Daniela Thrän
Urs Moesenfechtel *Editors*

The bioeconomy system

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ISBN 978-3-662-64414-0 ISBN 978-3-662-64415-7 (eBook)
https://doi.org/10.1007/978-3-662-64415-7

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Foreword

The new, old bioeconomy of today has, since its introduction as the Knowledge-Based Bio-Economy (KBBE) by the EU in September 2005, evolved politically from a research initiative, in preparation for the seventh[1] Framework Programme, to a considerable, comprehensive economic strategy. Around 60 states and more and more regions worldwide have adopted corresponding supporting and promoting strategies, action plans, and roadmaps, which either carry the name "Bioeconomy" directly or represent initiatives with identical content. Some of them, such as the EU, Germany and Italy, have even produced an updated edition of such strategies! And the number of institutions calling for and promoting the bioeconomy system, that is, greater use of and knowledge about biological resources in the broadest sense, continues to grow. Their goal: to contribute to resource efficiency, to sustainability, to the circular economy, and to the achievement of climate goals. Biological resources and knowledge about them can also create or "trigger" products and processes with new, previously unknown properties, that is, deliver highly innovative results.

However, it is becoming increasingly clear that there is and will be not one but many bioeconomies in the world. It is therefore all the more necessary to identify and outline the cornerstones, the commonalities, and unique selling points of the extremely complex system of a bioeconomy and to agree on their significance and relevance: availability of biological resources with their elements of renewability, climate neutrality, circularity, innovation, and relevance of value chains and systems – with implications for collaboration, education, training, financing, and communication. The bioeconomy in the Faroe Islands is just different from that in Finland or South Africa, and the biobased activities of large German chemical companies in the Ruhr region are not comparable to the practiced bioeconomy in the Argentinian pampas or the Austrian Alps.

Many different products are already being produced bio-based today because they have clear advantages in resource efficiency and quality, in cost, in terms of health and environmental impact, and indeed in sustainability. Industry will continue on this path, with or without strategies. Against this background, we need to respond to questions like: What is the changing role of the public sector in, for example, research, licensing, and regulation? Are consumers even aware yet of the benefits of bio-based products and services that are becoming clear? How does this gradually growing reality of a biobased world affect our academic and general education and training system, the so-called *soft skills* including the necessary funding? In view of the competition between the different uses of biological resources, biomass, its impact on the media of soil and water, will we be able to "afford" one or many bioeconomies on a large global scale at all, or will only waste remain as a resource in the end? What role can and will the digital transformation, of which the public is becoming increasingly aware, play here, either on its own or in conjunction with a corresponding biological transformation?

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[1] ► See https://de.wikipedia.org/wiki/Forschungsrahmenprogramm as well as ► https://www.horizont2020.de/.

All these complex aspects are clearly evident in the approaches and essays of this book. The book differs from many other current contributions in Europe specifically by the following accents:

- The focus is on the bioeconomy SYSTEM with its many facets, not on individual modules (sub-areas), even though these are of course dealt with intensively.
- The differentiation of the individual actors in their roles and relevance, from agriculture to associations, as inventors or consumers, in their various functions and interests, is being scientifically reviewed for the first time , although there is still much research to be done.
- The differentiation according to the economic or instrumental form of bioeconomy applications, from the waste-based bioeconomy to the bioeconomy of microorganisms and fungi, also addresses the digital bioeconomy – a highly interesting attempt to update this topic in view of the increasingly strong debate, at least in Germany, on the biological and digital transformation.
- For the first time, the relevance of the term cluster, also in practical regional examples, is highlighted. This is very important work with regard to the importance of value creation for the bioeconomy, which science has hardly done so far, but which should have quite a few practical consequences for the success of bioeconomies.
- For the first time, new job profiles that are emerging as a result will also be covered.
- Last but not least, the book ventures into the question of the governance of the bioeconomy, a topic in which there is as yet very little that is scientifically robust, both in the German language and international literature. Thus, with regard to the diversity of organizational forms and business models of the bioeconomy, including questions of delimitation, a great deal of work still needs to be done here.

All in all, this work can be described as ambitious, but also as courageous in its choice of topics. It is published at a time when the bioeconomy is approaching a further stage in its development in the competition of ideas, strategies, and conceptual designs for tackling the immense questions of the future on our planet, in our world today. Since its launch in Brussels in 2005 as a research initiative for the EU's Seventh Framework Programme for Research, through its further development as a general economic model, as a "partner" for the achievement of sustainability goals and in the implementation of a circular economy, it now faces the challenge of measuring itself against and allying itself with the potentials and characteristics of the digital world, the world of artificial intelligence, robotics, and automation.

To do this, it must reflect on its own unique qualities and advantages, make them clear, and, above all, make them understandable: this is an easier task for anyone who develops an iPhone or tablet, or who is concerned with autonomous driving. In my opinion, this book can make an important contribution to this.

Whether and how the bioeconomy gains and keeps its momentum does not only depend on the understanding of the bioeconomy as a system. The COVID pandemic has shown that the transformation into a bioeconomy is determined by far more influencing varying factors than presented in this book.

Christian Patermann
Bonn, Germany
April 2020

Preface

The bioeconomy aims to combine the tried and tested with the new. Since 2016, there has been international agreement that this should be done within the framework of the Sustainable Development Goals (SDGs) of the 2030 Agenda. This requires not only scientific knowledge and creative technical solutions but also a sustainable framework for action and comprehensive interaction between stakeholders. In addition, there are many and dynamic developments: Innovations in *genome editing* allow new insights and development and governance opportunities in the bioeconomy; future innovations in synthetic biology are likely to accelerate these opportunities. These developments are associated with great opportunities, but also risks, which must be weighed up not only from a scientific-technical but also from a social point of view.

On the other hand, the environmental situation is also deteriorating dynamically: climate change, degradation of agricultural land, and biodiversity loss are progressing unabated so far and are fueled by the increasing demand for food, products, and energy. For the bioeconomy, this means on the one hand a clear limitation of its future development within the framework of the natural resource base, but on the other hand also a higher expectation for the future contribution of bio-based products in an economy increasingly based on renewable resources: for food, building materials, basic chemicals, specialty products, and energy. These expectations are linked to the great hope of being able to anchor the bioeconomy comprehensively in a circular way for the transformation into a new economic system, as well as the concern that the bioeconomy, as a supposedly greener economy, will further accelerate the plundering of the planet. Many expectations and interactions – both positive and negative – must therefore be taken into account in order to embark on the path to a sustainable bioeconomy.

This is only possible with a system perspective that embeds the scientific-technical activities of the bioeconomy along the biogenic material flows in the societal context and takes into account future development opportunities and conflicting goals.

This book attempts to describe the bioeconomy system for Germany (and beyond) and to bring together the different levels of resource use, actors, and framework conditions. Because the bioeconomy is inconceivable without plants, wood, microorganisms, aquatic biomass, waste use, and data/information, we have chosen these as the starting point for describing the subsystems of the bioeconomy. In order to describe the concrete movers and shakers of the bioeconomy, individual perspectives are portrayed, and the networks and clusters are presented as nodes of joint action. The framework for action in which the bioeconomy is developing is also described. These include, for example, understandings of innovation, national and international governance, scenarios and models, monitoring activities, professional fields, and bioeconomy discourses.

Finally, a look is taken at the bioeconomy as a whole and its future developments – both for Germany and beyond. The book does not provide contradiction-free perspectives or a unique understanding of the system but gives an insight into the often very dynamic contexts of action of current bioeconomy actors and their own understanding of how they define and shape “the bioeconomy system.” This illustrates the diversity of the bioeconomy but also makes it possible to see where conflicting goals exist and how they can be overcome.

This book is aimed at actors from politics, administration, and civil society, entrepreneurs, and communicators as well as students and young professionals. It provides them with a quick, comprehensible, and interdisciplinary overview of the most important interrelationships of the bioeconomy. It is intended as an "orientation in the bioeconomy" and thus as a helpful support for understanding and action. It complements the books *Bioeconomy for Beginners* by Joachim Pietzsch and *Bioeconomy Shaping the Transition to a Sustainable, Biobased Economy* by Iris Lewandowski, which focus primarily on the utilization of biomass. This book is being published to coincide with the launch of the "Bioeconomy Science Year 2020" – another milestone in the German bioeconomy. We hope that in this context it will contribute not only to the scientific advancement but also to the practical introduction of the sustainable bioeconomy. The bioeconomy has the potential to sustainably shape necessary transformation processes. It is now also important to develop these more strongly in system contexts.

We would like to take this opportunity to thank the many people who have contributed to the creation of this book. First and foremost, we thank the authors of this book, who have painstakingly attempted, in some cases for the first time, to present their interrelationships in a compact manner. The authors represented in this book were supported by numerous other persons: by ideas, contributions, references, and reviews. Even if they are not mentioned here individually, they deserve special thanks. In addition, we would like to thank some people in particular. First and foremost, we thank Mr. von Braun, who has supported and accompanied this book in terms of content and concept from the very beginning. We also thank Dr. Eva Leiritz (PtJ) and Dr. Grit Zacharias (Freie Leiritz); Grit Zacharias (freelance editor and environmental scientist), who provided the original impetus for this book; Ms Diana Pfeiffer (DBFZ), whose comments contributed to a significant sharpening of the book concept and the quality of the content of the individual texts; and Mr Björn Schinkel (UFZ), whose graphic work created a coherent, overall visual image of the book and thus helped to illustrate the many ideas and concepts of the authors. Our special thanks also go to Ms. Maxie Wolf (UFZ), who checked all texts for their linguistic and formal consistency and correctness and also took over all accompanying work of the book production up to the handover to the publisher.

Finally, we would also like to thank our publisher, Springer, for making it possible for us to publish this book and always supporting us through Ms. Carola Lerch and Dr. Stephanie Preuss. Our thanks also go to you, for holding this book in your hands and having placed your interest and trust in us.

With our book, we would like to provide you with an introduction to the exciting world of the bioeconomy.

Daniela Thrän
Leipzig, Germany

Urs Moesenfechtel
Leipzig, Germany
January 2020

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Editors and Contributors

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Daniela Thrän

(born 1968) studied technical environmental protection at the University of Berlin and earned her doctorate at Bauhaus University Weimar. She researches how biomass can be produced and utilized as sustainably as possible. Since 2003, she has been heading the Bioenergy Systems Division at the German Biomass Research Centre in Leipzig. Since 2011, she has headed the Department of Bioenergy at the Helmholtz Centre for Environmental Research (UFZ) in Leipzig and has since held the Chair of Bioenergy Systems at the University of Leipzig. She contributes her expertise on the sustainable use and production of biomass to numerous committees. She leads research projects in the field of bioenergy, bioeconomy, and spatial effects of renewable energies and has developed, among other things, the Smart Bioenergy concept.

Urs Moesenfechtel

(born 1978) studied German language and literature, adult education, and political science at the universities of Cologne and Leipzig from 1998 to 2005 and has since been working at the interfaces of press and public relations, event organization, and education management. The communication of environmental and nature conservation topics is a focus of his work. He has been working at the Helmholtz Centre for Environmental Research (UFZ) since 2013, where he has already served as press and public relations officer for the projects “Natural Capital Germany (TEEB DE),” “Soil as a Sustainable Resource for the Bioeconomy (BONARES),” and “Network Forum on Biodiversity Research Germany (NeFo).” Likewise, he has been working at the UFZ Department of Bioenergy since 2013 as a science communicator with a focus on the bioeconomy. There, he managed the communication activities within the framework of the accompanying research of the Bioeconomy Cluster of Excellence as well as the Bioeconomy Information Office.

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1

Introduction to the Bioeconomy System

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Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_1

1.1 The Challange of Transformation

Humans have been gathering and storing knowledge for millions of years, using it to improve their lives. Knowledge, wealth and also humanity have grown dramatically in the past. However, such growth as we know from the past is considered finite, especially by environmental scientists. Already in 1972, the Club of Rome pointed out in its paper “Limits to Growth” that unlimited growth was impossible in a world with limited resources (Meadows et al., 1972). Today, the various impacts of resource depletion have been demonstrated manifold (International Resource Panel, 2017). The most pressing global challenges that will arise for humanity in the future, or that already exist, are above all

1. preserving of a diverse, efficient natural environment as a basis for life,
2. overcoming the high dependence on fossil raw materials and the associated climate change with its global consequences,
3. the care of a growing world population with increasingly ageing societies and
4. reducing the contradictions between economic growth and sustainability (BMBF, 2014).

The goal of using the earth in the future in such a way that all countries of the world receive equitable development opportunities and without thereby diminishing the development opportunities of future generations (Vereinte Nationen, 2015a) was already adopted by the United Nations (UN) in the Declaration of Rio de Janeiro in 1992 (Vereinte Nationen, 1992). As a result of this declaration – in response to increasingly complex global challenges – the *Sustainable Development Goals* (SDGs) were ratified in autumn 2015 (Vereinte Nationen, 2015b), which apply to all states and are to be implemented by 2030. The 17 goals and 169 subgoals underpin the guiding vision of sustainable development in a comprehensive way, even if they have not yet been fully differentiated and are sometimes contradictory (Pfau et al., 2014). They form a globally agreed framework that includes the resource base as well as society and the economy in their development opportunities (◘ Fig. 1.1) Although the living conditions (life expectancy, water scarcity, economic growth, poverty, etc.) of many people have improved significantly globally in the last decade,[1] the global challenges for a sustainable economy are more precarious than ever before. The Global Footprint Network calculated that the time span in which globally available resources are consumed for the year has shortened by 1–6 days every year since 1987, and in 2018 fell on August 1 (Mosbergen, 2016).

To overcome the challenges, the many smaller drivers must be turned – in the right direction and in a coordinated interplay. This requires both keeping an eye on the big picture and activating the right adjust key levers. To stay in the technical picture: The engine room of the transformation towards a sustainable society is a complex system that must be kept in view as a whole, but also adjusted in the right places. It is a space in motion, in which not only adjustments and controls are made, but in which the system is also constantly being rebuilt so that something fundamentally new emerges.

This is our motivation for writing this book: We want to outline the bioeconomy as a system, using Germany as an example, in terms of its opportunities and risks for meeting the global challenge, but also to shed light on the subsystems that set the necessary wheels in motion with their various achievements, and expectations. We want to organise the vast amount of information on bioeconomy, make it understandable for dif-

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[1] For more information see: ▶ https://ourworldindata.org/

Fig. 1.1 The United Nations (UN) Sustainable Development Goals. (Source: Vereinte Nationen, 2015c)

ferent actors, and thus reduce the "impenetrable" complexity so that development perspectives become clearer. System knowledge is the crucial prerequisite for shaping a sustainable bioeconomy.

1.2 Bioeconomy as an Opportunity for the Future

The constant emergence of new life, the interaction with nature and the balance of biological processes are the central basis for human existence. The natural balance has provided these over millions of years. Using these principles of living nature as a model for human economic activity is seen as an important approach to dealing with global challenges (Biodiversity in Good Company, 2016).

Looking at biological processes in detail, a comprehensively better understanding has also developed over the past centuries and especially in recent decades: Genetics, biotechnology and material sciences now offer the possibility not only of replicating natural processes, but also of developing them further, thus opening up a wider view of the contribution that the natural balance can make to solving global challenges.

The idea of the bioeconomy is located precisely in this area of tension. Even if the term "bioeconomy" is used in different ways (Infobox: What Is Bioeconomy?), at least the more comprehensive definitions include an important element of social change towards a sustainable economy. The bioeconomy is generally based on natural cycles and the claim that these should be preserved in the interests of environmental protection and resource conservation (Berger, 2018).

Accordingly, the bioeconomy should not be understood as a branch of industry, but rather as evidence of a rethinking process towards a "green economy", which should be complemented by other important elements (Bioökonomierat, 2019): If sustainable management of the natural resources water, air and soil, the protection of biodiversity and the consideration of social aspects are included, the bioeconomy can contribute to climate protection, resource conservation and global food security.

