

The growing global population, which will become increasingly affluent, combined with the projected effects of climate change, requires a major transition in the way food, energy, and raw materials are produced, consumed, processed, and disposed. The concept of a SCB has emerged as an important part of a potential solution for these sustainability challenges. Without doubt, transitioning from a fossil-based economy to a bio-based economy entails much more than substituting fossil resources with renewable biological resources. This transition entails an exceptionally complex, uncertain, and lengthy process, which will require the active participation of the myriad of actors involved in the bioeconomy value chains.

Our paper uses the historical case of the remarkable persistence of sailing ships to stay in the market in the face of the development of steam-driven ships in the second half of the 19th century as a source of inspiration. We posed the question in which way the SSE perspective can help to better understand the processes taking place in the transition towards a SCB. The SSE provides a narrative about technological improvements of incumbent technologies and helps to shed light on the complexity of the SCB transition as it *sails into stormy seas* towards a widespread market adoption. By using the SSE analogies for the SCB, for the production of more sustainable, bio-based industrial chemicals, liquid fuels, and plastics, we have separated and closely examined some of the transition dynamics observed in the historical context of the SSE (*e.g.* technology lock-in, changed regulatory settings, cross-fertilizing innovation, co-existence, co-evolution and complementarities) that also take place within the current SCB transition. One fundamental difference observed is the additional motivation for fossil industries to innovate stemming from the megatrends sustainability and digitalization – two kinds of landscape changes that put extra pressure on incumbents of the SCB transition and have no analogy in the SSE.

We would like to motivate future research to explore questions like, what kind of supply chain models have a stronger impact on the transition towards a SCB, or to what extent do the companies' traditional value propositions hinder constructing business models for bio-based markets to realize ecological and social value. The application of the sailing ship analogy is considered to be helpful here. Referring to the SSE and the particular differences in the present-day transition highlights the effect of co-existence of established companies and start-ups and the role of co-evolutionary dynamics which improve the new bioeconomy technologies and reduce the environmental footprint of established technologies. Two hundred years ago, sailing ships had limited room for improvement of speed and reliability. Similarly, the fossil-based industry today has no room for renewability, less room for circularity, and therefore limited room for a contribution to sustainable development. The steamships' niche transformed into a new regime with novel practices, which culminated in a complete technological transformation that led to a change in socio-technical regime. While the SSE was followed by an industrial revolution, the establishment of the SCB, too, has the potential to make a lasting impact on the system: the substitution of fossil by bio-based technology holds the potential to incite the required sustainability revolution.

REFERENCES

ALMUDI, I., FATAS-VILLAFRANCA, F. (2018), Promotion and Coevolutionary Dynamics in Contemporary Capitalism, *Journal of Economic Issues*, 52(1), 80-102.

ARI, E. (2020), *Deconstructing Paradigms: National Bioeconomy Policies and Their Capacity to Break the Fossil Era*, Master Thesis, University of Hohenheim.

BEFORT, N. (2020), Going Beyond Definitions to Understand Tensions within the Bioeconomy: The Contribution of Sociotechnical Regimes to Contested Fields, *Technological Forecasting and Social Change*, 153, 119923.

BERGGREN, C., MAGNUSSON, T., SUSHANDOYO, D. (2015), Transition Pathways Revisited: Established Firms as Multi-Level Actors in the Heavy Vehicle Industry, *Research Policy*, 44(5), 1017-1028.

BIOÖKONOMIERAT (2018), *Bioeconomy Policy (Part III): Update Report of National Strategies around the World*, A Report from the German Bioeconomy Council.

BOSMAN, R., ROTMANS, J. (2016), Transition Governance towards a Bioeconomy: A Comparison of Finland and the Netherlands, *Sustainability*, 8(10), 1017.

BUGGE, M., HANSEN, T., KLITKOU, A. (2016), What is the Bioeconomy? A Review of the Literature, *Sustainability*, 8(7), 691.

CASTILLA-ARCHILLA, J., O'FLAHERTY, V., LENS, P. N. L. (2019), Biorefineries: Industrial Innovation and Tendencies, in Bastidas-Oyanedel, J.-R., Schmidt, J. E. (eds), *Biorefinery*, Cham, Springer International Publishing, 3-35.

D'AMATO, D., DROSTE, N., ALLEN, B., KETTUNEN, M., LÄHTINEN, K., KORHONEN, J., LESKINEN, P., MATTHIES, B. D., TOPPINEN, A. (2017), Green, Circular, Bio Economy: A Comparative Analysis of Sustainability Avenues, *Journal of Cleaner Production*, 168, 716-734.

DE BESI, M., MCCORMICK, K. (2015), Towards a Bioeconomy in Europe: National, Regional and Industrial Strategies, *Sustainability*, 7(8), 10461-10478.

