The Bioeconomy from the Point of View of Innovation Economics

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"Add as many mail-coaches as you please, you will never get a railroad by so doing." – With these words, the economist Joseph Schumpeter symbolized the discontinuity of progress, a fitting characterization of the transition to the bioeconomy as well. (© spiritofamerica/Fotolia torsakarin/Fotolia)

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6.1 The Discontinuity of Progress

After more than 200 years of industrial production, large portions of humankind are wealthier than ever before. At the same time, industrial production is closely linked to the exploitation of natural resources. The influence of human activity has reached global dimensions as can be seen most clearly from the accumulation of climate-damaging gases in the atmosphere. This endangers human survival on planet Earth. Continuing "business as usual" is no longer an option. But how can the future be shaped, and humanity provided with a high or even increasing level of welfare, without continuing to risk the natural conditions of life? At the beginning of the twenty-first century, many economies worldwide are linking their answers to this question with the knowledge-based bioeconomy. Is this really a way out? This will be examined in the following from the perspective of innovation economics.

Among economists there is wide agreement that technological progress is the main driver of quantitative growth measured by the per capita income of economies. However, far less agreement exists on the qualitative characteristics of economic development: while the mainstream-oriented branch of economics, neoclassical economics (often referred to as the "economic sciences"), is limited to the purely quantitative view, and thus remains within its short term orientation, Neo-Schumpeterian economics assumes the qualitative perspective, and thus places change in fundamental economic structures over longer periods of time at the centre of its analysis.

Processes of change can be attributed both to incremental innovations and to structural changes, such as the emergence of new industries and the disappearance of old ones. To simplify matters, one can assume that incremental technological improvements in the sense of gradual improvement innovations build on already existing technological solutions, while structural changes are triggered by radical technological breakthroughs (major innovations) that question larger production contexts. They can, if necessary, lead to drastic changes, in the sense of "creative destruction" (Schumpeter 1943) of the world production system as a whole (► Excursus 6.1).

This chapter deals with a fundamental transformation of production systems: The overcoming of the *lock-in* of the current production system in fossil energy sources (Unruh 2000) and the simultaneous establishment of a knowledge-based bioeconomy (Pyka 2017; Pyka and Buchmann 2017). There is no doubt that this is a radical, qualitative and long-term transformation process that must be considered in the innovation-economic approach of Neo-Schumpeterian economics.

Excursus 6.1 The Great Cycles of Innovation

By 1939, in his *Business cycles*, Schumpeter had already revived Kondratieff's "Theory of long waves," explaining that this is a process of economic development that is quite normal in the long term. Most famous is his picture for clarifying the discontinuous character: "*Add as many mail-coaches as you please, you will never get a railroad by so doing*" (Schumpeter 1934). The first long wave began around 1800 with industrialization and was driven by the basic technology of steam engines and cotton processing. The wide availability of steel and railways then determined the second long wave, from around 1850 onwards, which, in turn, was replaced at the beginning of the twentieth century by electrical engineering and the chemical industry. With mass production and the automotive and petrochemical industries, the third long wave started rolling in the middle of the last century. As a result, a second fossil energy source, crude oil, moved to the centre of production activities, alongside coal. Since the 1980s, a fifth long wave is emerging which is reflected in solutions related to information and communication technology. At the beginning of the twenty-first century, another paradigmatic change of this kind is now on the horizon, albeit with a great difference from the previous upheavals. While the past cycles were driven by economic bottlenecks and the need to overcome them technologically, in the twenty-first century, humankind is faced with the crucial question of how it can restore the ecological sustainability of economic activity. A central role in this process of change, which is characterised by true uncertainty (Knight 1921), is to be played by the approach known as the knowledge-based bioeconomy (▣ Fig. 6.1).