Fig. 1.2 Opportunities and risks of the bioeconomy. (Source: Own representation)

The opportunities arising from the concept of the bioeconomy are aimed at different fields of action (Fig. 1.2):

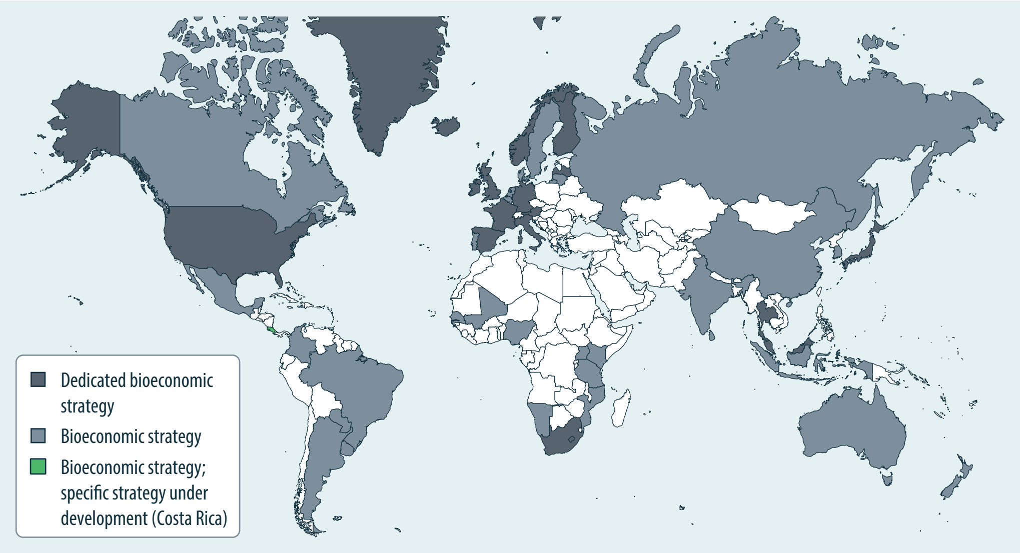
- The secure nutrition of a growing world population requires both the continuous further development of existing agricultural production and the development of new production systems, for example for the provision of proteins from aquacultures, algae, insects and other raw materials or the establishment of production systems in growing cities *(urban farming)*.
- The substitution of fossil raw materials is a central challenge for achieving the internationally agreed climate protection targets. Biological building materials, but also bio-based chemical products produced in biorefineries, are considered important fields of action here. Energy from biomass can substitute fossil fuels, but is limited by the amount of biomass available, so that widespread use will not be possible. Appropriate use of biomass as an energy source should therefore be targeted, for example to close material cycles or supply gaps in a sustainable energy system.
- New, smarter products and processes offer opportunities for innovation and competitiveness. Materials with improved properties compared to those made from petroleum or concrete can, for example, enable less material-intensive and at the same time more durable construction. In medicine and pharmacy, therapies and active ingredients that are individually tailored to the individual person achieve greater healing success than products that have been commonly used to date. However, much of the potential for innovation still lies in the dark: For example, only a very small proportion of the estimated several hundred million species of microorganisms living on earth have been classified (Kallmeyer et al., 2012).
- The sustainable production and processing of biogenic resources also offers the opportunity to maintain jobs in rural areas or to create new decentralised value chains. As the past has shown, this requires not so much technical innovations as new organisational and social concepts.
- The bioeconomy can serve as a building block for "green growth" if the larger material cycles are designed accordingly. Recycling and circular economy form important elements here. The bioeconomy, which is oriented towards natural material budgets, also requires a reduction in consumption and a change in consumer behaviour (Grefe, 2016). This requires the necessary changes in the attitudes of each individual.
- The bioeconomy is particularly dynamic due to its speed of development – currently in the field of industrial biotechnology and genetics. This can be illustrated, for example, by the development of the cost of genome sequencing.

The increase in performance and reduction in costs is much faster than in the case of Moore's Law, which described the speed of doubling of performance in the IT industry in its establishment phase (Schaller, 1997). In 2006, genome sequencing cost about US$14 million; in 2015, it cost only US$1500 (Thrän & El-Chichakli, 2017). In the short term, a further reduction in cost to US$100 is expected (Ropers, 2018). It is widely assumed that with the help of biotechnology and information technology, technical developments will become possible in the coming years "that are beyond the imagination of previous generations" (Fritsche and Rösch 2017 in Berger, 2018, p. 7; Harari, 2018; MPG, 2019).

In line with the potential and the challenges, bioeconomy strategies have been adopted not only in Germany (BMBF, 2010), but also in many countries in recent years (■ Fig. 1.3).

While in many parts of the world the potential for innovation is seen as unreservedly positive, not least because of these prospects for new markets (Zinke et al., 2016), there is also considerable criticism of the bioeconomy, particularly in Germany and the European Union, which addresses a whole range of risks:

- The use of plants and their products in a wide range of applications entails conflicts over biomass and the land needed to provide it. Species loss and soil degradation are the consequences of intensive agricultural production worldwide.
- Restrictions on the distribution of and access to land and food also pose considerable risks, as the so-called "plate-or-tank" debate in the 2000s showed. At that time, political incentives in many countries simultaneously propagated and promoted the cultivation of energy crops, especially palm oil and maize, for biofuel production. Because there was a simultaneous increase in demand for food, world market prices for agricultural products rose dramatically within a short period of time. Even if the actual effects on food security are disputed, the image of starving people next to the fuel



■ **Fig. 1.3** Overview of adopted bioeconomy strategies around the world. (Source: Own representation) cap of a high-priced car has consolidated the impression of ethically unjustifiable competing uses.

- The possibilities of targeted modification of the genetic material of microorganisms, plants and other organisms using molecular biological tools *(genome editing*[2]*)* have significantly changed the breeding of crops and the conversion of their products. Many biotechnology processes were made possible in the first place. Newer techniques – in particular CRISPR/Cas[3] – have enormous potential for development and application, as they are less complex and more precise to use than previous methods, and their application is associated with considerable time and cost savings. It is foreseeable that this technology will decisively shape, multiply and accelerate the transformation process towards a bioeconomy. The central question of the twenty-first century will be how the economy and society can best face these developments regionally, when this technology will change our entire agricultural and bioproduction systems (and possibly also ecosystems) worldwide and thus affect all areas of social life. *Genome editing* already triggers moral questions of great significance. For example, the use of the biological information of the individual person carries the risk of endangering individual fundamental rights. The question of how to deal with personal genetic information has not yet been decided in society.
- The consistent exploration and exploitation of biological principles and processes also harbours further social dangers of a comprehensive economisation of nature. The sequencing of genes as the basic building blocks of life and their release for commercialisation through patenting are described as a revaluation of all living things into the raw material "biomass", which subjects life to short-term profit targets and thus represents a continuation and expansion of the system oriented towards quick profits (Gottwald & Krätzer, 2014).

Given the range of expectations, it is not surprising that extensive and contradictory interactions are seen between the SDGs and the bioeconomy. In Germany, stakeholders from science, business and civil society interested in the bioeconomy expect the bioeconomy to contribute above all to "No Hunger" (SDG 2), "Clean Water and Sanitation" (SDG 6), "Responsible Consumption & Production Patterns" (SDG 12), "Climate Protection Measures" (SDG 13) and "Sustainable Development" (SDG 13). "production patterns" (SDG 12), "Climate action" (SDG 13) and "Life under water and on land" (SDGs 14 and 15) are unanimously rated as very important, while opinions differ significantly, for example, on "No poverty" (SDG 1), "Affordable and clean energy" (SDG 7) and "Industry, innovation and infrastructure (SDG 9)" (Zeug et al., 2019).

The diverse interactions with the SDGs also point to a central area of tension. Actors in the most diverse areas of life are involved with the bioeconomy: Bioeconomy is understood in the context of agriculture, forestry, microbiology, the marine economy and their respective products, but also as part of waste management, energy management and digitalisation.

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[2] We understand this term here as a collective term for the application of new molecular biological tools (such as zinc finger nucleases, TALEN and CRISPR/Cas. See also: ► https://www.dialog-gea.de/de/themen/inhalte and ► https://de.wikipedia.org/wiki/Genome_Editing

[3] For more information, see: ► https://www.mpg.de/11018867/crispr-cas9

In the system, different actors interact in the various economies or economic sectors. They base their actions on their respective achievements and expectations – and this can lead to tensions, but it can also inspire them: In order to seize the future opportunity of the bioeconomy, it is precisely these sectors and actors that must interact in an appropriate manner, i.e. turn the adjusting screws described in the previous chapter. The second part of this book is therefore devoted to a systemic view of the sub-sectors of the bioeconomy.

However, looking beyond the experts' horizons also provides a very different picture: In the past, according to survey results from 2013 (IfD, 2013), the majority of Germans were unaware of the concept of the bioeconomy (Bioökonomierat, 2013). More recent surveys are not available, but there is little evidence that the picture has fundamentally changed. To date, there is a lack of clear visions or guiding principles of what a bioeconomic future should look like. For example, although the European Union's 2018 revised strategy aims to take a comprehensive view of the bioeconomy in a healthy environment and also to pay attention to urban and rural environments, it still does not include concrete targets or transformation pathways (EC, 2018). The new national bioeconomy strategy also has a similar tenor. Public dialogue and discourse events are rare and critics describe the bioeconomy as a smokescreen (denkhausbremen, 2018). Recent research among actors in the forestry and timber sector also found that there is a great deal of uncertainty about what future developments will look like (Stein et al., 2018).

Nevertheless, the bioeconomy is developing – driven by actors and in regional cooperations – with different motivations and fields of action across the economies. We dedicate the third part of this book to these movers and organisational forms of the bioeconomy in Germany.

▪ What Is Bioeconomy?

Bioeconomy is derived from the terms bios (life), oikos (house) and nomos (law). As a principle, the term was first used in the 1960s by Zeman (Bonaiuti, 2014), who used it to highlight the biological basis of almost all economic activities. Another genesis of the term is described in connection with the discoveries of genetics in the late 1990s and the associated expectation of a comprehensive revolution in the industrial sector.

Today, the Bioeconomy Council of the German Federal Government defines the bioeconomy as the production and utilisation of biological resources (including knowledge) to provide products, processes and services in all sectors of trade and industry within the framework of a sustainable economy (Bioökonomierat, 2019). It identifies agriculture and forestry, the energy industry, fisheries and aquaculture, chemicals and pharmaceuticals, the food industry, industrial biotechnology, the paper and textile industry, and environmental protection as important fields of application. In its economic breadth, its consideration of the most diverse uses and future needs, this definition represents a comprehensive (systemic) claim. This is why we follow it in this book – both in the overall consideration of the bioeconomy in Germany and in the presentation of individual aspects.

In addition, there are many other definitions that span between this broad definition and a much narrower understanding of the further development of industrial biotechnology. The term "bio-based economy" is often used synonymously.

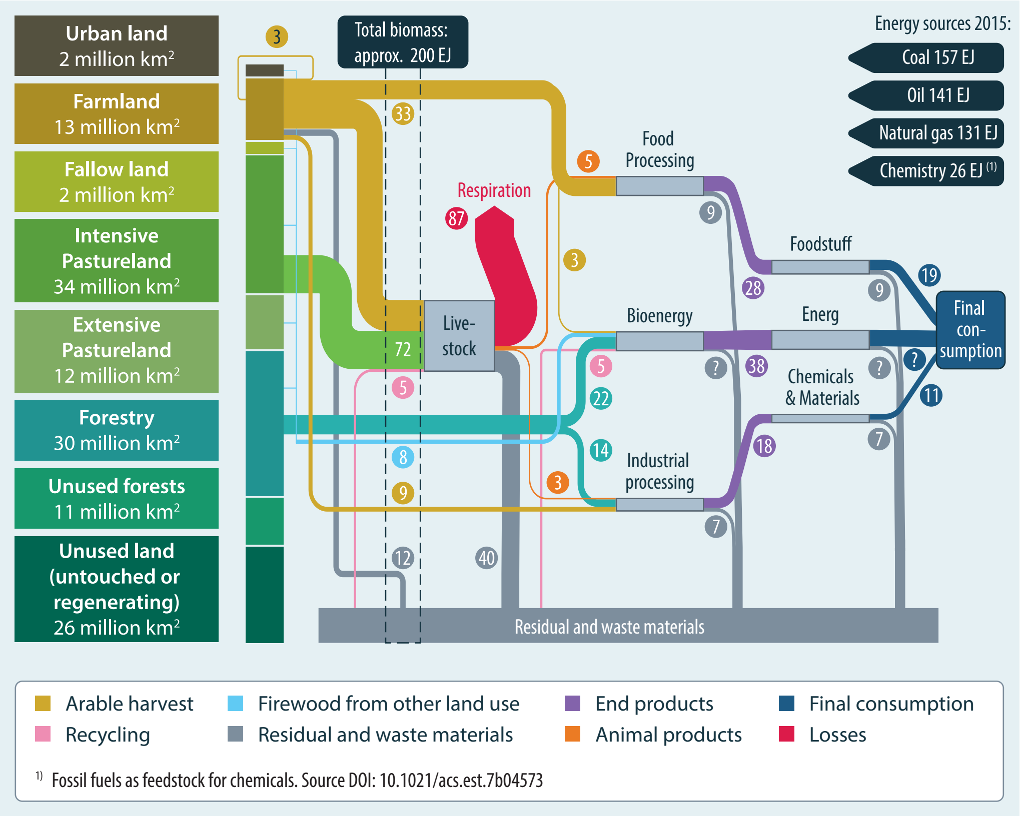
The term "biological transformation" (biologisation) is a collective term for the increasing integration of principles of nature into modern economic sectors, or the development of products or solutions to problems, driven by the knowledge gained in the life sciences and especially biotechnology. For example, there is talk of the biologisation of the economy, the biologisation of industry or the biologisation of technology.

1.3 The Resources of the Bioeconomy

Land, biomass, microorganisms, technologies, knowledge, etc. form the resources of the bioeconomy. They are provided by nature again and again or can be generated by closing the loop at the end of human use. Both elements together form the resource base.

Biomass is traded as a raw material in a wide variety of processing stages and is also frequently imported into Germany. A national consideration of raw materials always remains incomplete. ◘ Figure 1.4 therefore provides an overview of land use and global biomass flows utilised by humans. The data shown are from the year 2000, as no more recent consistent balances are available. The total amount of biomass harvested has increased since 2000; however, the overall picture, particularly with respect to land use and the magnitudes and relations of fluxes to each other, should still be essentially valid (Angerer et al., 2016).

Three quarters of the global land area – with the exception of Greenland and Antarctica – is already used by humans (Erb et al., 2017). The still unused land areas consist on the one hand of unproductive soils such as deserts, and on the other hand of the last untouched primeval forests. Additional land areas can and should therefore largely not be cultivated (Angerer et al., 2016).



1) Fossil fuels as feedstock for chemicals. Source DOI: 10.1021/acs.est.7b04573

◘ **Fig. 1.4** Flow chart of harvested global biomass fluxes in exajoules per year for the year 2000. The left column illustrates the use of global land areas. (Source: Own representation, based on data from Angerer et al., 2016)

A total of 235 EJ/year of biomass is harvested globally by humans (Zeddies & Schönleber, 2014). Half of this amount consists of crops grown on arable land, half of which is used as livestock feed. The harvested biomass further includes one third grasses consumed by livestock and one sixth wood. Thus, a total of 135 EJ, i.e. more than half of the total biomass used, is used to feed livestock. Of this, in turn, only 5 EJ (4%) enter the human diet in the form of animal products. The rest is consumed by the animals or ends up as a waste product (Angerer et al., 2016).

These figures show the strong influence of dietary habits on current and future land requirements for food production. For example, a purely plant-based diet could feed about twice as many people worldwide from the same amount of land as today.

Agricultural land would be freed up for bioenergy production or other uses. For example, if meat consumption were halved, biofuel production could increase by 7.7 times, which would curb 14% of greenhouse gases in the transport sector (Zech & Schneider, 2019). However, in light of population growth and rising demand for animal foods in populous countries such as India and China, the Food and Agriculture Organisation of the United Nations (FAO) projects that global agricultural production will need to increase by 60% by 2050 compared to 2005 levels (Alexandratos & Bruinsma, 2012).

▣ Figure 1.4 also shows that less than half of the harvested biomass (86 EJ/year) reaches humans in the form of food, energy sources, chemicals and materials. Much of the residues from crop and wood harvesting remain in the field or forest and contribute, among other things, to the natural fertilisation of the soil, humus formation and the preservation of biodiversity (for example, deadwood beetles) (IEA, 2017). Usable residues and waste materials are generated during harvesting and further processing of biomass, but also during or after use (Angerer et al., 2016). For example, consumers in Germany throw away about 70–90 kg of food per inhabitant per year (Kranert et al., 2012). At the same time, a comparable amount of used and waste wood is produced at the end of the use phase, which can be reused in use cascades (Umweltbundesamt, 2019).

The figures show impressively that biomass use by humans in the big picture has so far been little cycle-oriented and resource-conserving. However, there are already successful niche products: Phosphorus is one of those substances whose occurrence is very limited, but which is of great importance for soil fertilisation and food production. Microorganisms enable the recovery of phosphorus from sewage sludge. For example, in a waste water treatment plant operated by Berliner Wasserbetriebe, phosphorus compounds are biologically extracted from municipal wastewater with the help of microorganisms and then crystallised using a chemical-physical process. The resulting recycling product is called magnesium ammonium phosphate (MAP). Wasserbetriebe also sells it as a long-term mineral fertiliser at a low price to farmers or small customers under the brand name “Berliner Pflanze” (Berliner Wasserbetriebe n.d., in Thrän & El-Chichakli, 2017). To conserve resources, future approaches to develop nutritious, tasty and healthy food alternatives can make an important contribution. One example lies in the development of other protein sources such as plant-based egg, milk and meat substitutes, foods made from fungal or insect proteins, or lab-grown meat (Bioökonomierat, 2015).

Also, the comparison of biomass and fossil material flows clearly shows that it is unsustainable to supply our current economy entirely with biomass: the total biomass harvest of 235 EJ/year contrasted with fossil fuel consumption of 440 EJ/year in 2000, which increased to 550 EJ/year by 2015 (Our Finite World, 2018).

The comparison of material flows provides an assessment of the resource availability, efficiency and substitution potential of the bioeconomy. However, material flow analyses have the representation problem that small material flows with a high value creation potential are difficult to identify, and thus the opportunities arising from a very raw material-efficient use of biomass are easily overlooked. Biological knowledge is naturally not included in the analyses.