DELOITTE (2019), The Changing Plastics Landscape: Is the Chemical Industry Prepared?, Available online at https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-the-changing-single-use-plastics-landscape.pdf

DEMIL, B., LECOCQ, X. (2010), Business Model Evolution: In Search of Dynamic Consistency, *Long Range Planning*, 43(2-3), 227-246.

DIETZ, T., BÖRNER, J., FÖRSTER, J., VON BRAUN, J. (2018), Governance of the Bioeconomy: A Global Comparative Study of National Bioeconomy Strategies, *Sustainability*, 10(9), 3190.

EASTMAN (2019), *Eastman to Recycle Discarded Carpet into New Materials*, Available online at https://www.eastman.com/Company/News_Center/2019/Pages/Eastman-to-recycle-discarded-carpet-into-new-materials.aspx

EUROPEAN COMMISSION (2019), *The European Green Deal: Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions*, Off. J. Eur. Union, 1.

FILATRELLA, G., DE LISO, N. (2020a), Predicting one Type of Technological Motion? A Nonlinear Map to Study the 'Sailing-Ship' Effect, *Soft Computing*, 24(18), 13813-13822.

FILATRELLA, G., DE LISO, N. (2020b), The R&D Stochastic Component within the 'Sailing-Ship Effect', *Economics of Innovation and New Technology*, 1-19.

FOXON, T. J., KOHLER, J., MICHIE, J., OUGHTON, C. (2013), Towards a New Complexity Economics for Sustainability, *Cambridge Journal of Economics*, 37(1), 187-208.

FREEMAN, C. (1994), The Economics of Technical Change, *Cambridge Journal of Economics*, 18(5), 463-514.

FRITSCHE, U., BRUNORI, G., CHIARAMONTI, D., GALANAKIS, C., HELLWEG, S., MATTHEWS, R., PANOUTSOU, C. (2020), *Future Transitions for the Bioeconomy towards Sustainable Development and a Climate-Neutral Economy – Knowledge Synthesis Final Report*, Luxembourg, Publications Office of the European Union.

GAUTAM, R., BASSI, A. S., YANFUL, E. K. (2007), A Review of Biodegradation of Synthetic Plastic and Foams, *Applied Biochemistry and Biotechnology*, 141(1), 85-108.

GAWEL, E., PANNICKE, N., HAGEMANN, N. (2019), A Path Transition towards a Bioeconomy: The Crucial Role of Sustainability, *Sustainability*, 11(11), 3005.

GEELS, F. W. (2002), Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study, *Research Policy*, 31(8-9), 1257-1274.

GEELS, F. W. (2005a), The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860–1930), *Technology Analysis & Strategic Management*, 17(4), 445-476.

GEELS, F. W. (2005b), *Technological Transitions and System Innovations: A Co-Evolutionary and Socio-Technical Analysis*, Cheltenham, UK, Edward Elgar.

GEELS, F. W., SCHOT, J. (2007), Typology of Sociotechnical Transition Pathways, *Research Policy*, 36(3), 399-417.

GEELS, F. W., VERHEES, B. (2011), Cultural Legitimacy and Framing Struggles in Innovation Journeys: A Cultural-Performative Perspective and a Case Study of Dutch Nuclear Energy (1945–1986), *Technological Forecasting and Social Change*, 78(6), 910-930.

HAEFNER, L., STERNBERG, R. (2020), Spatial Implications of Digitization: State of the Field and Research Agenda, *Geography Compass*, 14(12).

HAGEMANN, N., GAWEL, E., PURKUS, A., PANNICKE, N., HAUCK, J. (2016), Possible Futures towards a Wood-Based Bioeconomy: A Scenario Analysis for Germany, *Sustainability*, 8(1), 98.

HEIMANN, T. (2019), Bioeconomy and SDGs: Does the Bioeconomy Support the Achievement of the SDGs?, *Earth's Future*, 7(1), 43-57.

HERMANS, F. (2018), The Potential Contribution of Transition Theory to the Analysis of Bioclusters and Their Role in the Transition to a Bioeconomy, *Biofuels, Bioproducts and Biorefining*, 12(2), 265-276.

HOWELLS, J. (2002), The Response of Old Technology Incumbents to Technological Competition: Does the Sailing Ship Effect Exist?, *Journal of Management Studies*, 39(7), 887-906.

ILES, A., MARTIN, A. N. (2013), Expanding Bioplastics Production: Sustainable Business Innovation in the Chemical Industry, *Journal of Cleaner Production*, 45, 38-49.

IMBERT, E., LADU, L., MORONE, P., QUITZOW, R. (2017), Comparing Policy Strategies for a Transition to a Bioeconomy in Europe: The Case of Italy and Germany, *Energy Research & Social Science*, 33, 70-81.