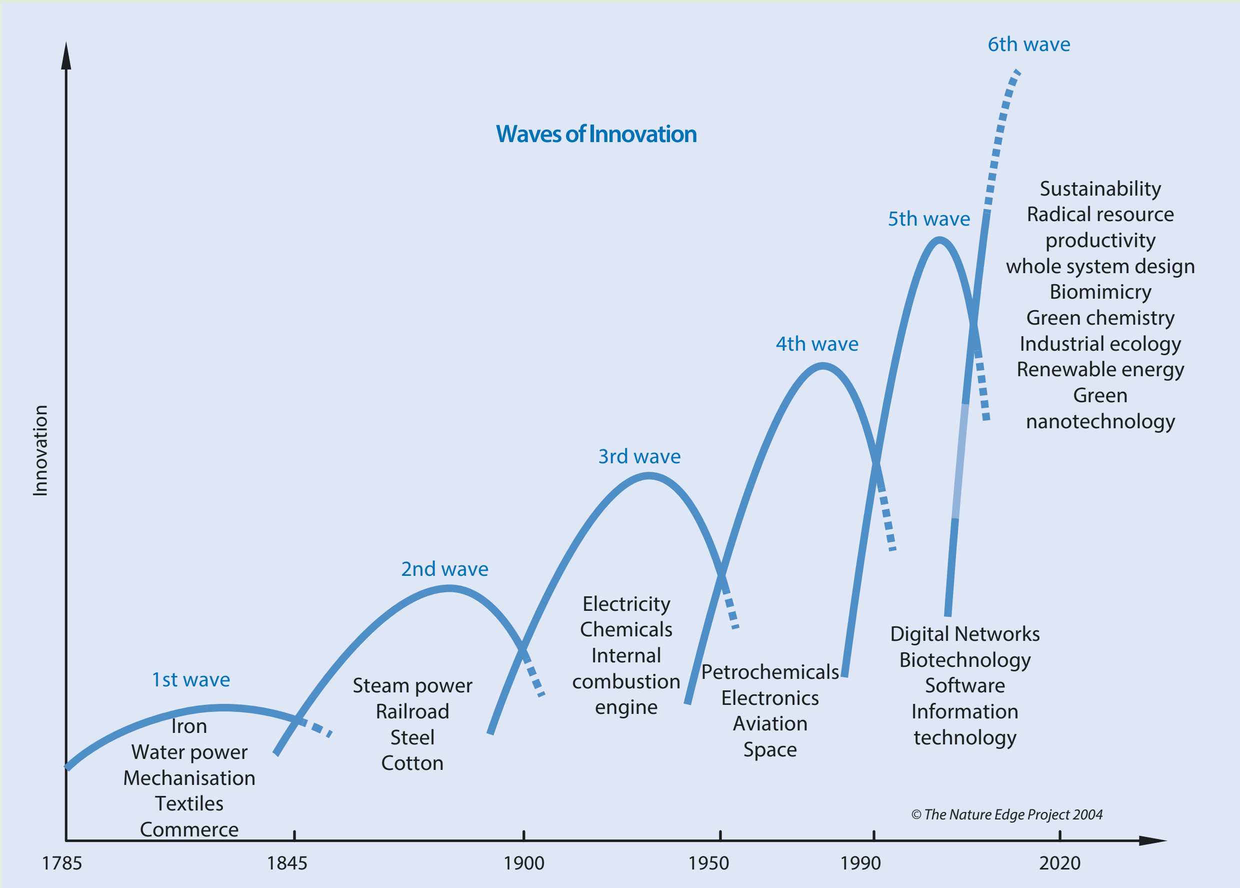


Fig. 6.1 According to Kondratieff's theory, the essential technologies of the sixth wave of innovation, which began at the turn of the twenty-first century, can be assigned to the necessity of ecological sustainability. (Own representation after von Weizsäcker 2010)

In the meantime, the literature discusses numerous alternative terms for structural changes and processes of change that affect the entire production system of the world economy. Freeman and Dosi call them "techno-economic paradigm changes" (Dosi 1982; Freeman 1991), Sahal uses cartographic analogies and refers to "technological guideposts" that are pointing to new "technological avenues" (Sahal 1985). In all of the studies, it is emphasized that economic systems over larger periods of several decades are confronted again and again with enormous upheavals, which question practically all established production approaches. Even in cases in which a single technology triggers these upheavals, this technology alone is not alone responsible for comprehensive changes to be observed. Rather, it forms the basis for several complementary developments. Let us look at the combustion engine, for example. It is part of a package of interdependent technologies, such as advances in petrochemicals and the introduction of assembly line production. The integration of these technologies, in turn, triggers numerous infrastructural developments, such as the establishment of a network of petrol stations and the expansion of motorways. This goes hand in hand with behavioural changes. People settle in suburbs and exurbs around the megacities. They commute to work and shop in shopping malls outside of the city. This results in institutional changes. The policy field of spatial planning is established, and commuting allowances are introduced for tax purposes. These are merely representative examples of the complex diversity of interdependent elements in fundamental processes of change. Only the interplay of all such elements allows a new paradigm to displace the old.