A sustainable bioeconomy – so the conclusion – must therefore understand the limited resources as a starting point and push technical and social innovations with strong emphasis in order to conserve resources, close cycles and at the same time meet the needs of a growing world population. The description of possible innovations and their chances of realisation are therefore a central element in the coming chapters. The process principles on which they are based are presented in the following chapters.

1.4 Process Principles of a Knowledge-Based Bioeconomy

Metabolic activities of various organisms are the starting point for life on our planet, for microorganisms, plants, animals and humans. Natural *photosynthesis* represents a central metabolism: Plant cells use solar energy to convert CO_2 from the air together with water into oxygen and hydrocarbons. The latter form the basis for plant growth: Roots, stems and stems, leaves, flowers and fruits are formed (biological synthesis) as well as the transport of nutrients, information and defense substances is organised. Because the plant has to fulfil a wide variety of tasks, energy production from sunlight is only carried out to the extent necessary. The effectiveness of photosynthesis in relation to the total sunlight falling on the earth is less than 3%. More than 5.5% are never reached (Chemie Lexikon, n.d.). Photosynthesis forms a central basis for all process principles of the knowledge-based bioeconomy by providing plant-based hydrocarbons (◘ Fig. 1.4).

Humans, like many other living creatures, use the hydrocarbons of plants for their own metabolism – as an energy supplier. Because sunlight only produces a good mood and/or possibly skin irritations. And humans are also choosy about plant biomass: they can only digest and use fruits and seeds as well as selected leaves and roots. Straw, husks and wood are not usable energy suppliers. Unlike many other creatures, however, man has understood over thousands of years how to cultivate plants and how to reproduce the desired characteristics in plants through *breeding*. The beginning of the cultivation of plants and thus also of plant breeding began about 12,000 years ago in Mesopotamia (today mostly Iraq) with barley (Pflanzenforschung Lexikon, n.d.). Einkorn, a type of primordial wheat, bears 500 g of grain on 1 kg of straw (Konvalina et al., 2014). Today's wheat has more than 1.1 kg of grain on 1 kg of straw (Weiser et al., 2014). And with the new methods of *genome editing* (▶ Sect. 1.2), things may go much further: not only more grain to straw, but also more valuable ingredients such as vitamins and trace elements in the grain, lower susceptibility to pests and rapid ripening could make plant biomass an even more affordable human food.

Biomass is also constantly transformed in the natural cycle, both in the individual cell and the individual organism, but also along food chains: Biomass is eaten by insects, for example, which then serve as food for snails, which are on the menu of rodents, for example, etc. Metabolism is complex, but there are always very special structures that ensure a survival advantage for the individual species, for example, defensive substances against pests, special enzymes for wood decomposition in the digestive tracts of beavers or rubber-like substances in Caucasian dandelions that protect against frost damage (Global Bioeconomy Summit, 2018).

The list is arbitrarily long and much is still largely unexplored today. However, man began a very long time ago to extract, ferment and preserve these special ingredients and to use them especially in the fields of art, culture and medicine. Frankincense, for example, the air-dried gum resin from the frankincense tree, is considered one of the oldest remedies in the world. References to the use of frankincense can be found in three and a half thousand year old texts from the Nile Valley. The Egyptians used frankincense for ointments and wound treatment, but also for the mummification of pharaohs (Pfeifer, 2018). The processing of food with the help of certain microorganisms and enzymes, such as those contained in yeasts, has also been known for thousands of years (Biotechnologie.de, 2019b). For example, the tradition of brewing beer has already been proven in the Mesopotamian culture 6000 years ago (Hirschfelder & Trummer, 2016), and viticulture in the comparable period in Georgia (McGovern et al., 2017).

Biotechnology has developed from these approaches, using enzymes, cells and whole organisms in technical applications. Since the nineteenth century, modern biotechnology has increasingly drawn on microbiological findings and methods and, since the middle of the twentieth century, increasingly on molecular biological, genetic and genetic engineering findings and methods (Biotechnologie.de, 2019a). This has made it possible to develop manufacturing processes for chemical compounds, for example as active pharmaceutical ingredients, basic chemical substances, biosensors, diagnostic methods or new plant varieties (Biotechnologie.de, 2019b). Biotechnological processes can be applied in a variety of ways in different areas. In some cases, attempts are made to sort these processes according to areas of application, such as

- Medicine (Red Biotechnology),
- plants and agriculture respectively (green biotechnology) and
- industry (white biotechnology) (Kafarski, 2012).

In some cases, a distinction is also made according to the living beings to which the methods are applied, such as in blue biotechnology or yellow biotechnology, which refers to applications based on marine organisms or insects. The term brown biotechnology, which is used primarily to refer to waste management, is also used (ibid.).

In the 1980s, the combination of an ever better understanding of molecular biology and biotechnology made genetic engineering possible as a new field of technology. Its aim is to specifically modify the properties of organisms by interfering with their genetic material in order to achieve desired properties or products in a targeted manner. To this end, methods have been developed to transfer individual genes from organism A to organism B, for example. The first genetic modifications were realised in the USA in 1972 (Wu & Taylor, 1971). The cloned sheep Dolly was born in 1998 (Wilmut et al., 2001). With increasingly precise genetic engineering methods, tools for so-called *genome editing* have been available since the mid-2000s (Chandrasegaran & Carroll, 2015). With the aid of special enzymes (so-called designer nucleases), it is possible to open the DNA at specific target sequences and, for example, to remove, exchange or add gene sequences there. Applications of genetic engineering and *genome editing* are already being used in important areas of biotechnology (e.g. white biotechnology, green biotechnology, red biotechnology) (Sampson & Weiss, 2013; Voytas & Gao, 2014; Laible et al., 2015).

The synthetic biology approach uses the tools of *genome editing,* but goes beyond intervention in existing organisms. It is a field at the interface of molecular biology, organic chemistry, engineering, nanobiotechnology and information technology.

The goal is to create biological systems at the level of molecules, cells and organisms that do not occur naturally and that possess novel properties (EC, 2005). Different strategies are being pursued: On the one hand, artificial, biochemical systems are integrated into organisms, which thereby acquire new properties; on the other hand, chemical systems are gradually constructed in accordance with biological models in such a way that they exhibit certain properties of living organisms (biomimetic chemistry). Other approaches aim to reduce organisms to the most essential system components (minimal genomes), which serve as a kind of "scaffolding" to create biological circuits by incorporating so-called *bioparts* (ibid.). What both approaches have in common is that they aim to create complete artificial biological systems – an intervention in the natural system that clearly goes beyond the previous considerations of genetic engineering. Synthetic biology approaches are also used to develop mechanisms for artificial photosynthesis. This can significantly exceed the efficiency of natural photosynthesis and thus offers very high innovation potential for the production of hydrocarbons. However, their development is still at the basic research stage (Fischer, 2017).

Finally, the oldest cultural technique of man is biomass combustion for the generation of heat. Until about 200 years ago, it was the main source of energy for humans for millions of years (Goudsblom, 1992). However, it was – and in some developing countries still is – not particularly effective in providing energy in open fireplaces: less than 10% of the heat from an open fire actually reaches the inside of the cooking pot. Process engineering developments have also made it possible to achieve better efficiencies in the bioenergy sector, to expand the products into electricity, heat and fuels and other products. Also, today, not only thermal processes are used to convert biomass, but also fermentation and digestion processes as well as chemical processes. The principle of the biorefinery developed from this is comparable to that of a petroleum refinery, in which the complexly composed raw material petroleum is separated and processed into individual fractions (methane, petrol, diesel, kerosene, etc.), which can be used as fuel, energy or chemical raw materials (Grühling, 2013). Depending on the regional boundary conditions and the biomasses used, very different biorefinery concepts can be realised (Lindorfer et al., 2019). First biorefineries are based on the conversion of biomasses containing sugar, oil and starch into bioethanol, among others. Lignocellulosic biorefineries that process straw and wood, green biorefineries and refinery concepts based on algae are still at the pilot stage (Lamers et al., 2016; Pietzsch, 2017).

After thermal conversion to heat and energy, the biomass is converted back into the initial product CO_2. CO_2 forms the basis for new photosynthesis. However, due to the additional emission of CO_2 from the combustion of fossil hydrocarbons, the natural system is disturbed. New considerations on the processes of the knowledge-based bioeconomy therefore go beyond the elements in ◘ Fig. 1.5: permanently removing CO_2 from photosynthesis from the atmosphere could help to keep global warming within the maximum two degrees Celsius agreed in Paris. One option is to capture carbon dioxide in bioenergy plants and store it permanently underground (BECCS) (Angerer et al., 2016).

The products of the bioeconomy fulfil a variety of functions in our society. On the one hand, they satisfy the basic needs of food, clothing, housing and communication and, on the other, they provide the basis for the further development of fundamental knowledge and increasingly existential options for shaping the environment. Under the claim of sustainability, however, the benefits of the bioeconomy must go beyond

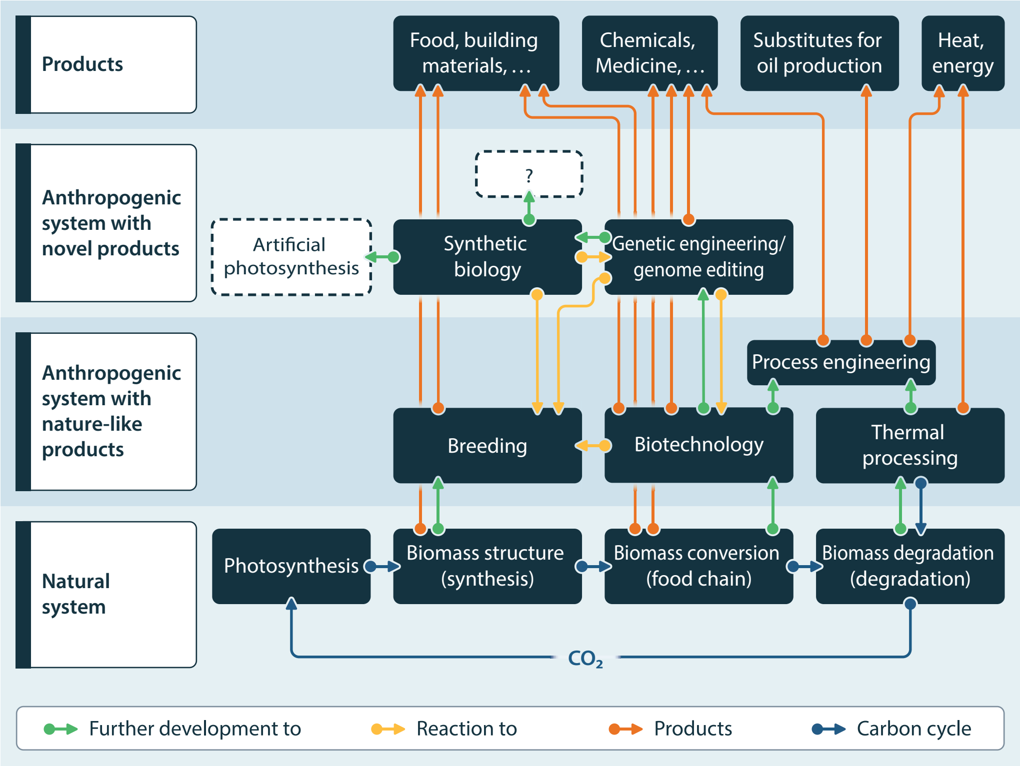


Fig. 1.5 Development of the knowledge-based bioeconomy. (Source: Own representation)

products and make contributions to the various areas of social responsibility. Technology falls short in this respect. A holistic, systemic view is necessary.

1.5 Bioeconomy from a Systemic Perspective

Thousands of individual parts are necessary to assemble a smartphone. Each part is important. A smartphone can only transmit, receive, flicker and sound if the individual parts work together as a whole in an organised and purposeful manner. The individual components and their interconnection constitute a system. The term is derived from the ancient Greek word sýstēma (σύστημα), which means "whole composed of several individual parts". In principle, the concept of system is applicable to a wide variety of phenomena – from a cell of the human body to humanity as a whole, but also to ant colonies, nations and galaxies. Systems theories have been developed since the 1950s. By system they mean the holistic interrelationship of entities (elements) whose relationships to each other differ quantitatively (greater number of interactions) and qualitatively (greater yield of interactions) from their relationships to other entities. This difference in relationships constitutes a system boundary through which the system distinguishes itself from its environment (Gabler Wirtschaftslexikon, n.d.). Bioeconomy is characterised by different fields of action, actors and relationships. It represents a complex system that

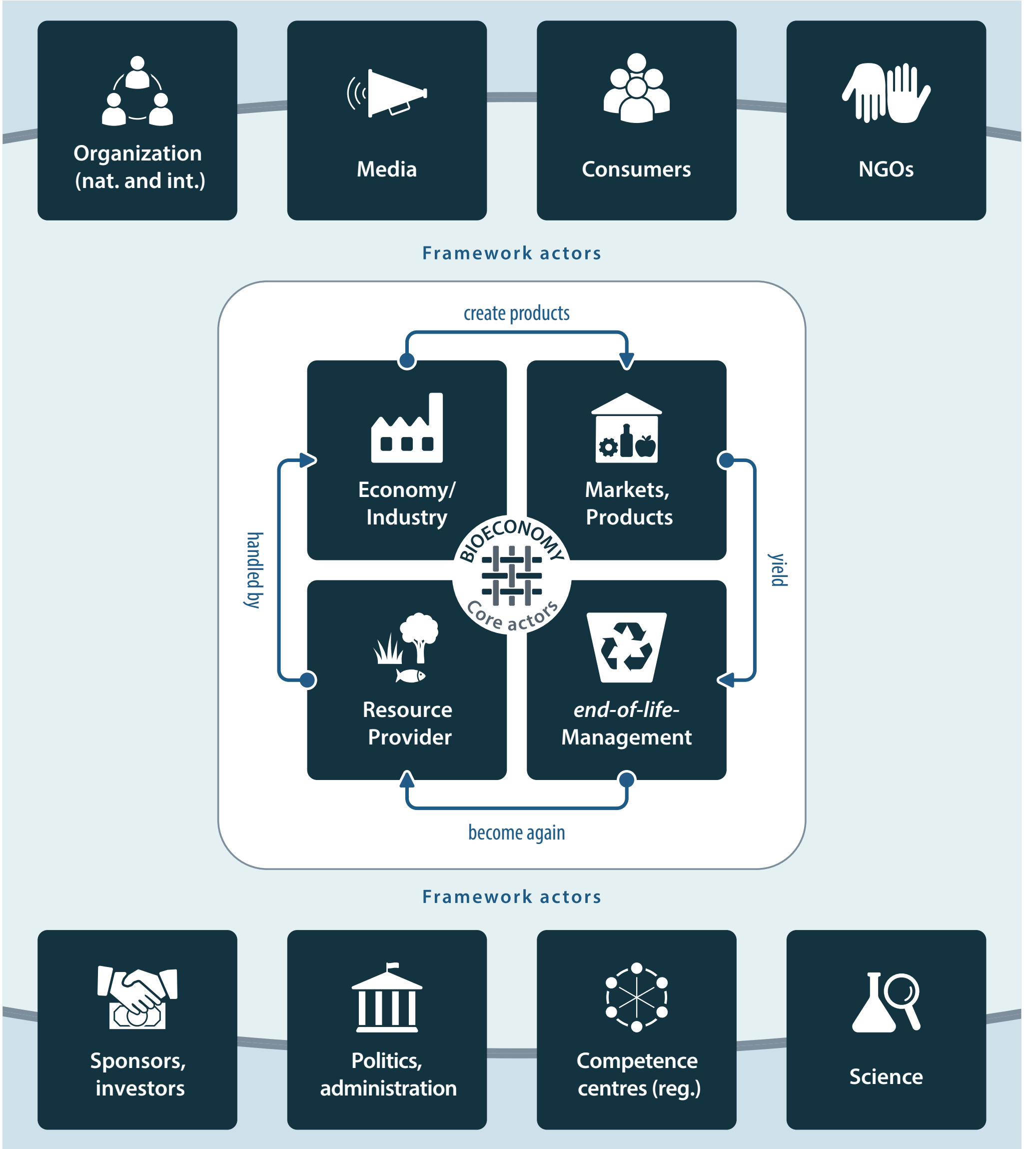


Fig. 1.6 System picture of the elements. (Source: Own representation)

interrelates resources, techniques and economic sectors as well as areas of responsibility (Fig. 1.6):

- Farmers, foresters and fishermen provide the biomass,
- Technicians from a wide variety of fields (bioengineers, food technicians, wood technicians, designers, pharmacists, etc.) process the biomass into a wide variety of products,
- brought to the market and traded by companies and used and consumed by consumers.
- The residual materials are reused or disposed of in the energy industry and waste management.

- Researchers are looking for new components, processes and products, but also for evaluation standards to determine which uses have which effects on the environment, the economy and society. Politicians, under the critical eye of the electorate, are shaping the framework conditions, which requirements are to be placed on cultivation, production and use, and are attempting to control the material flows with certificates, taxes and levies.
- Associations and cooperations (of various kinds) such as competence centres, associations, national and international organisations and NGOs serve the exchange, bundle interests and want to accelerate the respective system contribution.