INFOHOLIC RESEARCH LLP (2019), *Recycled Plastics Markets Report*, Available online at www.infoholicresearch.com/report/recycled-plastics-market/

JANDER, W., GRUNDMANN, P. (2019), Monitoring the Transition towards a Bioeconomy: A General Framework and a Specific Indicator, *Journal of Cleaner Production*, 236, 117564.

KEAS, A., FORSTER, J. (2020), *Global Chemical Industry Mergers and Acquisitions Outlook*, Available online at https://www2.deloitte.com/de/de/pages/energy-and-resources/articles/global-chemical-mergers-acquisition-outlook.html

KÖHLER, J., GEELS, F. W., KERN, F., MARKARD, J., ONSONGO, E., WIECZOREK, A., ALKEMADE, F., AVELINO, F., BERGEK, A., BOONS, F., FÜNFSCHILLING, L., HESS, D., HOLTZ, G., HYYSALO, S., JENKINS, K., KIVIMAA, P., MARTISKAINEN, M., MCMEEKIN, A., MÜHLEMEIER, M. S., NYKVIST, B., PEL, B., RAVEN, R., ROHRACHER, H., SANDÉN, B., SCHOT, J., SOVACOOL, B., TURNHEIM, B., WELCH, D., WELLS, P. (2019), An Agenda for Sustainability Transitions Research: State of the Art and Future Directions, *Environmental Innovation and Societal Transitions*, 31, 1-32.

KUCKERTZ, A., BERGER, E. S., BRÄNDLE, L. (2020), Entrepreneurship and the Sustainable Bioeconomy Transformation, *Environmental Innovation and Societal Transitions*, 37, 332-344.

LARSON, A., O'BRIEN, K., ANDERSON, A. (2012), *Natureworks: Green Chemistry's Contribution to Biotechnology, Innovation, Commercialization, and Strategic Positioning: Entrepreneurship and Sustainability*, Darden Case No.

LISO, N. DE, FILATRELLA, G. (2008), On Technology Competition: A Formal Analysis of the 'Sailing-Ship Effect', *Economics of Innovation and New Technology*, 17(6), 593-610.

LYONDELLBASELL (2019), *LyondellBasell and SUEZ Collaborate with Samsonite to Create Recycled Plastic Suitcase Collection*, Available online at https://www.lyondellbasell.com/en/news-events/corporate--financial-news/lyondellbasell-and-suez-collaborate-with-samsonite-to-create-recycled-plastic-suitcase-collection/

MARKET RESEARCH FUTURE (2021), *Bio-Based Chemicals Market: Information by Type (Bioplastics, Bio-Lubricants, Bio-Solvents, Bio-Alcohols, Bio-Based Acids, Bio-Surfactants), Application (Food & Beverage, Pharmaceuticals, Agriculture, Packaging), and Region: Global Forecast till 2023*, Available online at https://www.marketresearchfuture.com/reports/bio-based-chemicals-market-5706.

MCCORMICK, K., KAUTTO, N. (2013), The Bioeconomy in Europe: An Overview, *Sustainability*, 5(6), 2589-2608.

MENDONÇA, S. (2013), The "Sailing Ship Effect": Reassessing History as a Source of Insight on Technical Change, *Research Policy*, 42(10), 1724-1738.

MEYER, R. (2017), Bioeconomy Strategies: Contexts, Visions, Guiding Implementation Principles and Resulting Debates, *Sustainability*, 9(6), 1031.

MORONE, P. (2018), Sustainability Transition towards a Biobased Economy: Defining, Measuring and Assessing, *Sustainability*, 10(8), 2631.

NAINWAL, A. (2018), Sailing Ship Effect, *International Journal of Economics & Management Sciences*, 07(01).

NELSON, R. R., DOSI, G., HELFAT, C., PYKA, A., SAVIOTTI, P. P., LEE, K., DOPFER, K., MALERBA, F., WINTER, S. (2018), *Modern Evolutionary Economics: An Overview*, Cambridge, Cambridge University Press.

PANNICKE, N., GAWE, E., HAGEMANN, N., PURKUS, A., STRUNZ, S. (2015), The Political Economy of Fostering a Wood-based Bioeconomy in Germany, *German Journal of Agricultural Economics*, 64(670-2018-1988), 224-243.

PFAU, S., HAGENS, J., DANKBAAR, B., SMITS, A. (2014), Visions of Sustainability in Bioeconomy Research, *Sustainability*, 6(3), 1222-1249.

PLANKO, J., CRAMER, J. M., CHAPPIN, M. M., HEKKERT, M. P. (2016), Strategic Collective System Building to Commercialize Sustainability Innovations, *Journal of Cleaner Production*, 112, 2328-2341.

PROTHERO, A., MCDONAGH, P. (2015), Introduction to the Special Issue, *Journal of Macromarketing*, 35(1), 7-10.