The Neo-Schumpeterian approach provides decisive clues as to how the forthcoming processes of change can take place. This will be clarified in ▶ Sect. 6.2. It briefly outlines the reflections of growth-pessimistic approaches, such as the *post-growth* or *degrowth* approaches, which enjoy great popularity. Then, it contrasts them with growth-optimistic approaches that uphold Schumpeter's intellectual heritage and rely on the creative forces of capitalist economies to overcome humankind's fundamental problems. Innovations are based on the discovery and successful dissemination of new knowledge. Knowledge-based societies organise innovation systems that are composed of different actors successfully combining their knowledge. This is what ▶ Sect. 6.3 deals with. No innovation would ever have been able to succeed on the market if consumers had not taken an interest in it and if their purchasing power had not helped innovative solutions to break through. ▶ Section 6.4 sheds light on the consequences of this insight. In knowledge-based societies, new concepts, in the sense of responsible innovation, will play an important role if an entire economy is to be steered onto a new, sustainable path of development. From these technology- and knowledge-driven changes, massive economic developments take their point of departure. This is discussed in ▶ Sect. 6.5. In addition to technological change, in a co-evolutionary process, institutional change will also have to take place to enable the new sustainable technologies to provide the prerequisites for the desired transformation of the economic system. ▶ Section 6.6 shows that economic policy must actively accompany this change if it is to succeed.

6.2 Limits to Growth?

As early as 1972, when the *Club of Rome* published its report "The Limits to growth" (Meadows et al. 1972), the status quo in Western industrialized economies calls into question the capitalist organization concerning its sustainability. Since then, the conservation of resources through growth abstinence on the one hand and the decoupling of growth and the exploitation of resources on the other have been discussed as two fundamentally different solution strategies for society. The first idea can be summarized by the keywords "abstinence" and "downscaling." Its proponents call for a move away from a lifestyle based on consumption and the increasing deployment of resources (Kallis et al. 2012; Blewitt and Cunningham 2014). This demand goes hand in hand with a mistrust of the adaptability of market-oriented economic systems, which are not expected to be able to change through endogenous market forces in the direction of greater sustainability. The most extreme versions ask for a return to small-scale regional agriculture or subsistence farming. Only in this way could a way of life and economy be made possible that is sustainable and that conserves resources. It is easy to see that this notion is in line with the neoclassical view, which refers to economic growth solely in regard to existing economies and their quantitative change, without taking into account the dynamics of change.

The second way, on the other hand, is characterised by the idea that innovation, market forces, structural change and urban lifestyles are part of the solution to the sustainability problem. It can thus be assigned to the Neo-Schumpeterian view. Especially in the late 20th and early 21st centuries, the capitalist-oriented economy has impressively demonstrated its global power for change: Through creative entrepreneurship in free markets, such as in China, for example, more people could be brought out of poverty in a short time (one of the 17 sustainable development goals of the United Nations until 2030) than through 50 years of development aid before. New creative solutions can reform our way of doing business in a sustainable way in the future, supporting the achievement of the UN's sustainable development goals and, at the same time, allowing growth and development to take place (Mazzucato and Perez 2015).

The guiding idea of the knowledge-based bioeconomy is based on the premise that abstinence, in the sense of economic dismantling, is neither the first goal nor the only solution. In principle, however, there is agreement with the supporters of the first approach that certain production and consumption patterns of the past urgently need to be changed, and that participatory elements must be included. In particular, concepts that result in a more intensive use of goods, and thus contribute to the conservation of resources (*sharing economy*), are of importance. The same applies to closed material cycles, recycling and intelligent waste treatment. Such concepts are ideally suited to the triggering of learning processes and behavioural changes among consumers. The core idea of the knowledge-based bioeconomy, however, is that, within the framework of a comprehensive economic transformation process (Geels 2002), new technological solutions are demanded and provided, i.e., that alternative goods and services are demanded, produced and delivered in a different, namely sustainable way. Exploiting the technological possibilities of the bioeconomy not only creates new investment opportunities, but is also a prerequisite starting point for socio-economic and cultural change – which will only succeed if consumers accept bio-based products and ask for appropriate solutions from companies. As a result, innovation, functioning markets and changing consumer attitudes become complementary conditions for creating a sustainable production system.