German policy is therefore attempting to “position the bioeconomy in the system” with the aim of developing integrated, systemic and innovative solutions with a view to the entire value and process chains in order to optimally exploit the opportunities and potential of the bioeconomy.[4] It is expected that the economic benefits of the bioeconomy will unfold primarily through complex substitution and synergy effects in the system, since not only innovative individual value chains, but above all the linking of these chains in the system will represent a significant innovation contribution of bioeconomy research (Bioökonomierat, 2010).

A systemic view of the bioeconomy therefore encompasses at least four system levels:

1. Discourse field level:
   How is the bioeconomy defined, what is talked about, what is negotiated?
2. Actor level:
   Who is part of the discourse field on the basis of self-attribution or attribution by others (or through a defined action within the discourse field)? A distinction can be made here between:
   - Bioeconomy circle actors defined by the concrete handling of biomass (the relevant material flows and the actors shaping them)
   - Framework actors who influence this system or are influenced by it (e.g. media, sponsors, science, NGOs, politics and administration, etc.).
3. Action/interaction level:
   How do these actors interact with and among each other and thereby define the bioeconomy system? What are the operating principles of this interaction?
   - the bioeconomy circles among themselves (for example, *value chains*, process chains, material flows, coupling and cascade use, circular economy)
   - the framework in relation to the bioeconomy circle (critical monitoring, research, framework setting, etc.)
4. General framework:
   What frameworks are set or created by this interaction? (for example governance, innovation, training, communication?).

The following chapters provide examples of how these system levels are specifically designed and how they interact using Germany as an example. Part IV, for example, is devoted to the framework conditions and companions of the bioeconomy. This includes the topics of steering the bioeconomy, national and international cooperation, innovations, training, and communication and sustainability discourses. These topics link the sub-areas of the bioeconomy – or rather, they must be related to each other in order to understand the bioeconomy as an overall system.

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[4] For more information, see: ► https://www.baden-wuerttemberg.de/fileadmin/redaktion/dateien/PDF/Broschuere_Konzept-baden-wuerttembergische-Forschungsstrategie-Biooekonomie.pdf

The various system perspectives – the subsectors of the bioeconomy in Part II, the doers in Part III and the trailblazers in Part IV – can be used to describe the bioeconomy system in the same way and perhaps also to clear the "smokescreen" of the bioeconomy a little.

This description and analysis of the bioeconomy system is intended for newcomers and friends to the bioeconomy who are interested in the system as well as for "old hands" in the respective sub- and subject areas.

References

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050. The 2012 Revision. ESA Working Paper No. 12–03 FAO. http://www.fao.org/3/ap106e/ap106e.pdf. Accessed: 19.07.2019.

Angerer, G., Buchholz, P., Gutzmer, J., Hagelüken, C., Herzig, P., Littke, R., Thauer, R.K., & Wellmer, F.-W. (2016). Rohstoffe für die Energieversorgung der Zukunft. Schriftenreihe Energiesysteme der Zukunft. https://energiesysteme-zukunft.de/fileadmin/user_upload/Publikationen/PDFs/ESYS_Analyse_Rohstoffe_fuer_die_Energieversorgung.pdf. Accessed: 19.07.2019.

Berger, L. (Hrsg.). (2018). Bioökonomie und Biodiversität. Workshop Dokumentation. Bundesamt für Naturschutz: Bonn. https://www.bfn.de/fileadmin/BfN/service/Dokumente/skripten/Skript496.pdf. Accessed: 17.07.2019.

Biodiversity in Good Company. (2016). Biologische Vielfalt als Thema unternehmerischer Nachhaltigkeitsstrategien stärken. Erfahrungen und Empfehlungen der ‚Biodiversity in Good Company' Initiative. https://www.business-and-biodiversity.de/fileadmin/user_upload/documents/Die_Initiative/Zentrale_Dokumente/161115_Standpunktepapier_de_doppel.pdf. Accessed: 17.07.2019.

Bioökonomierat. (2010). Innovation Bioökonomie. Gutachten der BioÖkonomieRats. https://biooekonomierat.de/fileadmin/Publikationen/gutachten/boer_Gutachten2010_lang.pdf. Accessed: 18.07.2019.

Bioökonomierat. (2013). Der "neue" Bioökonomierat 2012–2016. https://www.nabu.de/imperia/md/content/nabude/gentechnik/tagungsergebnisse/140114-nabu-vogel-boer_vilm_2013-1.pdf. Accessed: 07.08.2019.

Bioökonomierat. (2015). Global visions for the bioeconomy – An international delphi-study. https://biooekonomierat.de/fileadmin/Publikationen/berichte/Delphi-Study.pdf. Accessed: 18.07.2019.

Bioökonomierat. (2019). Was ist Bioökonomie? https://biooekonomierat.de/biooekonomie/. Accessed: 17.07.2019.

Biotechnologie.de. (2019a). Meilensteine der Biotechnologie – ein Überblick. http://biotechnologie.de/knowledge_base_articles/2-meilensteine-der-biotechnologie-ein-ueberblick. Accessed: 18.07.2019.

Biotechnologie.de. (2019b). Was ist Biotechnologie? http://biotechnologie.de/knowledge_base_articles/1-was-ist-biotechnologie. Accessed: 18.07.2019.

BMBF (Bundesministerium für Bildung und Forschung). (2010). Nationale Forschungsstrategie BioÖkonomie 2030. Unser Weg zu einer biobasierten Wirtschaft. Berlin/Bonn. https://www.bmbf.de/upload_filestore/pub/Nationale_Forschungsstrategie_Biooekonomie_2030.pdf. Accessed: 18.07.2019.

BMBF (Bundesministerium für Bildung und Forschung). (2014). Wegweiser Bioökonomie. Forschung für biobasiertes und nachhaltiges Wirtschaftswachstum. https://biooekonomie.de/sites/default/files/publications/wegweiser-biooekonomiepropertypdfbereichbiooekosprachederwbtrue.pdf. Accessed: 17.07.2019.

Bonaiuti, M. (2014). Bio-economics. In G. D'Alisa, F. Dematia, G. Kallis (Hrsg.), *Degrowth: A vocabulary for a new era* (S. 52–55). Routledge/Taylor & Francis Group.

Chandrasegaran, S., & Carroll, D. (2015). Origins of programmable nucleases for genome engineering. *Journal of Molecular Biology, 428*(5) Part B, 963–989.

Chemie Lexikon. (n.d.). Photosynthese. https://www.chemie.de/lexikon/Photosynthese.html. Accessed: 18.07.2019.

denkhausbremen. (2018). Bioökonomie – die neue Nebelwand aus der PR-Abteilung. https://denkhausbremen.de/biooekonomie-die-neue-nebelwand-aus-der-pr-abteilung/. Accessed: 18.07.2019.

EC (European Commission). (2005). *Synthetic biology: Applying engineering to biology: Report of a NEST-High-Level expert group*. Office for Official Publications of the European Commission.

EC (European Commission). (2018). A sustainable bioeconomy for Europe: Strengthening the connection between economy, society and the environment. Updated bioeconomy strategy. https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf#view=fit&pagemode=none. Accessed: 07.08.2019.

Erb, K.-H., Luysaaert, S., Meyfroidt, P., Pongratz, J., Don, A., Kloster, S., Kuemmerle, R., Fetzel, T., Fuchs, R., Herold, M., Haberl, H., Jones, C. D., Marín-Spiotta, E., McCallum, I., Robertson, E., Seufert, V., Fritz, S., Valade, A., Wiltshire, A., & Dolman, A. J. (2017). Land management: Data availability and process understanding for global change studies. *Global Change Biology*. https://doi.org/10.1111/gcb.13443

Fischer, L. (2017). Zellattrappe betreibt Fotosynthese. https://www.spektrum.de/news/zellattrappe-betreibt-fotosynthese/1442259. Accessed: 18.07.2019.

Gabler Wirtschaftslexikon. (n.d.). System. https://wirtschaftslexikon.gabler.de/definition/system-50117. Accessed: 07.08.2019.

Global Bioeconomy Summit. (2018). World bioeconomy exhibition. https://biooekonomierat.de/fileadmin/Publikationen/Sonstige/Ausstellungskatalog_final.pdf. Accessed: 18.07.2019.

Gottwald, F.-T., & Krätzer, A. (2014). *Irrweg Bioökonomie. Kritik an einem totalitären Ansatz*. Suhrkamp.

Goudsblom, J. (1992). Feuer im Industriezeitalter. In J. Goudsblom (Hrsg.), Feuer und Zivilisation (2. Aufl., S. 287–336). Springer VS.

Grefe, C. (2016). *Global Gardening: Bioökonomie – Neuer Raubbau oder Wirtschaftsform der Zukunft?* Verlag Antje Kunstmann.

Grühling, B. (2013). Bioraffinerien machen Abfall zu Erdöl-Ersatz. WirtschatsWoche. https://www.wiwo.de/technologie/green/rohstoffe-bioraffinerien-machen-abfall-zu-erdoel-ersatz/13547834.html. Accessed: 18.07.2019.

Harari, Y. N. (2018). *21 Lektionen für das 21. Jahrhundert*. Beck.

Hirschfelder, G., & Trummer, M. (2016). *Bier: Eine Geschichte von der Steinzeit bis heute*. Wissenschaftliche Buchgesellschaft.

IEA (International Energy Agency). (2017). Technology Roadmap. Delivering Sustainable Bioenergy. https://www.iea.org/publications/freepublications/publication/Technology_Roadmap_Delivering_Sustainable_Bioenergy.pdf. Accessed: 18.07.2019.

IfD (Institut für Demoskopie Allensbach). (2013). IfD-Umfrage 11013.

International Resource Panel. (2017). Assessing Global Resource Use. A systems approach to resource efficiency and pollution reduction. Paris: UNEP. https://resourcepanel.org/file/904/download?token%3DYvoiI2o6. Accessed: 17.07.2019.

Kafarski, P. (2012). Rainbow code of biotechnology. *Chemik, 66*, 811–816.

Kallmeyer, J., Pockalny, R., Ram Adhikari, R., Smith, D. C., & D'Hondt, S. (2012). Global distribution of micorbial abundance and biomass in subseafloor sediment. *PNAS*. https://doi.org/10.1073/pnas.1203849109

Konvalina, P., Stehno, Z., Capouchová, I., Zechner, E., Berger, S., & Grausgruber, H. (2014). Differences in grain/straw ratio, protein content and yield in landraces and modern varieties of different wheat species under organic farming. *Euphytics*. https://doi.org/10.1007/s10681-014-1162-9

Kranert, M., Hafner, G., Barabosz, J., Schuller, H., Leverenz, D., & Kölbig, A. (2012). Ermittlung der weggeworfenen Lebensmittelmengen und Vorschläge zur Verminderung der Wegwerfrate bei Lebensmitteln in Deutschland. https://www.bmel.de/SharedDocs/Downloads/Ernaehrung/WvL/Studie_Lebensmittelabfaelle_Langfassung.pdf?__blob=publicationFile. Accessed: 18.07.2019.

Laible, G., Wie, J., & Wagner, S. (2015). Improving livestock for agriculture – Technological progress from random transgenesis to precision genome editing heralds a new era. *Biotechnology Journal, 10*, 109–120.

Lamers, P., Searcy, E., Hess, R. J., & Stichnothe, H. (2016). *Developing the global bioeconomy: Technical, market, and environmental lessons from bioenergy*. Academic Press.

Lindorfer, J., Lettner, M., Fazeni, K., Rosenfeld, D., Annevelink, B., & Mandl, M (2019). Technical, economic and environmental assessment of biorefinery concepts. Published by IEA Bioenergy 2019.

McGovern, P., Jalabadze, M., Batiuk, S., Callahan, M. P., Smith, K. E., Hall, G. R., Kvavadze, E., Maghradze, D., Rusishvili, N., Bouby, L., Failla, O., Cola, G., Mariani, L., Boaretto, E., Bacilieri, R., This, P., Wales, N., & Lordkipanidze, D. (2017). Early Neolithic wine of Georgia in the Sousth Caucasus. *PNAS*. https://doi.org/10.1073/pnas.1714728114

Meadows, D., Meadows, D., Zahn, E., & Milling, P. (1972). *Die Grenzen des Wachstums. Bericht des Club of Rome zur Lage der Menschheit*. Deutsche Verlagsanstalt.

Mosbergen, D. (2016). We've already used up earth's resources for 2016 – And It's Only August. Huffpost. Environment. https://www.huffpost.com/entry/earth-overshoot-day-2016_n_57a4258fe4b056bad2151b49?guccounter=1&guce_referrer=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnLw&guce_referrer_sig=AQAAAABMj7bxGNRxQYodS_ZpAEcbiOAJ7t1MSuCaAF6zf2-7OFex1t7XPEUwAQd5aiO4dBboEDJCdHp9H_RSf33EzocmYk-5SpUKSQEIJnMQobNTkwqq0Em6jYOc-

3w8bNn-_Aq6aw6r1V9KRE1qtYGrJiSj8M4QWe-hA2mIN2ZN9Bzjh9M. Accessed: 17.07.2019.

MPG (Max-Planck-Gesellschaft). (2019). Earth day 2019: "Viren können eine gesamte Population in kurzer Zeit verändern". https://www.mpg.de/13363910/earth-day-2019-reeves. Accessed: 07.08.2019.

Our Finite World. (2018). World energy consumption by fuel – BP. https://ourfiniteworld.com/2018/06/22/eight-insights-based-on-december-2017-energy-data/world-energy-consumption-to-2017-bp-fossil-fuel-other/. Accessed: 18.07.2019.

Pfau, S. F., Hagens, J. E., Dankbaar, B., & Smits, A. J. M. (2014). Visions of sustainability in bioeconomy research. *Sustainability, 6*, 1222–1249.

Pfeifer, M. (2018). *Der Weihrauch. Geschichte, Bedeutung, Verwendung* (3. Aufl.). Friedrich Pustet.

Pflanzenforschung Lexikon. (n.d.). Pflanzenzüchtung (Geschichte). https://www.pflanzenforschung.de/de/themen/lexikon/pflanzenzuechtung-geschichte-447/. Accessed: 18.07.2019.

Pietzsch, J. (Hrsg.). (2017). *Bioökonomie für Einsteiger*. Springer Spektrum.

Ropers, H. -H. (2018). Medizinische Genomsequenzierung: Warum Deutschland nicht länger abseits stehen darf. Konrad Adenauer Stiftung, Nr. 324. https://www.kas.de/documents/252038/3346186/Analysen+&+Argumente+324+-+Medizinische+Genomsequenzierung.pdf/b24bfa86-b10a-04d5-2870-843e3f219d79?version=1.1. Accessed: 17.07.2019.

Sampson, T. R., & Weiss, D. S. (2013). Exploiting CRISPR/Cas systems for biotechnology. *BioEssays, 36*, 34–38.

Schaller, R. R. (1997). Moore'slaw: Past, present and future. *IEEE Spectrum, 34*(6), 52–59.

Stein, M.W., Giurca, A., & Kleinschmit, D. (2018). "Wir sind die Bioökonomie" – Perspektiven von Akteuren aus dem deutschen Forst- und Holzsektor. *Allgemeine Forst- und Jagdzeitung 189*. Jg. 1/2.

Thrän, D., & El-Chichakli, B. (2017). Bioökonomie: Mehr als nur Ersatz für Öl. https://www.boell.de/de/2017/09/18/mehr-als-nur-ersatz-fuer-oel?dimension1=division_sp. Accessed: 17.07.2019.

Umweltbundesamt. (2019). Altholz. https://www.umweltbundesamt.de/altholz#textpart-1. Accessed: 07.08.2019.

Vereinte Nationen. (1992). Rio-Erklärung über Umwelt und Entwicklung. https://www.un.org/Depts/german/conf/agenda21/rio.pdf. Accessed: 17.07.2019.

Vereinte Nationen. (2015a). Millenniums-Entwicklungsziele. Bericht 2015. https://www.bmz.de/de/mediathek/publikationen/reihen/infobroschueren_flyer/infobroschueren/Materialie267_Millenniums_Entwicklungsziele_Bericht_2015.pdf. Accessed: 17.07.2019.

Vereinte Nationen. (2015b). United Nations Sustainable Development Summit 2015. https://sustainabledevelopment.un.org/post2015/summit. Accessed: 17.07.2019.

Vereinte Nationen. (2015c). The global goals for sustainable developments. http://www.globalgoals.org. Accessed: 11.12.2019.

Voytas, D. F., & Gao, C. (2014). Precision genome engineering and agriculture: Opportunities and regulatory challenges. *PLoS Biology, 12*(6), e1001877.

Weiser, C., Zeller, V., Reinicke, F., Wagner, B., Majer, S., Vetter, A., & Thrän, D. (2014). Integrated assessment of sustainable cereal straw potential and different straw-based energy applications in Germany. *Applied Energy, 114*, 749–762.

Wilmut, I., Campbell, K., Tudge, C., & Kober, H. (2001). *Dolly: der Aufbruch ins biotechnische Zeitalter*. Hanser.

Wu, R., & Taylor, E. (1971). Nucleotide sequence analysis of DNA: II. Complete nucleotide sequence of the cohesive ends of bacteriophage λ DNA. *Journal of Molecular Biology, 57*(3), 491–511.