PYKA, A. (2017a), Dedicated Innovation Systems to Support the Transformation towards Sustainability: Creating Income Opportunities and Employment in the

Knowledge-Based Digital Bioeconomy, *Journal of Open Innovation: Technology, Market, and Complexity*, 3(1), 385.

PYKA, A. (2017b), Die Bioökonomie unter dem Blickwinkel der Innovationsökonomie, in Pietzsch, J. (ed.), *Bioökonomie für Einsteiger*, Berlin, Springer Spektrum, 129-138.

PYKA, A., PRETTNER, K. (2018), Economic Growth, Development, and Innovation: The Transformation towards a Knowledge-Based Bioeconomy, in Lewandowski, I. (ed.), *Bioeconomy*, Cham, Springer, 331–342.

ROSENBLOOM, D., BERTON, H., MEADOWCROFT, J. (2016), Framing the Sun: A Discursive Approach to Understanding Multi-Dimensional Interactions within Socio-Technical Transitions through the Case of Solar Electricity in Ontario, Canada, *Research Policy*, 45(6), 1275-1290.

SCHLAILE, M. P., URMETZER, S., BLOK, V., ANDERSEN, A., TIMMERMANS, J., MUELLER, M., FAGERBERG, J., PYKA, A. (2017), Innovation Systems for Transformations towards Sustainability? Taking the Normative Dimension Seriously, *Sustainability*, 9(12), 2253.

SCIAVONE, F. (2014), Innovation Approaches for Old Products Revitalization after Technological Change: The Rise of Technology Reverse, *International Journal of Innovation Management*, 18(02), 1450011.

SICK, N., NIENABER, A.-M., LIESENKÖTTER, B., VOM STEIN, N., SCHEWE, G., LEKER, J. (2016), The Legend About Sailing Ship Effects – Is It True or False? The Example of Cleaner Propulsion Technologies Diffusion in the Automotive Industry, *Journal of Cleaner Production*, 137, 405-413.

SUSHANDOYO, D., MAGNUSSON, T., BERGGREN, C. (2012), 'Sailing Ship Effects' in the Global Automotive Industry? Competition between 'New' and 'Old' Technologies in the Race for Sustainable Solutions, in Calabrese, G. (ed.), *The Greening of the Automotive Industry*, London, Palgrave Macmillan, 103-123.

THE ELLEN MACARTHUR FOUNDATION (2013), *Towards a Circular Economy*.

TULLO, A. (2005), News of the Week: Industrial Biotech: Codexis, Cargill Claim Chemical Breakthrough, *Chemical and Engineering News*, 83(26), 11.

TURNHEIM, B., GEELS, F. W. (2013), The Destabilisation of Existing Regimes: Confronting a Multi-Dimensional Framework with a Case Study of the British Coal Industry (1913–1967), *Research Policy*, 42(10), 1749-1767.

UMWELTBUNDESAMT (2013), *Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics*, Umweltbundesamt.

UNITED NATIONS (2015), *Transforming Our World: The 2030 Agenda for Sustainable Development.*, New York, UN Publishing.

URMETZER, S. (2020), *The Bioeconomy: A Knowledge-Based Innovation Paradigm to Foster Sustainability Transformations*, Doctoral Thesis, University of Hohenheim.

URMETZER, S. (2021), Dedicated Business Models: Connecting Firms' Values with the Systemic Requirements of Sustainability, *Journal of Business Model*, 9(2), 87-108.

URMETZER, S., LASK, J., VARGAS-CARPINTERO, R., PYKA, A. (2020), Learning to Change: Transformative Knowledge for Building a Sustainable Bioeconomy, *Ecological Economics*, 167, 106435.

URMETZER, S., PYKA, A. (2017), Varieties of Knowledge-based Bioeconomies, in Dabbert, S., Lewandowski, I., Weiss, J., Pyka, A. (eds), *Knowledge-driven Developments in the Bioeconomy: Technological and Economic Perspectives*, Cham, Springer, 57-82.

VIVIEN, F.-D., NIEDDU, M., BEFORT, N., DEBREF, R., GIAMPIETRO, M. (2019), The Hijacking of the Bioeconomy, *Ecological Economics*, 159, 189-197.

WILKE, U., SCHLAILE, M. P., URMETZER, S., MÜLLER, M., BOGNER, K., PYKA, A. (2021), Time to Say 'Good Buy' to the Passive Consumer? A Conceptual Review of the Consumer in the Bioeconomy, *Journal of Agricultural and Environmental Ethics*, 34(4), 1-35.

ZINKE, H., EL-CHICHAKLI, B., DIECKHOFF, P., WYDRA, S., HÜSING, B. (2016), *Bioökonomie für die Industrienation – Ausgangslage für Biobasierte Innovationen in Deutschland Verbessern*.