Representatives of the Neo-Schumpeterian school (Dosi et al. 1988; Lundvall 1992, 1998; Nelson 1993) point to the systemic character of innovation processes in knowledge-intensive economic sectors. So-called innovation systems consist of different actors (including companies, research institutions, political actors, and consumers) and the links between these actors (e.g., flows of goods, research and development cooperations, knowledge transfer relations, consumer-producer relations). Such connections are the prerequisite for mutual learning and joint knowledge development for the purpose of solving complex innovation tasks. Such systems are dynamic and co-evolutionary. This makes them enormously complex, because, over time, both the actors and their knowledge and the links and interactions between them are exposed to changes.

According to this systemic understanding, technological paradigms are defined as "…a set of procedures, a definition of the 'relevant' problems and of the specific knowledge related to their solution" (Dosi 1982). Applied to the knowledge-based bioeconomy, the problem is the substitution or saving of carbon-based materials and energy with bio-based materials and energy, for which very heterogeneous technological processes across the entire depth and breadth of the value chains are used. It is also about the development of economic complementarities, in the sense of the cross-fertilization of different fields of knowledge. The expansion of value chains through the possibilities of digitisation will play an important role because it will increase value creation in new sustainable areas of CO_2-neutral production, e.g., in autonomous electromobility or the expansion of intelligent power grids. However, the concept of technological paradigms implies that a paradigm shift is not always possible. A *window of opportunity* for the paradigm shift will only open up if several interconnected technologies are developed and the demand-side and institutional conditions are in place that are conducive to it. Only when these prerequisites for the emergence of a new bioeconomic innovation system are in place can the transformation process succeed and gain momentum.

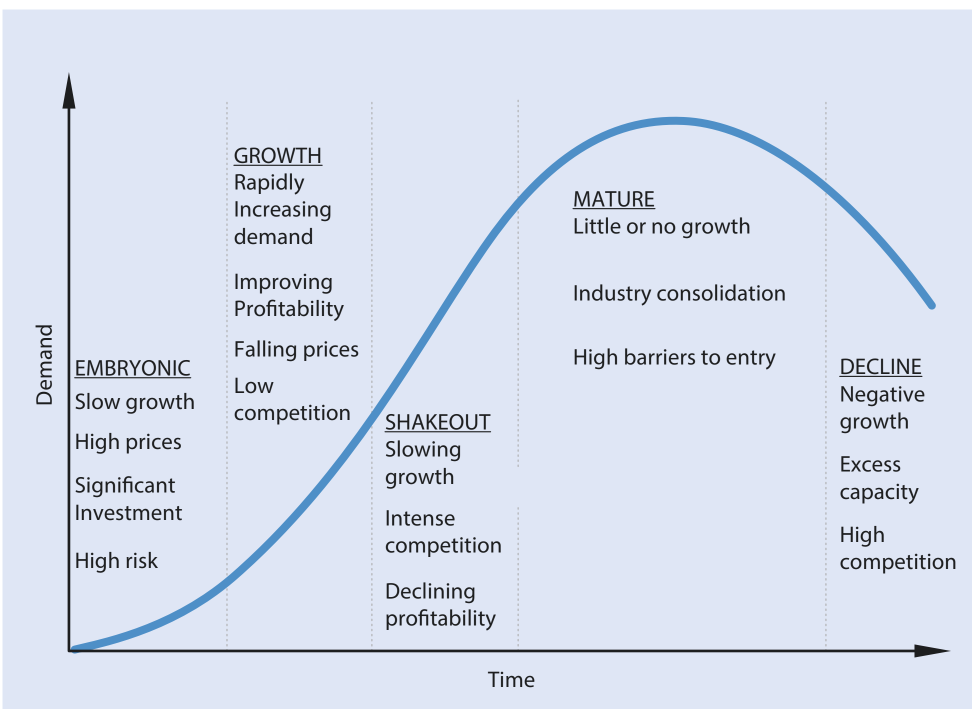
6.3 Innovation Systems and Knowledge

A first indication of the development of innovation systems can be found in the theory of industrial life cycles, which emphasizes the pronounced dynamics in the emergence and maturation process of industries (Audretsch and Feldman 1996). Industrial development is therefore typically divided into four phases (▪ Fig. 6.2):