Zech, K. M., & Schneider, U. A. (2019). Technical biofuel production and GHG mitigation potentials through healthy diets in the EU. *Agricultural Systems*. https://doi.org/10.1016/j.agsy.2018.10.004

Zeddies, J., & Schönleber, N. (2014). Literaturstudie: Biomasse – Flächen- und Energiepotenziale. Universität Hohenheim. http://www.forschungsradar.de/fileadmin/content/bilder/UHOH_Literaturstudie_Bioenergie_Dez14.pdf. Accessed: 18.07.2019.

Zeug, W., Bezama, A., Moesenfechtel, U., Jähkel, A., & Thrän, D. (2019). Stakeholders' interests and perceptions of bioeconomy monitoring using a sustainable development goal framework. *Sustainability*. https://doi.org/10.3390/su11061511

Zinke, H., El-Chichakli, B., Dieckhoff, P., Wydra, S., & Hüsing, B. (2016). Bioökonomie für die Industrienation. Ausgangslage für biobasierte Innovationen in Deutschland verbessern. Bioökonomierat. https://biooekonomierat.de/fileadmin/Publikationen/berichte/Hintergrundpapier_ISA_Vero__ffentliching_2.pdf. Accessed: 17.07.2019.

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Sub-systems of the Bioeconomy

Contents

Sectors of the Bioeconomy

Johann Wackerbauer

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_2

2.1 Introduction

The bioeconomy, in its property as an economic sector, can be divided into individual industries. This is based on the idea that total economic production can be broken down into different economic sectors or industries, whereby the term sector can be used either in the sense of a high level of aggregation (agriculture and forestry – industrial sector – service sector) or also at a low level of aggregation, where one also speaks of industries.

Sectors include those producers who produce largely similar products or services (e.g. automotive or insurance industries). In this context, official statistics use exact economic activity classifications, such as the Classification of Economic Activities, 2008 edition (last updated according to the current status) of the Federal Statistical Office, in short WZ 2008, which distinguishes economic activities according to five levels of classification: Sections, divisions, groups, classes and subclasses.

The special feature of the bioeconomy in this context is that it cannot be assigned in its entirety to a single section, division, group or class, but extends across official statistics. In addition, although there are areas of the bioeconomy that are identical with a single division, group or class, such as agriculture and forestry, there are also many other areas that, even at the lowest level of classification (subclasses), only constitute a sub-sector of the respective economic sector, for example bio-based plastics. The latter makes it particularly difficult to describe the bioeconomy in terms of determining economic indicators such as turnover, value added or jobs. Therefore, it is advisable to start with an investigation of the sectoral structure of the bioeconomy at the national level before using international economic classifications.

From the specific economic perspective, the bioeconomy can be seen as a cross-cutting sector, a characteristic it shares with other modern economic sectors such as the environmental economy or the health industry. This cross-sectional characteristic means that the bioeconomy, like the other economic sectors mentioned above, cannot be clearly defined in official statistics and it is difficult to map and describe it completely on this basis. As in the environmental or health economy, attempts are therefore being made to achieve a holistic representation of this cross-sectional sector on the basis of research projects and market studies. There are still no uniform conventions and the results therefore depend strongly on the definitions and delimitations on which the various approaches are based.

Therefore, this section will describe which approaches to a sectoral view of the bioeconomy are already being pursued, on which assumptions they are based, what results are gained, and what advantages and disadvantages the various approaches bring with them or what gaps remain. The relevant studies that were available up to mid-2019 are taken into account.

2.2 The European Commission’s Approach

In its 2017 publication “Bioeconomy development in EU regions”, the European Commission describes the bioeconomy in terms of three sectors, which it calls “core bioeconomy”, “partial bioeconomy” and “indirect bioeconomy”. For this purpose, it lists the respective sectors. The core of the bioeconomy thus includes agriculture, forestry, fisheries and aquaculture, bioenergy and biofuels, food and beverages, the feed industry and bio-based products and processes.

The chemical and plastics industry, construction, paper and pulp industry, pharmaceutical industry, textile industry, waste management and biotechnology are listed under "partial bioeconomy". According to this classification, technologies, machinery and equipment, services, water supply and wastewater treatment, energy, and retail trade belong indirectly to the bioeconomy (European Commission, 2017).

This classification makes it clear that the core bioeconomy includes those branches of the economy that are completely bio-based, whereas the branches of the partial bioeconomy are those that are only partially bio-based. Finally, in the indirect sector, these are industries that are not bio-based, but which could be partly related to bio-based products because they support them, such as machinery for agriculture and the food industry, water and energy consumption in the production of bio-based products, and the retail trade in bio-based products. On the other hand, some industries that produce at least a significant proportion of bio-based products are missing, such as the production of furniture, wood products and printed matter or ship and boat building. The description of the bioeconomy is therefore incomplete if a holistic view of this cross-sectional industry is to be pursued. However, since the aim of this Commission study is to analyse the research and development strategies for the promotion of the bioeconomy in the various regions of the European Union, the sectors, industries and product groups presented are in any case not quantified.

2.3 The Approach of the Federal Ministries of Education and Research and Food and Agriculture

In the publication "Bioeconomy in Germany", published by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Food and Agriculture (BMEL) in May 2014, ten economic sectors are named that are relevant to the bioeconomy but cannot be fully attributed to it, in this order: automotive industry, construction, chemicals, energy, agriculture and forestry, mechanical engineering, food industry, pharmaceutical industry, consumer goods and textiles and clothing. For the individual branches of the economy, examples are given of the respective products that are to be assigned to the bioeconomy, although the turnover or employment figures generated in this context cannot be quantified in most cases (exceptions see ◘ Fig. 2.1). Rather, the respective total number of companies, employees and total turnover in the individual economic sectors is given (BMBF and

	2010	2011	2012	2013
Biopharmaceuticals	3.9	4.2	4.7	
Biogas plants[1]				6.6
Food industry			170	

[1] Plant construction, operation and maintenance of biogas plants

◘ **Fig. 2.1** Turnover in selected areas of the bioeconomy according to BMBF and BMEL (2014) (billion €). (Sources: German Biogas Association; The Federation of German Food and Drink Industries (BVE); cited after BMBF and BMEL, 2014)

BMEL, 2014), which would thus only be attributable to the bioeconomy to an unknown extent.

This gives the impression that the overall figures are intended to describe the development potential of the bioeconomy, which would only be exploited if the relevant sectors were to switch to bio-based products to a large extent or even completely. Furthermore, the impression is created that the order in which the economic sectors are listed implies a prioritisation, since this list is not based on the sequence of the economic sector classification. However, whether these economic sectors are actually important for the bioeconomy in the chosen order can clearly be questioned. In the field of mechanical engineering, for example, agricultural engineering or agricultural machinery are given as examples, which indicates that the publication pursues the broadest definition of the bioeconomy, including the "indirect bioeconomy" as defined by the Commission. However, wholesale and retail trade in organic products and services related to the bioeconomy are excluded.

2.4 The Approach of the German Bioeconomy Council

In its report "Innovation Bioeconomy" of 2010, the Bioeconomy Council describes the value chains from the production of biomass in the sectors of agriculture and forestry, fisheries and aquaculture, culture media (microbial production) and waste management, which, via processing and refinement using biotechnology, chemistry, process engineering and biorefinery, leads to the production and marketing of food, feed, bio-based products and bioenergy sources (BioÖkonomieRat, 2010). This description of the value chains is accompanied by a list of sectors such as food and animal feed, beverages, leather, wood products, paper and pharmaceutical raw materials, which remains incomplete. This approach therefore also provides an indication of the difficulties of describing the individual sectors of the bioeconomy in a differentiated but also complete manner. Accordingly, the Bioeconomy Council points out that the bioeconomy is currently not yet an economic sector in the traditional sense, but for the time being a conglomerate of industries on the way to a new sector.

In another joint publication by the Bioeconomy Council and the Fraunhofer Institute for Systems and Innovation Research (ISI) entitled "Bioeconomy for the industrial nation – Improving the starting position for bio-based innovations in Germany" from December 2016 (Zinke et al., 2016), a distinction is made between eight sectors, whereby their analysis is focused on the importance of innovation systems.

These are the pharmaceutical industry, the chemical industry, the energy industry, biotechnology, plant engineering, the automotive industry, the construction industry and information and communication technologies. This list is reminiscent of the BMEL's sectoral differentiation, although agriculture and forestry, the food industry, and the textile and clothing industry are missing. This is certainly due to the orientation towards the innovative potential of the sectors described. In addition, there are the information and communication technologies (ICT), by which bioinformatics is probably primarily meant. All in all, this sector is again rather broadly defined in the sense of the European Commission, but as with the BMEL, without including services, wholesale and retail trade. The study quotes some empirical sectoral figures for individual economic sectors: According to these, biopharmaceuticals generated around 6.5 billion € in 2013, one fifth of the turnover of the entire German pharmacy market. In 2011, the German chemical industry used around 19 million tonnes of fossil raw materials for material processing and around 2.7 million tonnes of renewable raw materials. The share of renewable raw materials was thus about 13% and is expected to grow in the future. In the European and American chemical industry, around 5% of products and processes are bio-based. By 2025, the proportion of bio-based products and processes is expected to double or quadruple.

According to Zinke et al. (2016), the number of employees in the bioenergy and biofuel sectors was 126,400 in 2013. More recent figures can be found at the German Bioenergy Association (BBE). The BBE reports around 105,600 employees in the German bioenergy sector for 2016. According to the BBE, the total bioenergy sector turnover in 2016 was 12.05 billion € – corresponding to 40% of the total turnover of all renewable energies of 29.6 billion €. Investments in bioenergy plants in 2016 amounted to approx. 1.64 billion €.

These are mainly investments in new construction and, to a lesser extent, in the expansion or upgrading of facilities. In addition to investments by energy supply companies, investments from industry, commerce, wholesale and retail trade and private households are also included (Bundesverband Bioenergie, 2019).

Zinke et al. (2016) gives a relatively comprehensive and detailed description of biotechnology. It shows a high proportion of small and young companies. In Germany there are only about 30 companies with more than 100 employees. In contrast, almost every second biotech company is a micro company with fewer than ten employees. The average age of all 579 companies was 11 years in 2014. In 2014, they achieved a turnover of approximately 3 billion € with research and development (R&D) expenditures of approximately 1 billion €. About half of the dedicated biotechnology companies located in Germany focus on medical applications. One third of German biotech companies see themselves as service providers, for example as contract producers for other biotech companies. Only a few companies in Germany specialise in industrial (10%) or green biotechnology (4%).

Around 5% of companies have so far concentrated on the future field of "bioinformatics". In addition to the dedicated biotech companies, there are also companies in the sector whose business is only partly based on biotechnological methods. These include in particular groups from the pharmaceutical, chemical and food industries. In total, around 37,000 jobs in Germany can be attributed to biotechnology (biotechnologie.de, 2015).

A more recent study entitled "The German Biotechnology Sector" published by BIOCOM AG in 2017 estimates that in 2016, 615 biotechnology companies generated revenues of 3.5 billion € with R&D expenditure of 1.1 billion € and 42,280 employees. With a time series from 2008 to 2016, biotechnology is thus the best documented sub-segment of the bio-based economy in Germany (BIOCOM AG, 2017).

2.5 The Approach of the Johann Heinrich von Thünen Institute

The Johann Heinrich von Thünen Institute has already pursued a comprehensive approach to quantifying the bio-based economy in a 2012 report entitled "Economic significance of the bio-based economy in Germany". The authors determine the economic importance of the bio-based economy in Germany in a cross-sectoral overall view, using the classification of economic sectors as a guide. In a first step, the economic sectors or economic branches of the national accounts (VGR) are selected that have an obvious connection to the bio-based economy. In a further step, an attempt is made to identify and consider those economic sectors that use bio-based inputs. For wholesale and retail trade, meaningful quotients are formed to quantify the share of the bioeconomy, whereas the areas of research and governmental institutions are generally not taken into account. This approach generates empirical results for the indicators turnover, employment, number of companies and value added by tracking the material flows, whereby the authors point out that only rough estimates can be made (Efken et al., 2012).

Nevertheless, these estimates provide a comprehensive picture of the sectoral composition of the bioeconomy in 2007 (▣ Fig. 2.2).

According to the calculated key figures, the bioeconomy had a share of 12.5% of total employment and 7.6% of total gross value added in Germany in 2007. The largest sub-segment within the German bioeconomy was processing with a share of around 37% of the employees in the bioeconomy and almost 52% of the gross value added in the bioeconomy, followed by wholesale and retail trade with a share of 27% and 26% respectively. The third largest segment was the production stage with almost 18% of the employees and almost 12% of the gross value added. Thus, the biobased services had the lowest share with 18% and 10% respectively.

The presentation of the bioeconomy is comprehensive here. However, it would be of interest if the figures determined for the "processing" sector could be shown in a more detailed differentiation according to the individual industrial and service sectors.

This was followed in 2016 by an updated article of the von Thünen Institute in the Wageningen Journal of Life Sciences (NJAS) entitled "Measuring the importance of the bioeconomy in Germany: Concept and illustration". This is based on the definition of the Bioeconomy Council, according to which bioeconomy is defined as

> » all economic activities, including services, that produce, process or use biological resources in any way. (Efken et al., 2016, p. 10)

The supporting economic sectors (indirect bioeconomy as defined by the European Commission) are not included. To quantify the primary sector (agriculture, forestry, fisheries), statistics from the national accounts are used. For all other economic sectors, the European System of Accounts serves as a basis. Based on this, especially the value added tax statistics, various cost structure statistics and the material and goods receipt survey are used to quantify the bioeconomy. While the primary sector is completely attributed to the bioeconomy, the bioenergy sector is quantified with the help of publications of the Federal Ministry of Economics and supplementary calculations. For the other industrial sectors, the bioeconomy share is determined with the help of the material and goods receipt sur-

	Companies (number)	**Employees** (number)	**Turnover** (billion €)	**Gross value added** (billion €)
Generation stage	403,924	884,436	50.8	19.0
Processing	158,845	1,823,618	334.0	84.8
Wholesale and Retail Trade	127,677	1,359,574	333.9	43.6
Biobased services	130,005	889,983	34.8	17.1
Total	818,832	4,957,530	753.5	164.5

▣ **Fig. 2.2** Key figures of the bioeconomy in Germany by functional areas 2007. (Source: Own presentation, based on Efken et al., 2012) vey, which shows the extent to which biogenic resources are used as input in the various economic sectors. For food retailing, drugstores and DIY stores, relevant estimates by various market research institutes are used and, in the absence of other information, restaurants are fully attributed to the bioeconomy.In the overall result (◘ Fig. 2.3), around five million people were employed in the bioeconomy in 2010, which corresponds to 12.4% of all people employed in the economy as a whole, and the gross value added amounted to 140 billion € or 6% of the total economic value added.

Compared to 2002, the increase in the number of people in employment at +30% and in the value added at +22% was significantly higher than the overall economic growth (+ 4% respectively +16%). With regard to the development of the individual sectors, it should be noted that the growth of the bioeconomy was based, among other things, on increases in wholesale and retail trade and services, whereas the production and processing of biological resources virtually stagnated.

According to Efken et al. (2016), sectoral differentiation is hardly advanced compared to Efken et al. (2012). The sector of agriculture, forestry and fisheries corresponds to the production stage in the previous study; processing there is only differentiated into bioenergy and industry. Although the new study also reports results for individual sectors, it does so exemplarily and not comprehensively for all sectors. The clearly different results for the year 2007 in the previous study and the year 2006 in the new study are also striking. These results represent the most comprehensive and up-to-date empirical approach for the analysis of the bioeconomy in Germany to date. However, here too, the results are already outdated and need to be updated.

In ◘ Fig. 2.4 the described approaches are compared once again. It becomes clear from this that the various publications differ

	2002	**2006**	**2010**
Employment in the bioeconomy (in 1000 employed persons)	3,929	4,304	5,089
Share of total economy	9.9 %	10.9 %	12.4 %
Gross value added (in € billion)	115	122	140
Share of total economy	5.7 %	5.6 %	6.0 %
Sectoral breakdown of gross value added (in billion €)[1]			
▶ Agriculture and forestry fisheries	18	15	17
▶ Bioenergy	2	6	6
▶ Industry	47	48	45
▶ Wholesale and retail trade	34	37	48
▶ Services	14	16	24

[1] Shifts between the industrial sector on the one hand and the trade and services sectors on the other are partly due to changes in statistical classifications.

◘ **Fig. 2.3** Development of the bioeconomy in Germany 2002–2010. (Source: Own representation, based on Efken et al., 2016)

Author	Sectoral differentiation	Information or economic indicators
European Commission 2017	• Distinction between • Core bioeconomy • Partial bioeconomy • Indirect bioeconomy	Presentation of regional and national bioeconomy strategies in the EU member states
BMBF/BMEL	Ten bioeconomy-relevant economic sectors	• Number of companies, employees and total turnover (= potential of the bioeconomy) • Sales for biopharmaceuticals, biogas plants and food industry
Bioeconomy Council 2010	Presentation of the value chains of the bioeconomy: • Production of biomass • Preparation and refinement • Production and marketing	Largely qualitative description of the value chains
Bioeconomy Council/ Fraunhofer ISI 2016	Eight bioeconomy relevant economic sectors	• Biopharmaceuticals: Bioenergy turnover: employees, turnover, investments (BBE 2016) • Biotechnology: number of companies, turnover, R&D expenditure (also for BIOCOM AG 2017)
Thünen Institute 2012	Four sectors: • Generation • Processing • Wholesale and retail trade • Services	• Number of companies • Employees • Turnover • Gross value added
Thünen Institute 2016	Five sectors: • Agriculture, forestry and fisheries • Bioenergy • Industry • Wholesale and retail trade • Services	• Employees • Gross value added

Fig. 2.4 Comparison of the different approaches to capture the sectoral structure of the bioeconomy. (Source: Own representation)

considerably in terms of sectoral differentiation, as between three and ten different sectors are considered. At the sector level, bioenergy and biotechnology are quantitatively covered to the greatest extent possible due to the policy attention they receive; this also applies to the food industry and biopharmaceuticals with some exceptions.

In addition to the identification of marketable bioeconomic products on the basis of economic indicators such as turnover and employment, it must be taken into account that many innovations and concepts in the bioeconomy are still in the early stages of research and development and are therefore not yet widely used commercially. They are therefore characterised by individual examples of success with rather small production volumes. For example, in the segments of bioplastics, biofuel, bio-based chemicals or bio-based aroma and fragrances, the share of products whose production involves biomass as a raw material and/or biotechnological process steps is less than 5% of the respective total market (Wydra & Hüsing, 2018). In these segments, the economic significance of innovative bio-based products can therefore be assessed less by turnover and employment figures than by early indicators such as patent applications and expenditure on research and development.

Conclusion

In summary, it can be said that the sectoral delimitation in the various existing studies was often chosen ad hoc and with regard to the respective objectives of the respective study due to the lack of uniform conventions. For this reason, different approaches use different delimitations of the bioeconomy and different definitions of the bioeconomy. Thus, the description of the bioeconomy lacks clarity, completeness and comparability and, where the criterion of completeness is fulfilled to the greatest extent possible, the timeliness of the results (as of mid-2019). It would therefore be necessary for the actors in German – and ideally also in European – bioeconomy research to agree on common definitions and classifications and on a coherent description of the bioeconomy that encompasses all relevant economic sectors from the production of biomass and its processing to the retail trade in bio-based products and the corresponding services. In order to ensure comparability with other sectors, the classification should be based on the classification of economic sectors – supported by production statistics when it is necessary to determine the bio-based share in the individual sectors. The scientific foundations for this were laid in a research project commissioned by the Federal Ministry for Economic Affairs and Energy (Wackerbauer et al., 2019). In this project, methods were developed to determine the shares of the bioeconomy in the individual economic sectors on the basis of suitable indicators in order to be able to comprehensively and differentially map their development. The corresponding results will make it possible to make statements about the sectoral importance of the bioeconomy in Germany using the proposed approach. In addition, the European Commission is funding a major research project under the acronym “BioMonitor”, which aims to quantify the bioeconomy and its economic, social and environmental effects in the member states of the European Union.

References

BIOCOM AG. (2017). The German biotechnology sector – Facts & figures 2017. https://www.iwbio.de/fileadmin/Publikationen/IWBio-Publikationen/German-Biotech-Sector_2017.pdf. Accessed: 20.08.2019.

BioÖkonomieRat. (2010). Gutachten des Bioökonomierats 2010 – Innovation Bioökonomie. https://biooekonomierat.de/fileadmin/Publikationen/gutachten/boer_Gutachten2010_lang.pdf. Accessed: 20.08.2019.

biotechnologie.de. (2015). Die deutsche Biotechnologie-Branche – Daten & Fakten 2015. https://www.iwbio.de/fileadmin/Publikationen/IWBio-Publikationen/Biotech-Statistik-Umfrage2015.pdf. Accessed: 20.08.2019.

BMBF (Bundesministerium für Bildung und Forschung) und BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2014). Bioökonomie in Deutschland Chancen für eine biobasierte und nachhaltige Zukunft. https://www.bmbf.de/upload_filestore/pub/Biooekonomie_in_Deutschland.pdf. Accessed: 20.08.2019.

Bundesverband Bioenergie. (2019). Wirtschaft. https://www.bioenergie.de/themen/wirtschaft. Accessed: 20.08.2019.

Efken, J., Banse, M., Rothe, A., Dieter, M., Dirksmeyer, W., Ebeling, M., Fluck, K., Hansen, H., Kreins, P., Seintsch, B., Schweinle, J., Strohm, K., & Weimar, H. (2012). Volkswirtschaftliche Bedeutung der biobasierten Wirtschaft in Deutschland. Johann Heinrich von Thünen-Institut, Arbeitsberichte aus der vTI-Agrarökonomie 07/2012. https://literatur.thuenen.de/digbib_extern/dn051397.pdf. Accessed: 20.08.2019.

Efken, J., Dirksmeyer, W., Kreins, P., & Knecht, M. (2016). Measuring the importance of the bioeconomy in Germany: Concept and illustration. *NJAS – Wageningen Journal of Life Sciences*. https://doi.org/10.1016/j.njas.2016.03.008

European Commission. (2017). The future of food and farming. Communication from the commission to the European Parliament, the council, the European Economic and Social Committee and the Committee of the Regions. https://ec.europa.eu/agriculture/sites/agriculture/files/future-of-cap/future_of_food_and_farming_communication_en.pdf. Accessed: 20.08.2019.

Wackerbauer, J., Rave, T., Dammer, L., Piotrowski, S., Jander, W., Grundmann, P., Wydra, S., & Schmoch, U. (2019). Ermittlung wirtschaftlicher Kennzahlen und Indikatoren für ein Monitoring des Voranschreitens der Bioökonomie. ifo Forschungsberichte 104. https://www.ifo.de/DocDL/ifo_Forschungsberichte_104_2019_Monitoring-Biooekonomie.pdf. Accessed: 26.08.2019.

Wydra, S., & Hüsing, B. (2018). Von einer fossil basierten zu einer biobasierten Wirtschaft. *Ökologisches Wirtschaften, 1*(2018), 16–18.

Zinke, H., El-Chichakli, B., Dieckhoff, P., Wydra, S., & Hüsing, B (2016). Bioökonomie für die Industrienation – Ausgangslage für biobasierte Innovationen in Deutschland verbessern. Bioökonomierat und Fraunhofer Institut für System- und Innovationsforschung. https://biooekonomierat.de/fileadmin/Publikationen/berichte/Hintergrundpapier_ISA_Vero__ffentlichung_2.pdf. Accessed: 20.08.2019.

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3

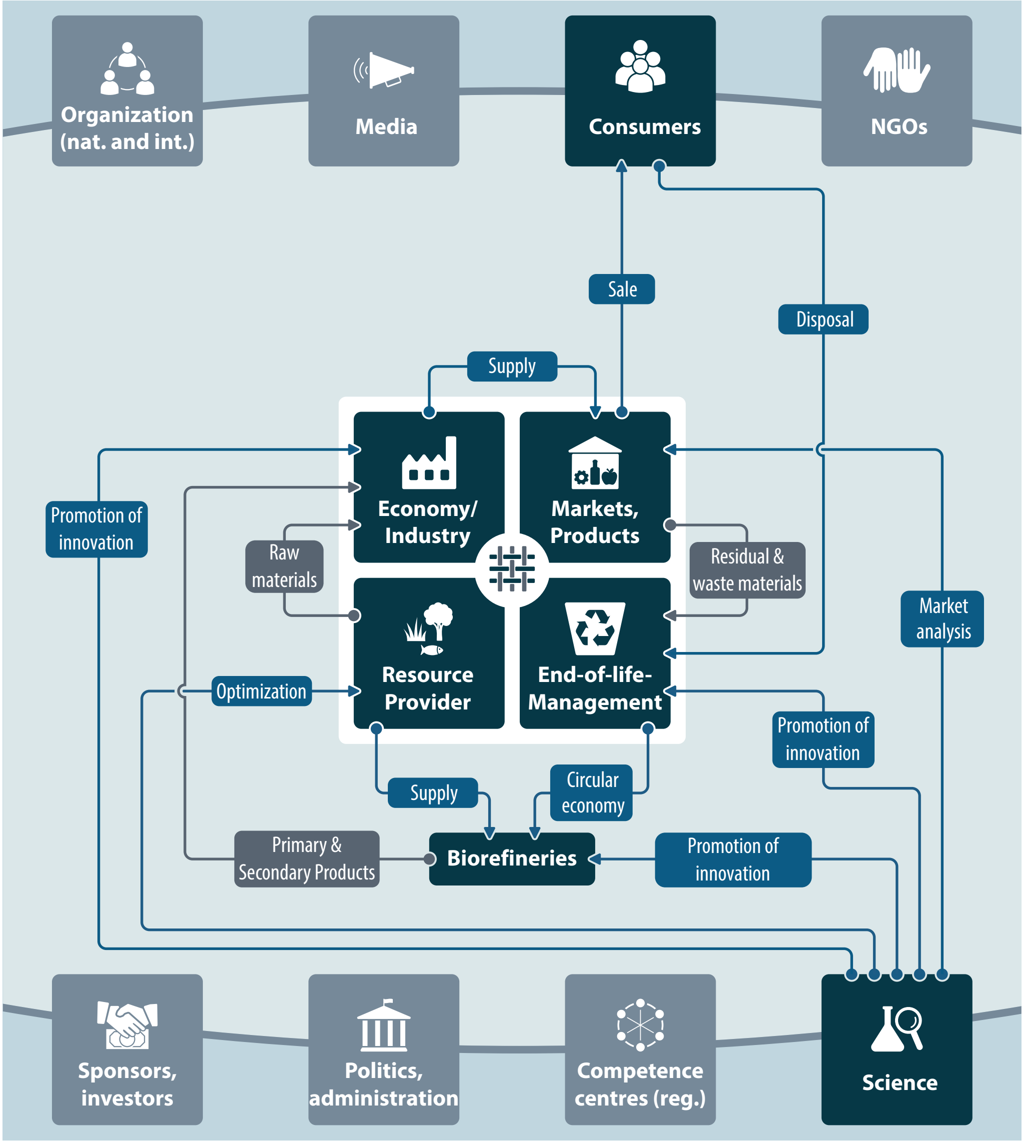
Plant-Based Bioeconomy

Klaus Pillen, Anne-Laure Tissier, and Ludger A. Wessjohann

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_3

3.1 Overview Graphic



Resource Provider
- Agriculture, forestry, aquaculture, medicinal and aromatic plant cultivation

Economy/Industry
- Food, Fuels, Biogas, Oleochemicals, Chemicals, Pharmaceuticals, Cosmetics, Pulp & Paper, Packaging, Plastics, Resins & Adhesives, Lubricants, Paints & Varnishes, Textiles, Surfactants

Markets & Products
- Food, energy, pharmaceuticals & cosmetics, papers, plastics, adhesives, lubricants, paints and varnishes, textiles, surfactants

End-of-life-Management
- Circular economy (bioreactors), recycling, degradability

Organizations (nat. and int.)
- BIO Deutschland e. V., Bioeconomy Council

Media
- Print and online publications of the stakeholders, BIOCOM AG

Consumers
- Population and special users as listed

NGOs
- DECHEMA e.V, environmental and consumer protection associations

Sponsors, investors
- BMBF, BMEL, DFG, FNR, Horizon 2020, foundations

Politics, administration
- Federal and state research institutes, federal and state ministries

Competence centres (reg.)
- ScienceCampus Halle – Plant-based Bioeconomy, BioEconomy Cluster e.V., Bioeconomy Science Center, Cluster of Excellence on Plant Sciences, Campus Straubing for Bioeconomy and Sustainability, Research Center for Bioeconomy, Community for the Promotion of Plant Innovation, and others.

Science
- Martin Luther University Halle-Wittenberg, Technical University Munich, Research Centre Jülich, University of Düsseldorf, RWTH Aachen University, University of Hohenheim, Leibniz Institutes (for Plant Genetics and Crops, Agricultural Engineering and Bioeconomics, Plant Biochemistry), Julius Kühn Institute, Helmholtz Centre for Environmental Research, German Biomass Research Centre, Nova Institute, etc.

3.2 System Description

3.2.1 Overview of Central Elements of the System

The **resources** of the plant-based bioeconomy are provided by agriculture, forestry and algae production, among others. **Resource provisioning** is typically ensured by genome-based plant breeding, high-throughput phenotyping, smart farming, biorefineries (sugar, starch, vegetable oil, algal lipid, lignocellulosic, gas refineries) and biotechnology. The main **types of production** are primary crop production as well as conversion and processing of plant biomass. Food, energy, pharmaceuticals and cosmetics, papers, plastics, adhesives and lubricants, paints and varnishes, textiles and surfactants are considered as the **most important products** of the plant-based bioeconomy. The main **markets and uses** of plant-based bioeconomy products are food (human and animal), energy, chemical and health sectors, and material and construction sectors. **Life cycle, circular economy, recycling and degradability** are regarded as central overarching themes of the plant-based bioeconomy. Important **system boundaries** and **frameworks for action** are the food vs. fuel dilemma, conflict, the promotion of innovation versus the precautionary principle, and the adaptation to framework conditions versus the adaptation of framework conditions.

3.2.2 The Main Elements in Detail

3.2.2.1 Plants and Economy

Since time immemorial, and at the latest since the advent of agriculture, plants have not only been cultivated for the production of food, but have also been used as active ingredients and materials, for example in the production of medicines and clothing. The "plant-based bioeconomy" is thus not an invention of modern times. However, with the onset of industrialisation, petroleum has replaced previously plant-based products in a variety of ways. For a long time, the plant-based bioeconomy of recent decades was seen merely as a petroleum replacement strategy to forestall the so-called *peak oil.* The main focus here was on the use of plants for energy. In the meantime, however, the plant-based bioeconomy is rightly regarded as a driver of necessary innovation, sustainability and social change. Nowadays, plant-based bioeconomy does not only mean finding biological alternatives to fossil-based resources from plant raw materials or from the components derived from the plant value chain. Plant-based bioeconomy includes complete material cycles from nature (*circular bioeconomy*) and to imitate and maintain them in all economic as well as social areas (WissenschaftsCampus Halle, 2017).

Plant-based bioeconomy involves a trans- and interdisciplinary approach to economics, starting with the adaptation and production of primary resources, the processing and conversion, enabling the production of a finished product or service, and ensuring acceptance or support from politicians and the public.

Especially for a high-wage country, for example Germany, plant-based biotechnology can be particularly effective where the value chain produces high-quality and high-priced products or services. Energy production, on the other hand, can only be an – albeit considerable – additional effect at the end of the value chain due to the limited availability of production area in Germany.

3.2.2.2 Origin and Use of Biomass

The first building block of the plant-based bioeconomy is the provision of renewable raw material, i.e. biomass.

Biomass is defined as living and growing or already dead – but not fossil – matter and the resulting waste material (ÖNORM M 7101 Bbl 2, 1996). Thus, plant primary biomass corresponds to the totality of living plants and algae as well as the resulting dead material.

Plant-based biomass is produced and used in

- the agricultural industry (including in the food and animal feed industries, but increasingly also for so-called material recycling – for example as chemicals or as fibre composites – and ultimately energy supply) (Destatis, 2019).
- forestry (including for the construction and furniture industries, pulp production and energy. Secondary use is less pronounced than for agricultural products, but already established in some sectors such as the food and flavour industry) (BMEL, 2018).
- algae production (inter alia as food and as components for biofuels).

Although wild species of plants can be used, the bioeconomy at the economic level mainly uses plant biomass cultivated by humans, such as cereals, rapeseed, potatoes, sugar beet, wood, algae and plants with special properties, for example aromatic and medicinal plants (Pflanzenforschung.de, n.d.). Of the approximately 500,000 plant species that currently grow on earth, only 4% are used in the food, chemical and pharmaceutical industries or in the fields of material sciences and energy production (Pflanzenforschung.de, n.d.). And only a small part of them is used in the secondary sector (industrial production). On the other hand, the secondary sector is characterised by high-quality and specialised products. It can thus be stated that for plant-based bioeconomy many raw material resources and opportunities are yet unused and underresearched.