1. Development phase (new knowledge creates the condition for innovation)
2. Entrepreneurship and growth phase (many entries of smaller innovative companies into the new industry)
3. Saturation and consolidation phase (development of industry standards, mergers and acquisitions, as well as market exits)
4. Downturn phase (oligopolistic competition in only moderate innovative industries)

In order to understand the transformation into a knowledge-based bioeconomy, the findings of the industrial life cycle theory are of great importance, especially for the first phases of its emergence and growth, although the bioeconomy is, of course, not a self-contained branch of industry. Rather, the bioeconomy is characterized by its cross-sectoral character. On the one hand, new sectors will emerge, such as bioplastics, waste management and biorefineries. On the other hand, the technological possibilities of the bioeconomy will trigger new dynamics to already existing sectors such as agricultural vehicle construction, battery technology and pharmaceutical production among others. It can therefore be assumed that the establishment of bioeconomic technologies will lead to the emergence of new industries and, in parallel, to new impulses for the development dynamics of existing industries. In the sense of co-evolution, these processes will be accompanied by the adaptation of old and the development of new institutions (e.g., the Renewable Energy Act or the Greenhouse Gas Emissions Trading Act), the adaptation of consumer habits and the creation of new educational opportunities.

The development patterns of the bioeconomy and the way in which new companies are created are influenced primarily by the national institutional framework (Casper et al. 1999; Whitley 1999). Institutions can be defined as "a set of rules, formal or informal, that actors generally follow, whether for normative, cognitive, or material reasons" as well



▪ **Fig. 6.2** Origin, maturation and decay of industries, measured as demand for their products over time, according to the theory of industrial life cycles. (Klepper 1997) as "organizations as durable entities with formally recognized members, whose rules also contribute to the institutions of the political economy" (North 1990; Hall and Soskice 2001). One of the most important prerequisites for the transformation towards a bioeconomic production system is the knowledge base of an economy built up by the education and research system (Geels 2002). On the one hand, there is still a great deal of uncertainty with regard to the future competencies required for a bioeconomy; on the other hand, numerous individual fields of knowledge that play an important role in the transition have already been identified, such as synthetic chemistry, process engineering, genetic engineering, food technology and computer science. To generate an innovation system, it is necessary to understand the dynamics of these knowledge fields and the way in which they can be recombined with other knowledge fields and corresponding actors. The combination of different fields of knowledge (*cross-fertilization*) is often responsible for the emergence of major technological opportunities. For example, the fusion of information and database technology and molecular biology has led to the creation of the bioinformatics sector as a completely new branch of industry, which finally was the basis for the these days florishing big data service industries. At the same time, the combination of different areas of knowledge is confronted with great uncertainty, which makes public innovation policy an important factor. A supportive research and development policy should therefore identify development paths from analysis of the dynamics of knowledge and networking, which indicate the areas in which intensified research and development efforts must be undertaken in order to close existing gaps and build bridges between hitherto unconnected fields of knowledge (Burt 2004; Zaheer and Bell 2005).

6.4 Innovation in Knowledge-Based Societies

In the knowledge-based bioeconomy, the knowledge of consumers also plays a decisive role in the development and establishment of sustainable consumption patterns (Geels 2002). This puts the focus on the interaction of technology development, demand and acceptance of innovative solutions and sociological variables. The latter include, for example, education, age, income and gender, all important explanatory factors that determine the individual's attention to and willingness to address bioeconomic issues. Without consumer acceptance, there will be no successful bioeconomic innovations. Consumers determine the direction of the transformation process, as do political leaders. The overall question is how aware and receptive people will be to the bioeconomy and its products.

The role of (real and virtual) social networks is of great importance for the establishment of new consumption patterns. They make a significant contribution to the diffusion of consumer behaviour patterns and values (Robertson et al. 1996; Valente 1996; Nyblom et al. 2003; Deffuant et al. 2005). New studies show that attitudes are important for the formation of social relationships, and that social relationships, in turn, have a significant influence on behaviour and attitudes. In the field of renewable energies, for example, it was, in many cases, only the initiative of public utilities customers that led to a "green" orientation in regional electricity supply. In individual cases, such citizens' initiatives have even installed investor communities that are themselves involved in the energy industry.