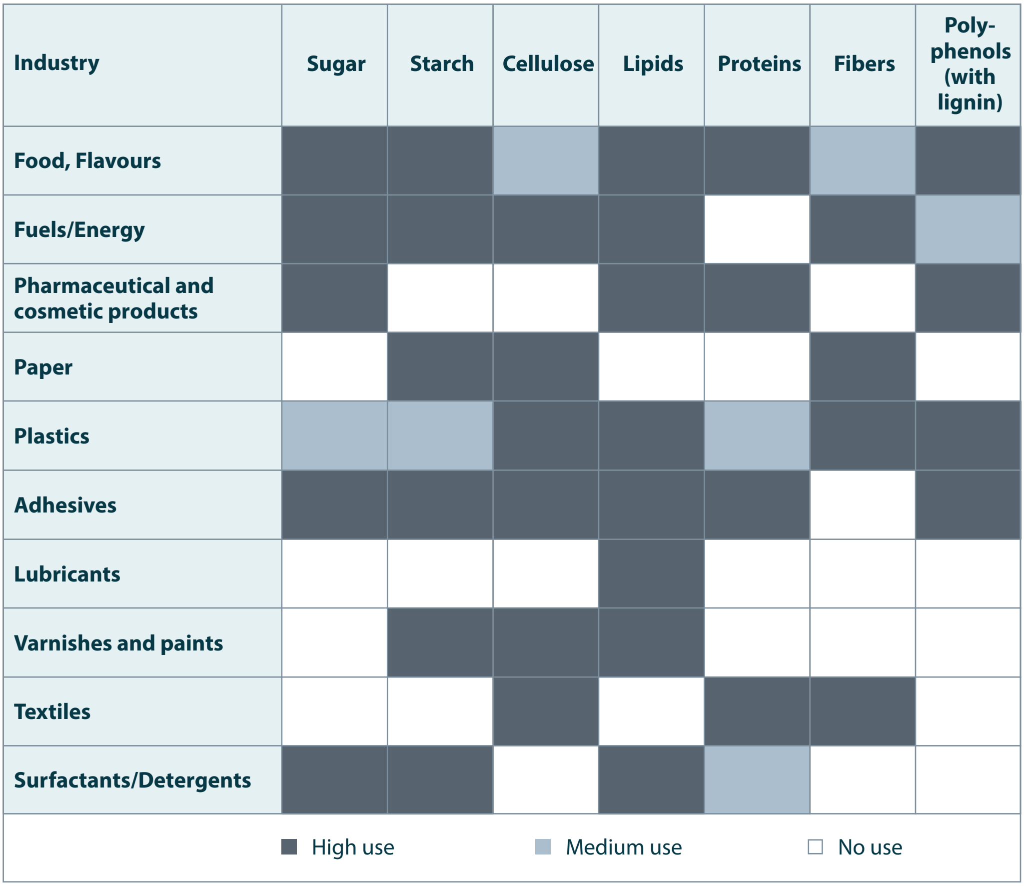
3.2.2.3 Classes of Substances from the Plant Biomass

The bioeconomy considers the plant biomass as a storage container of chemical substances which, according to their chemical composition, can be divided into the groups of carbohydrates, polyphenols with lignin, lipids (fats, oils, terpenoids), proteins and others. Here, for example, wheat and potato are not botanically categorised as *Triticum aestivum* and *Solanum tuberosum*, respectively, but as starch-producing plants. Furthermore, plants are increasingly being used as producers of molecules with special characteristics. The specific capabilities of these plant compounds may be physical, chemical or pharmacological. These complexly structured small molecules, the so-called secondary or specialised plant constituents, are primarily high-value and high-priced ingredients. They include for example colorants, flavors, fragrances or even medicinally active ingredients. They differ from many biopolymers, which are linkages of simple building blocks (monomers) to chains or networks or even three-dimensional structures (polymers and resins). The latter are responsible for energy content, structure and basic nutritional requirements.

3.2.2.4 Use of Herbal Substances

Plant biomass is used for dietary, chemical or material and energy purposes (◘ Fig. 3.1). The art of bioeconomy is to treat plants as suppliers of components and to regard the residues from the manufacture of one product as raw materials for a second product, possibly for use in another industrial sector. In other words, one tries to achieve the maximum of economically sensible utilisation with all plant parts. Any remaining residues can then be used for energy production and, subsequently, for fertilisation.

Numerous branches of industry are involved in the plant-based bioeconomy (e.g. in the biochemical industry cf. Infobox



Industry	Sugar	Starch	Cellulose	Lipids	Proteins	Fibers	Poly-phenols (with lignin)
Food, Flavours	■	■	▨	■	■	▨	■
Fuels/Energy	■	■	■	■	☐	■	▨
Pharmaceutical and cosmetic products	■	☐	☐	■	■	☐	■
Paper	☐	■	■	☐	☐	■	☐
Plastics	▨	▨	■	■	▨	■	■
Adhesives	■	■	■	■	■	☐	■
Lubricants	☐	☐	☐	■	☐	☐	☐
Varnishes and paints	☐	■	■	■	☐	☐	☐
Textiles	☐	☐	■	☐	■	■	☐
Surfactants/Detergents	■	■	☐	■	▨	☐	☐

■ High use ▨ Medium use ☐ No use

Fig. 3.1 The industrial use of herbal substances

"Use of Plant Based Materials in the polymer Industry"), which produce a wide variety of products based on different feedstocks (Fig. 3.1).

3.2.2.5 Use of Herbal Substances in the Polymer Industry

Almost 300 million tonnes of polymers (plastics and resins) are produced worldwide every year, 5% of which in Germany (Plastics Europe, 2015). But the production of plastics is becoming more demanding: on the one hand, because special applications require so-called performance polymers, and on the other hand, because their use is considered a problem to the environment and is no longer considered sustainable and sufficiently ecocompatible including especially additives such as leaching plasticisers.

For some applications, therefore, degradable plastics and those made from renewable raw materials are of increasing relevance. However, these two properties do not have to correlate. Plastics made from renewable raw materials may well be difficult to degrade, and this is often a deliberate advantage of plastics – as is also the case with some biopolymeric natural materials, for example various types of wood, which can easily last for centuries. On the other hand, petroleum-based plastics can also be chemically designed to be fully biodegradable, but they are expensive and mostly do not meet required property profiles yet.

In order to create new alternatives for plastics currently produced on the basis of petroleum, work has been going on for some years on the production of plastics from or partially in composite materials, using renewable raw materials. Bioplastics, which consist to a significant extent or exclusively of renewable raw materials such as carbohydrates (cellulose etc.), lignin, lipids and proteins, are playing an increasing role in the plastics market for special applications (◘ Fig. 3.1).

3.3 Innovations

3.3.1 Prioritisation Processes

After primary use, for example in human nutrition, the ideal value chain and cycle use of plants envisages that the non-utilised parts are subsequently put to a specific use in the bioeconomy, from high-priced products to low-cost components. They finally end as material for energy production (incineration, biogas, etc.), and the resulting residues can still be used as fertilisers. Some plants are also cultivated directly for bioeconomic use, since utilisation as food or feed is not desired or not possible, for example, for quality reasons. Apart from the directly usable and extractable high-value components, such as high-value secondary plant substances like colouring and flavouring agents as well as some lipids and monosaccharides, the bulk components are difficult to use in current industrial processes – for example, to serve the chemical industry as a basic supplier for feedstock for materials production.

3.3.2 Biorefineries

The use of plant components such as sugar, starch, cellulose, lignocellulose, oil and fibres in classic industrial processes requires their conversion into substances that can be fed into previously established and licensed processes (*drop in*). For this purpose, the raw materials are separated from the rest of the biomass by primary refining and pre-treated, for example, by mechanical or fermentative processes. They are then processed and refined. This refining is carried out by enzymatic or fermentative, thermal or chemical processes. It breaks down plant biopolymers and converts them into industrially usable low-molecular weight substances. The by-products, so-called coupled products, or residues are in the best case also used, e.g. for animal feed, energy production, or fertilisation. This overall concept is referred to as a biorefinery and aims to work with the fullest possible use of all plant raw material components. In terms of secondary refining, a distinction is made between the sugar or starch biorefinery, the vegetable oil and fat biorefinery, the lignocellulose biorefinery, and the gas biorefinery (Bundesregierung, 2012) (◘ Fig. 3.2).

3.3.3 Innovative Bioeconomy Technologies

The development of innovative technologies will help to minimise the conversion effort in the future and to produce final products with the desired properties, although they have – compared to current petroleum based products – a higher degree of oxidation due to the natural raw materials used. This can be particularly advantageous for the long-term degradability of plastics.

Innovations that have emerged in the plant-based bioeconomy in recent years are numerous and can therefore only be presented here as examples. For a better overview, these are assigned here to the “classic” sectors of the bioeconomy.

Biorefinery	**Biomass**	**Primary products**	**Secondary products**	**Industrial Use**
Sugar Biorefinery	Sugar beets, Sugar cane	Household sugar, Organic acids, Vitamins	Amino Acids, Lactic acid, Fermentation products	Food, Surfactants
Starch Biorefinery	Potato, Wheat, Corn	Starch, starch modifiers (thickeners), starch saccharification products		Food, Paper/pulp/packaging, Cosmetics
Vegetable oil Biorefinery	Oilseeds, oleaginous fruits	Virgin vegetable oil (fats and fatty oils)	Fatty acids, Glycerin	Fuel, Oleochemistry, Cosmetics, Pharmaceuticals, Lubricants, Surfactants, varnishes, Color
Algal Lipid-Biorefinery	Microalgae	Triglycerides, Carotenoids, Chlorophyll, Phytosterols, Proteins	Fatty acids, Glycerin	Food industry, Chemical Industry, Cosmetic Industry, Surfactant industry, Paint industry, Paint industry, Biogas industry
Lignocellulose-Biorefinery	Microalgae Straw (Cereals, Corn), Wood, Grass	Cellulose, Hemicellulose, Lignin, Ethanol, Turpentine	Glucose, Xylose, Acetic acid, Furfural, Phytosterols, Phenols	Chemical Industry, Fermentations processes, Resins/Adhesives
Gas Biorefinery	Agricultural Residuals (Cereal straw), Wood	Fuels/Alkanes, Methanol, Chemicals		Fuel industry, Chemical Industry, Plastics industry

Fig. 3.2 Biorefineries, biomasses used, primary and secondary products extracted and industrial uses of the plants

3.3.3.1 Biotechnology

Biotechnology means the

> Application of science and technology to living organisms, parts of them, their products or models of them for the purpose of modifying living or non-living matter to advance knowledge, produce goods and provide services. (OECD, n.d.)

Today, biotechnology is a highly developed cross-sectional technology that can be divided into different fields of application.

Plant Green Biotechnology (Agriculture and Plant Science)

Plant green biotechnology provides rapid and targeted ways to improve crop yield and sustainability (Lokko et al., 2018).

- In molecular breeding, new plant types are developed more quickly into new varieties based on available genome sequence information, which is applied in marker-assisted selection (MAS) and genomic prediction (GP). This is referred to as “precision breeding” (Wang et al., 2020; Hickey et al., 2019).
- Transgenic plants (first in 1995 with maize, then cotton, aubergines, beans, rice, sugar cane, poplars, etc.) are plants which have been endowed with additional or altered genes. For example, they are enabled to synthesise a toxin against insect pests (Bt toxin) and thus protect themselves without danger to humans and without the use of pesticides.
- Plants can also be enriched with micronutrients to provide special additional health-promoting benefits on top of the normal nutrient supply (*functional food*).
- Components of plants can also be adapted to foster their industrial use. Thus, the content of lignin in forest crops and cereals can be reduced, with the purpose of reducing waste and pollution during the production of paper and biofuels.

Plant Red Biotechnology (Medical and Veterinary)

Medical biotechnology (red biotechnology) is concerned, among other things, with the development of new therapeutic and diagnostic procedures.

- Using *microbial factories* the biosynthesis of important and scarce plant constituents can now take place in bacteria. For example, taxadiene, a precursor of the antitumor drug taxol, which was originally extracted from the bark of the endangered, slow growing Pacific yew tree, is now produced through red biotechnology.
- Conversely, human proteins can also be produced in transgenic or transiently genetically modified plants. An example are monoclonal antibodies, also known as *plantibodies,* which are an alternative to classical vaccines. Working with plants has the advantage that the production of *plantibodies* is cheaper and more efficient (higher production volume in less time) than the classical production of antibodies using mammalian cells. Most importantly, there are no plant viruses or other pathogens in plant cultures that could be dangerous to humans if the product is contaminated. This means that, unlike antibody production in animals or in animal or human cells, there is an additional safeguard against contamination (Oluwayelu & Adebiyi, 2016).

Plant-Based White Biotechnology (Industry with Predominantly Microbial Processes)

Industrial biotechnology (white biotechnology) is based on fermentation and other biocatalysis processes.

- Technical enzymes (such as cellulase, lipase, protease, amylase, phytase, xylase, etc.) contribute to the production of food as well as high-quality chemicals, pharmaceuticals, vitamins, detergents and cleaning agents. They are used, for example, in the processing of paper, leather and textiles. Plant enzymes are also playing an increasing role, in the production of fragrances or pharmaceuticals or their precursors. For example, terpene cyclases can foster the production of Taxol that is used against human breast cancer, or to produce artemisinin to fight malaria.
- Expression of technical enzymes in transgenic plants: An example is the enzyme α-amylase, which is used for the

conversion of starch into alcohol, or in the detergent industry. It has been transplanted from rice into tobacco (Kumagai et al., 2000) or from the bacterium *Bacillus licheniformis* into pea (Biesgen et al., 2002).

- Recombinant proteins with improved properties are produced. To this end, certain amino acids of the original protein or the whole proteins are omitted or replaced. In this way, either a new, more effective protein is formed and the properties of the recombinant enzymes are very precisely adapted to the desired needs, or the deletion of allergenic proteins can render plants and their products acceptable to a larger set of consumers.

3.3.3.2 Plant Genome Editing

Plant genome editing provides the generation of recombinant, i.e. genetically adapted, proteins that can be used as a more advantageous version of the original (native) protein. This is achieved by modifying DNA sequences of the gene that codes for the protein. Here, modern genome editing techniques use specific gene scissors to allow DNA modifications without leaving any transgenic residue. This requires various enzymes that cut, possibly replace and repair a targeted DNA sequence (Wada et al., 2020; Gao, 2021).

The flagship of genome editing is the so-called CRISPR/Cas technology, which allows to edit the genetic material of cells as desired. In this way, individual genes are switched off or targeted (foreign) DNA is integrated at specific sites in the genome. CRISPR/Cas is universal and works in humans, animals, plants and bacteria (Puchta, 2017). Plant breeding has been using CRISPR/Cas technology for several years (Kumlehn et al., 2018). For example, it was shown that genome editing of promoters using CRISPR/Cas generated a series of edited alleles in tomato. Those alleles varied in their effects on regulating fruit size, plant inflorescence and growth in tomato. Fixation of new alleles in transgene-free tomato has allowed fine tuning of yield components of the plant (Rodriguez-Leal et al., 2017).

3.3.4 Promoteing Innovation or Apply the Precautionary Principle?

Research in the field of the plant-based bioeconomy and its resulting innovations should meet the needs of society. Public acceptance of a new, sustainable economic system does not come by itself, but is based on societal learning processes. This learning aims at re-orienting action and thinking (Pies et al., 2017). The re-orientation of action is dedicated to the knowledge of new products and production processes of the plant-based bioeconomy as well as the corresponding framework conditions. It allows to align the supply and demand of plant-based bioeconomy innovations. But this requires the coordination of thinking, i.e. the "collective self-understanding of the interests and normative concerns of the population" as well as of intermediary institutions such as trade and commerce. For example, the misunderstanding of the precautionary principle in the field of innovation needs to be corrected. In the bioeconomy, in order to avoid an obstacle to innovation, a potential hazard should not lead to bans from the outset. Instead, the risks of banning and not banning should be assessed in parallel and only then should a decision be made (Pies et al., 2017).

3.4 Images of the Future

How can, will and should the plant-based bioeconomy develop in the future?

3.4.1 Plant Bioeconomy as a Circular Economy

The primary goal of the plant-based bioeconomy of the future is to secure food for people, achieve better nutrition, promote sustainable agriculture, ensure sustainable production methods and consumption, and use processes of minimal disturbance and maximal utilisation of resources and energy. Essential elements to achieve these objectives are the establishment of a *circular economy* and the preservation of biodiversity.

> » It can be concluded that one of the original goals of the bioeconomy must be to make the best possible use of the potential of renewable raw materials in cascades. Thus, the bioeconomy should be implemented as an interconnected system. (Pietzsch, 2017, p. 140)

3.4.2 Short-Term Research Needs of the Plant Bioeconomy

In view of scarce resources and increased expectations of the plant-based bioeconomy, the principle applies that, above all, plants with a high content of a particular class of valuable substances (e.g. starch, sugar, oils and fats, and high value constituents) should be improved by classical or advanced breeding methods so that they gain “higher contents of value-giving ingredients, lower contents of undesirable accompanying and residual substances and increased resistance to biotic and abiotic influences” (BMELV, 2012, p. 8). New physical, chemical, enzymatic, fermentative or biotechnological processes for derivatising, modifying or using the substance classes should therefore be researched more intensly. Furthermore, new products based on individual substance classes as well as new areas of application for the by-products and coupled products should be developed. The following developments can therefore be expected in the individual refinery classes in the future (Fachagentur Nachwachsende Rohstoffe e. V., 2015):

- In the sugar sector: Existing processes should be optimised with regard to the reduction of synthesis efforts, the use of protective groups and the use of reagents and solvents that are hazardous to the environment and health of living organisms including humans.
- In the starch sector: new starch qualities should be obtained under cost-effective and environmentally compatible conditions. Moreover specific properties of the various starch qualities and their by-products should be elucidated.
- In the area of lipids: The range of applications for vegetable oils and fats should be expanded in the areas of lubricants, surfactants, additives, cosmetics, polymers, adhesives, coatings and paints.
- In the area of proteins and protein preparations: In relation to the requirements of the technical application areas, proteins and protein preparations should be better characterised.
- Wild species of plants should be investigated for special constituents in order to be used for breeding and agriculture. Solutions should also be generated for specific cultivation problems of these plants (e.g. seed availability, fertilisation and plant protection strategies, resilience to biotic and abiotic stressors, optimisation of cultivation and harvesting techniques).