But not everything that is technically possible is also socially desirable. Critical questions must therefore be dealt with in democratic processes. In the field of bioeconomy, among others these questions include the use of genetically modified organisms in agriculture. They promise efficiency benefits in terms of productivity and land and water consumption. Critics point out, however, that long-term health or ecological risks cannot be conclusively ruled out in their use. Accordingly, technology development takes place depending on consumer acceptance and attitudes, and is thus dependent on the level of education within an economy. This raises the question of a society's openness to innovations, which is fundamentally associated with uncertainty. The term ***Responsible Innovation*** summarises the responsible design of development, which is currently being discussed with high priority by European policymakers. A comprehensive working definition of *Responsible Innovation* has been developed by Von Schomberg (2011). He describes it as "a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)." It is the question of whether innovations are judged exclusively on their economic efficiency or whether other aspects also play a role such as consumer protection or ecological criteria. Based on the discussion on biofuels ("food vs. fuel"), it can be seen that neither a purely economic approach nor a one-dimensional ethical approach are sufficient. The quality of the discussion depends on the mutual understanding, which, in turn, is determined by the level of knowledge of the participants.

Modern plant breeding and seed production is a bioeconomic area of innovation in which justice concerns are openly addressed. German consumers are sceptical about intervention in the genetic material of food plants, although it often remains unclear what the individual points of criticism are. New breeding techniques, which, since 2012, have been introduced under the name of *genome editing* (▸ Chap. 5), make it possible to modify the DNA building blocks of crop plants in a targeted manner. Researchers regard these methods as groundbreaking because they enable potentially powerful plants to be cultivated in a short time and at low cost. Varieties developed in this way can no longer be distinguished from varieties from conventional breeding. The German Central Committee on Biological Safety does not regard these methods as genetic engineering in legal terms, in particular, because they do not involve the recombination of genetic material. Since these procedures are not explicitly mentioned in the law regulating genetic engineering, the legislature is now faced with the task of clarifying whether they should be regarded as genetic engineering at all. The result will influence the dissemination potential and the acceptance of *genome editing*. Here, too, there is a renewed need to include education and information policy in shaping the transformation towards a knowledge-based bioeconomy (▶ Chap. 8).

Within the concept of ***social innovation*** (Hanusch and Pyka 2013), active civic participation in the innovation process is even more evident. According to the understanding of the European Union, this term includes innovations "that are social both as to their ends and their means and in particular those which relate to the development and implementation of new ideas (concerning products, services and models), that simultaneously meet social needs and create new social relationships or collaborations, thereby benefiting society and boosting its capacity to act" (European Parliament 2013a). By strengthening cooperative behaviour, social innovations primarily make an important contribution to rural development and promote the economic resilience of these regions. Rural cooperatives, such as regional producer and marketing associations, winegrowers' cooperatives and tourism associations, can contribute to developing regional competitiveness while respecting ecological and social criteria. This can open up new opportunities in the bioeconomy for rural regions that are particularly affected by demographic changes and the associated depopulation.

6.5 The Economics of Change

The previous remarks made clear that the transformation into a bio-based economy is an extremely complex process of change for the current economic system. There are very many different actors involved in different roles who contribute different knowledge. At the same time, this process will involve not only innovative adaptations in existing industries, but also the emergence of new industries and the dropping out of mature industries. In addition to substitutive relationships between new bio-based industries and traditional oil-based industries, there will be numerous important complementary relationships that will provide dynamic impulses for the transformation process (▶ Chap. 7). First and foremost there are the possibilities and applications of digitisation, which can be used to replace numerous petroleum-based products and energy-intensive services with bits and bytes. One example of this is the paper industry, which, in a particularly resource-intensive manner, produces tons of paper for our daily newspapers that have to be transported, first to the printing plants and then to the customer. Changes in the behaviour and attitudes of customers who consume newspapers in digital form completely eliminate this resource requirement. Through the coordination of decentralised and small-scale bioeconomic technologies and processes, digitisation opens up new opportunities, for example, in energy production and through so-called intelligent networks (*smart grids*) in power transmission. Digital coordination will affect the overall composition of many economic sectors. The coexistence of large diversified companies and highly specialised small technology companies will often be a potential solution. Finally, digitization also enables the effective organization of consumer platforms in the sense of *sharing economy* approaches. The successful emergence and diffusion of bioeconomy-relevant knowledge depends on dynamic innovation networks (Pyka 2002), in which different actors share existing knowledge and jointly create new knowledge. In the innovation networks, the demand side, represented, for example, by consumer associations and politicians, will also play a prominent role and help to establish innovation networks in the early phases of technology development.

Also in the knowledge-based bioeconomy investment and economic growth will be a crucial prerequisite for employment, international competitiveness and income generation. The bioeconomy can make an important contribution to increasing investment by providing new investment opportunities through fundamental innovations, and thus bringing the large amount of liquidity currently available to productive use, which, in turn, accelerates the technological paradigm shift. The emergence of new major investment opportunities represents a typical pattern for the early phases of a new techno-economic paradigm: Carlota Perez (2010, 2014), for example, identifies three waves of industrialization, the first being the *Great British Leap*, the second being the *Victorian Boom*, and the third being the combined post-war accomplishments of the *Belle Èpoque* in Europe, the *Progressive Era* in the USA, and the German economic miracle (*Wirtschaftswunder*), as phases of enormous economic growth triggered by a fundamental transformation of the economic system.

The time path of the transformation process represents another critical component that has so far gained little attention. On the one hand, there is a hurry to reduce carbon-based production methods; on the other hand, frictions will occur in the transformation process that are caused, for example, by a shortage of skilled workers. In this context, the so-called *sailingship effect* (Howells 2002), which can often be observed in eras of revolutionary innovations, could be advantageous. When, in the middle of the nineteenth century, new steamboats threatened the existence of the established sailing ship technology, sailboat builders suddenly undertook innovation efforts that they had not considered for many decades, if not centuries. Due to the threat posed by innovative technologies, their predecessor technologies are therefore subject to adaptation reactions designed to prevent them from being forced out of the market quickly. Fuel-efficient internal combustion engines and hybrid drive technologies, for example, represent such adaptation reactions to the emergence of electric vehicles. In terms of environmental policy, however, both the old and the new technologies pursue the same objective, namely, a reduction in noise and exhaust emissions. This is an advantage, because it allows the new technology to take more time for development. The transformation process into a bioeconomy will also be characterized by a co-existence of traditional and bio-based industries over a long period of time. During this time, it will also be important to further advance relevant innovation processes in traditional technologies. This co-existence increases the degree of complexity of change. At the same time, however, it creates time for the development of the bioeconomy and prevents the early introduction of immature technologies, which could cause failure of promising approaches.

The distributional effects of the transformation process continue to be important for social acceptance. A bio-based economy on an industrial scale will, to a large extent, be a knowledge-based economy. It will generate additional demand for highly qualified workers, while the opportunities for the low-skilled will continue to deteriorate. In addition, jobs for low-skilled workers in traditional industrial production will disappear. On the other hand, there will be demand for other goods and services whose value-added and labour-market-relevant compensation potential is still unclear. The question of the extent to which companies are well prepared for the bioeconomy must also be asked. The transformation process will ensure that competencies responsible for past success are devalued through innovation. Incumbent companies will be confronted by the question of how they will deal with the *not-invented-here-syndrome* to overcome their "business myopia" and how to actively shape the transformation process in order to maintain value creation on established sites.

Thus, the distribution effect has an important regional component: Does the bioeconomy strengthen the divergence processes between the regions or does it lead to stronger convergence? Promising, but rarely realized approaches, are networks that are based on the principle of *smart specialisation* (Foray et al. 2009) that combine regional strengths along value chains in the best possible way. In this way, polarization tendencies can be avoided that, in addition to the concentration of economic power, also lead to political and cultural concentrations and the formation of distinct center-periphery structures. So far, however, it is unclear how stable and functional politically-induced networks are vis-à-vis self-organised networks and to what extent politics can influence them. Initial findings, however, suggest that the withdrawal of state coordination bodies from networks may lead to a tendency towards disintegration (Green et al. 2013).

From the transformation towards a knowledge-based bioeconomic production system, it is expected that the negative consequences of economic growth in terms of environmental pollution, resource consumption, climate change and energy consumption will be resolved in a sustainable way. Which contribution can be expected from individual areas, how complex feedback loops will influence competitiveness and whether rebound effects may counteract the positive effects of the transformation process are all questions that are closely linked to the fundamental uncertainty of the innovation process. Answers cannot be anticipated. Institutional rules would be one way of reducing such uncertainties, at least in part. For example, it would make sense for oil-producing countries to commit themselves to reducing their production volumes in line with the declining demand for oil caused by the bioeconomy. Ultimately, all actors involved in the transformation into a knowledge-based bioeconomy – from companies to private households to politicians – must learn to abandon optimization approaches and profit maximization principles. The complexity and uncertainty of this process calls for a willingness to experiment (*trial and error*) afforded by all actors.

6.6 Transformation as a Political Priority

Since the Industrial Revolution, socio-economic systems have been exposed to permanent transformation processes. While these development processes have so far been driven by open-ended innovation processes, the bioeconomic transformation process is characterized by the fact that its socially and politically desired direction is clearly defined. In the past, major technological upheavals have largely overcome bottlenecks based on scientific or economic constraints, thereby shifting the socio-economic system along new trajectories without giving direct instructions to the direction of the development process. However, with the massive accumulation of carbon dioxide in the atmosphere since the Industrial Revolution and the threat to current ecosystem services at the beginning of the twenty-first century, it is clear that global thresholds have almost been surpassed. This restricts the level of freedom of future developments if one does not want to irreversibly damage natural conditions for human life and biological diversity on earth. It is yet unclear whether this transformation process will succeed in a targeted manner and how it can be controlled by political influence in order to achieve the socially existential goals.

New technological developments alone are not enough to transform the socio-economic system, but will initially only create the necessary potential for radical changes affecting the economy as a whole. Only a broad societal commitment to a specific use of these technologies will lead to converging trajectories and synergies that can ultimately initiate the paradigm shift (Pérez 2014) – i.e., the commitment to try out all developmental directions that are linked to corresponding investments, innovations and the ability to cope with fundamental insecurity through politics. The "green growth paradigm" based on bio-based technologies can be such a direction, bringing together the potential of different technological developments and making them flourish. This requires political decisions supporting a reorientation of macroeconomic research and innovation activities, the exploration of new energy sources, improvements in the productivity of natural resources and new sustainable ways of living and production (Pérez 2014). In addition, such a transformation process creates opportunities for economic development in catching-up economies without overexploiting global natural resources and the environment. It will be decisive for the success of the bioeconomic transformation process that it is given a direction by politics and society (Mazzucato and Perez 2015).

This includes, for example, the development of new products within emerging bioeconomic innovation systems. In this perspective, innovations require the interaction of the actors along value chains that might lead to the development of new industries. In the past, for example, the provision of cheap electricity led to the spread of refrigerators and freezers in private households, which, in turn, led to innovations in frozen food and packaging. Similarly, in a bioeconomy, the establishment of a *sharing economy* may lead to new digital coordination platforms and the establishment of sustainable designs among product manufacturers. This would eliminate the resource-wasting phenomenon of planned obsolescence that shortens product life cycles and create new sectors such as repair and maintenance services. Networking and cluster formation, which lead to a reduction of uncertainty and to self-reinforcing effects, are particularly important for long-term development. In addition, social changes and changing lifestyles are both an expression and a driver of this transformation process (Mazzucato and Perez 2015).

Therefore, the role of governments goes beyond simply correcting market failures. Rather, government action prepares the ground from which new markets can emerge and thrive in the first place by creating investment security and reducing risks and uncertainty (Mowery et al. 2010). The transition from the invention phase to the innovation phase, i.e., to the expansion of bioeconomic activities in the markets, is a high-priority task of innovation and business start-up policy. To realise a growth path on the basis of the bioeconomy requires more than just the replacement of crude oil with renewable raw materials or renewable energies. What is needed is an innovation system that creates synergy effects, knowledge transfer and networks between manufacturers, suppliers and consumers. There is a need for a comprehensive transformation that encompasses the entire economy and renews the patterns of production and consumption that were established as a result of the previous transformation process.

The technological potential of the bioeconomy is therefore a necessary, but by no means sufficient, condition for the transformation process. A political decision is needed as to how this technological potential is to be used and which trajectories are to be developed and merged. The market in which innovations are profitable does not emerge by itself, but rather requires feedback loops between political decisions, corporate strategies and consumer preferences.

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