3.4.3 New Purposes of the Plant Bioeconomy

In the coming years, applications in the plant bioeconomy will proliferate dramatically, and some of today’s science fiction visions will become reality. A few decades ago, we would not have thought of liquid wood, human antibodies produced in tobacco, or plants that report their pest infestations to drones?

The US Defense Advanced Research Projects Agency (DARPA), for example, is already preparing for future possibilities with its "Advanced Plant Technologies Program". This involves the development of robust plant-based sensors that can register chemicals, harmful organisms, radiation and other electromagnetic signals in the environment and then transmit the corresponding information via satellites.[1]

These examples show that plant bioeconomy can support or advance the economy and society in previously unexpected areas of application. The challenge is now to adapt the basic knowledge of plant organisms, the molecular, cellular and systemic mechanisms of action and the technologies available to new purposes.

3.5 Conflicting Objectives

3.5.1 Food Vs. Fuel Dilemma

The primary objective of the bioeconomy concept is food security and safety. However, this in particular is likely to be difficult to achieved when faced with the other objectives of bioeconomy. Indeed, for most fields of application of bioeconomy – with the possible exception of high value products – it is necessary to produce as much biomass as possible, and as sustainably as possible. Thus, not only economic growth and the desired ecological sustainability confront each other here, but also the preferences for use play a role. Moreover, at least in Germany, there is a lack of arable land to ensure a sufficient supply of raw materials without fossil fuels. This is still the case even if forestry and marine sectors could offer alternative biomass or *vertical farming* could save land.

What echos well in the press and social media often enough is not realistic a solution for mass demand. *Vertical farming*, for example, is limited by the amount of light and natural rainfall per unit of land area, but both are crucial factors for productivity. It gets worse from a sustainability perspective when the lack of sun and water is offset by artificial lighting and irrigation. Land use conflicts in the production of biomass for the plate, trough, or tank have led to rising food prices and thus social unrest, especially in developing or emerging economies. One example is Mexico, where in 2007 the price per kilo for the staple food tortilla made from maize more than doubled because of the dual use of maize for food and as biofuel.

The first step to avoid the conflict between plate, trough and tank is to set priorities for the use of renewable raw materials: (1) food, (2) feed, (3) high value products (e.g. medicinal) (4) material use (carbon-containing chemicals), (5) energy use, (6) fertilisation with the residues. Thus, bioeconomy has taken up the goal of *food first*, so that the conflict of goals seems to be clarified. Furthermore, agricultural production must reduce its climate-damaging emissions and cultivate plants more efficiently without endangering biodiversity through over-fertilisation or excessive land use. Improved methods of precision farming with biodiversity areas, the use of new fertilisation methods and substances and new, more compatible plant protection products, and more efficient harvesting and processing technologies have to contribute to meet these goals.

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[1] For more information, see: ► https://www.darpa.mil/

3.5.2 Bringing Science and the Public Together

As early as 2010, the German Bioeconomy Council stated that the success of the bioeconomy would be "determined by the social [and political] acceptance of the techniques and processes used" (Müller-Röber et al., 2010, p. 30). So far, despite numerous (political) initiatives, the concept of a plant-based bioeconomy has not reached the general public yet. It is a largely unknown concept, especially since the diversity of terms like *green economy, green growth*, *circular economy* and *sustainability* can lead to irritations. In order to be able to master the transformation towards a biobased economy in view of the numerous challenges, bioeconomy must place particular emphasis on a dialogue with the general public. Opportunities and risks must be presented in a scientifically sound and transparent manner, without lapsing into a communication of fear that makes it impossible to distinguish between danger and risk.

3.5.3 Selecting the Right Procedures

Plant-based bioeconomy corresponds to a holistic approach. In this sense, it can only become successful when almost all milestones of its value chain have been reached. This includes the factual conception, the implementation taking into account the circumstances, the clear communication as well as the support of involved stakeholders. In other words, to be successful, bioeconomy must be implemented as a concerted action. To this end, the cooperation of all actors, the information of future consumers and the adaptation of the policy strategies are urgently needed.

3.5.4 Putting Different Goals Together or Getting Different Actors to Agree on a Common Goal?

The notion of a plant-based bioeconomy with a linear approach in which solutions from research are uniformly implemented among producers is deceptive. Instead, the bioeconomy needs tacit knowledge from farmers and entrepreneurs to enable co-creation (EC, 2016). This interactive model of innovation relies on the skills and on the human and social capital of farmers and citizens, and cannot successfully function without them. In this sense, in order to be successful, bioeconomy must not be considered as modules acting in parallel or in sequence, but as a complex intertwined system.

References

Biesgen, C., Hillebrand, H., & Herbers, K. (2002). Technical enzymes produced in transgenic plants. *Phytochemistry Reviews, 1*(1), 79–85.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2018). Der Wald in Deutschland. Ausgewählte Ergebnisse der dritten Bundeswaldinventur. https://www.bmel.de/SharedDocs/Downloads/Broschueren/Bundeswaldinventur3.pdf?__blob=publicationFile. Accessed: 05.09.2019.

BMELV (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz). (2012). Förderprogramm Nachwachsende Rohstoffe. Förderung von Forschungs-, Entwicklungs- und Demonstrationsvorhaben. http://mediathek.fnr.de/media/downloadable/files/samples/b/r/brosch_foerderprogramm-nawaro-v05.pdf. Accessed: 27.08.2019.

Bundesregierung. (2012). Roadmap Bioraffinerien im Rahmen der Aktionspläne der Bundesregierung zur stofflichen und energetischen Nutzung nachwachsender Rohstoffe. https://www.bmel.de/SharedDocs/Downloads/Broschueren/RoadmapBioraffinerien.pdf?__blob=publicationFile. Accessed: 27.08.2019.

Destatis (Statistisches Bundesamt). (2019). Feldfrüchte und Grünland. Land- und Forstwirtschaft, Fischerei. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Feldfruechte-Gruenland/_inhalt.html. Accessed: 25.09.2019.

European Commission. (2016). A strategic approach to EU agricultural research and innovation. Final paper. http://ec.europa.eu/newsroom/horizon2020/document.cfm?doc_id=16669. Accessed: 27.08.2019.

Fachagentur Nachwachsende Rohstoffe e. V. (2015). Förderprogramm Nachwachsende Rohstoffe. http://www.fnr.de/fileadmin/allgemein/pdf/broschueren/foerderprogramm_2015.pdf. https://www.darpa.mil.

Gao, C. (2021). Genome engineering for crop improvement and future agriculture. *Cell, 184*, 1621–1635. https://doi.org/10.1016/j.cell.2021.01.005

Hickey, L. T., Hafeez, A. N., Robinson, H., Jackson, S. A., Leal-Bertioli, S. C. M., Tester, M., Gao, C., Godwin, I. D., Hayes, B. J., & Wulff, B. B. H. (2019). Breeding crops to feed 10 billion. *Nature Biotechnology, 37*, 744–754. https://doi.org/10.1038/s41587-019-0152-9

Kumagai, M. H., Donson, J., Della-Cioppa, G., & Grill, L. K. (2000). Rapid, high-level expression of glycosylated rice alpha-amylase in transfected plants by an RNA viral vector. *Gene, 245*(1), 169–174.

Kumlehn, J., Pietralla, J., Hensel, G., Pacher, M., & Puchta, H. (2018). The CRISPR/Cas revolution continues: From efficient gene editing for crop breeding to plant synthetic biology. *Journal of Integrative Plant Biology*. https://doi.org/10.1111/jipb.12734

Lokko, Y., Heijde, M., Schebesta, K., Scholtès, P., Van Montagu, M., & Giacca, M. (2018). Biotechnology and the bioeconomy – Towards inclusive and sustainable industrial development. *New Biotechnology, 40*(Part A), 5–10. https://doi.org/10.1111/jipb.12734

Müller-Röber, B., Bartmer, C.-A., Büchting, A. J., Daniel, H., Kast, H., Metzlaff, M., Prüfer, D., Schön, C.-C., & Schurr, U. (2010). Pflanzenforschung für eine nachhaltige Bioökonomie. Forschungs-, Technologie- und Handlungsbedarf. Berichte aus dem BioÖkonomieRat, Bericht 2. https://biooekonomierat.de/fileadmin/templates/publikationen/berichte/Berichte02-Pflanze.pdf. Accessed: 27.08.2019.

OECD (Organisation for Economic Co-operation and Development). (n.d.). Biotechnology Statistics – United States. http://www.oecd.org/sti/emerging-tech/biotechnologystatistics-unitedstates.htm. Accessed: 27.08.2019.

Oluwayelu, D. O., & Adebiyi, A. I. (2016). Plantibodies in human and animal health: A review. *African Health Sciences, 16*(2), 640–645.

ÖNORM M 7101 Bbl 2. (1996). Begriffe der Energiewirtschaft – Allgemeine Begriffsbestimmungen. FNA 093 Energiewirtschaft.

Pflanzenforschung.de. (n.d.). Welche Pflanzenvielfalt nutzen wir? https://www.pflanzenforschung.de/de/themen/vielfalt-der-nutzpflanzen/vielfalt-nutzen. Accessed: 27.08.2019.

Pies, I., Hielscher, S., Valentinov, V., & Everding, S. (2017). Gesellschaftliche Lernprozesse zur Förderung der Bioökonomie – eine ordonomische Argumentationsskizze. Diskussionspapier Nr. 2017–02. https://www.econstor.eu/bitstream/10419/170458/1/dp2017-02.pdf. Accessed: 27.08.2019.

Pietzsch, J. (Hrsg.). (2017). *Bioökonomie für Einsteiger*. Springer.

Plastics Europe. (2015). Plastics – the Facts 2014/15. An analysis of European plastics production, demand and waste data. https://www.plasticseurope.org/application/files/5515/1689/9220/2014plastics_the_facts_PubFeb2015.pdf. Accessed: 27.08.2019.

Puchta, H. (2017). Applying CRISPR/Cas for genome engineering in plants: The best is yet to come. *Current Opinion in Plant Biology, 36*, 1–8.

Rodriguez-Leal, D., Lemmon, Z. H., Man, J., Bartlett, M. E., & Lippman, Z. B. (2017). Engineering quantitative trait variation for crop improvement by genome editing. *Cell, 171*(2), 470–480.

Wada, N., Ueta, R., Osakabe, Y., & Osakabe, K. (2020). Precision genome editing in plants: State-of-the-art in CRISPR/Cas9-based genome engineering. *BMC Plant Biology, 20*, 234. https://doi.org/10.1186/s12870-020-02385-5

Wang, H., Cimen, E., Singh, N., & Buckler, E. (2020). Deep learning for plant genomics and crop improvement. *Current Opinion in Plant Biology, 54*, 34–41. https://doi.org/10.1016/j.pbi.2019.12.010

WissenschaftsCampus Halle. (2017). Jahresbericht 2016–2017. www.sciencecampus-halle.de/index.php/Jahresbericht.html?file=tl_files/data_site/Redaktionsdaten/_PDF-Daten/Jahresbericht_ScieneCampus_201617_Web.pdf. Accessed: 27.08.2019.

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Wood-Based Bioeconomy

Frank Miletzky, André Wagenführ, and Matthias Zscheile

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_4

4.1 Definitions of Wood-Based Bioeconomy

In addition to agriculture, the bio-based economy also affects forestry, the wood and paper industry, the chemical and, in particular, the plastics industry, the pharmaceutical industry and even the energy industry. Finally

> » Wood is by far the largest biobased source of raw materials for chemical and mechanical use in a wide range of products outside the food and animal feed sectors. For the use of agricultural and forest biomass, new ways and technologies for resource-efficient use and for new product lines are being sought within the framework of the bioeconomy, with chemistry and biotechnology playing an essential role. (Teischinger, 2016, p. 11)

The wood-based bioeconomy ideally uses the raw material wood (trunk wood, crown wood and, if necessary, stock wood, waste wood from previous use) in a cascade. Here, the refinement steps are refined further and further (chemical decomposition and modification) and residual materials and by-products from the previous steps are used for the next stage. Only at the end of this process is it sensible to use the residual materials as an energy source. However, the primary goal is the material use of wood, for example for construction, housing or paper, and the associated CO_2 storage and substitution of fossil materials.

4.2 System Description

The raw material wood is the oldest building material and energy source of mankind. In recent years, however, the variety of uses has increased and global demand has risen. In addition to the more traditional processing and application areas of the sawmill industry, the wood-based materials industry or the wood and pulp industry, the bioeconomy holds out the prospect of an expanded role for wood in the future supply of raw materials (Mantau, 2018). The reason for this shift (back) towards more wood use can be traced back to several points:

4.2.1 Change in Values and Awareness

The growing awareness of the dramatic impacts of human economic activity, with priority given to the exploitation of all resources, is increasingly challenging political actors, the economy and social groups to develop new forms of economy. Thus, political programmes of the German government and the EU define the bioeconomy as a path towards greater sustainability (BMEL, 2009, 2014; EC, 2019). The "Charter for Wood 2.0" of the German Federal Ministry of Food and Agriculture (BMEL) identifies several reasons for this.[1] As the most widespread and largest resource in terms of volume, wood is of particular importance.

4.2.2 Raw Material Availability

In the European economic area, there is an annual increase of approx. 403 million m^3. This means that large quantities of wood are available. Of the total 35 billion m^3 of wood in Europe's forests (of which 26.5 billion m^3 in the EU28), 84% can be used for wood supply (Domínguez et al., 2015). Conifers form 57% of the forest stock and hardwoods 43%, the share of which is increasing due to the targeted forest conversion. Germany, Austria and Switzerland (DACH region), as part of Central-West Europe, is the region with the largest timber resources and tradi-

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[1] For more information, see ► https://www.bmel.de/DE/Wald-Fischerei/03_Holz/_texte/Charta-Holz2017.html

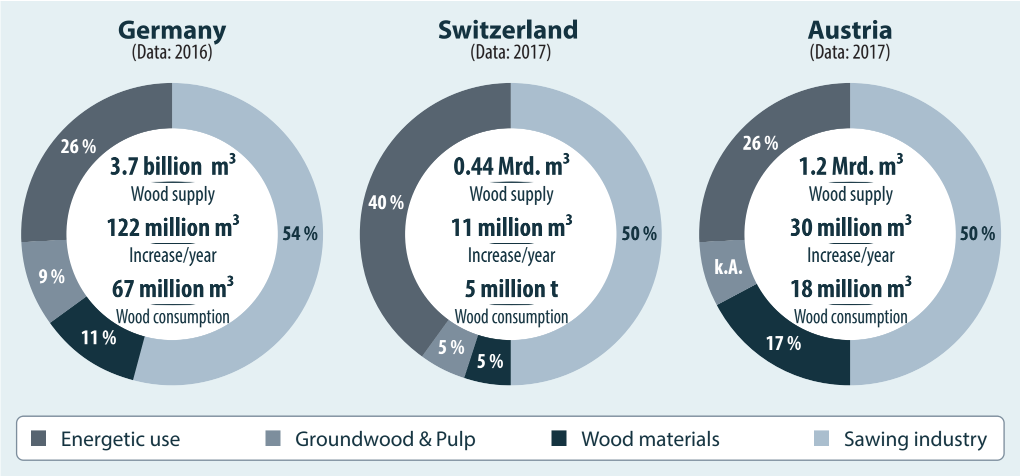

Fig. 4.1 **Timber** harvest by wood use, wood supply and increment – DACH region. (Source: Own representation based on UNECE, 2018; FNR, 2018; BFS, 2018; BMNT, 2018)

tionally has large quantities of timber (Domínguez et al., 2015) (► Sect. 4.1).

Among the conifers, spruce accounts for the largest share of trees, while among the hardwoods it is beech. This also indicates that the largest proportion of roundwood in Central Europe is processed (Fig. 4.1).

4.2.3 Stakeholders

The industry is divided into the following major groups:

- Silviculture and sawmilling
- Wood construction and carpentry
- Interior fittings and furniture production
- Wood-based panel industry
- Pulp and paper industry
- Nonwovens/textiles industry
- Chemical industry/pharmacy/medicine
- Recycling industry/energy industry

The sawmill industry and especially timber construction have always played a traditional and dominant pioneering role in the use of wood and its highest added value. A large number of high-performance sawmills with modern processing capacities, modern and flexible timber construction companies and carpentry firms, as well as large, well-known companies in the wood-based materials, pulp and paper industries have long been actively and successfully established in this economic sector (UNECE, 2018) (Fig. 4.2a and b).

4.2.4 Areas of Application

In recent years, significant efforts have been made, especially in Scandinavia, South America and New Zealand, to either further develop the well-known areas of application for wood as a raw material or to develop completely new ones. Worthy of special mention are development work on the use of lignin for the production of carbon fibers or application research on nano- or microfibrillated cellulose (NFC/MFC)[2] for barrier

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[2] Nano-/microfibrillated cellulose: a substance formed by disintegration (fibrillation) of cellulose, consisting of largely isolated cellulose microfibrils stabilised by water and possibly functional groups, no longer containing any crystalline components and having the character of a hydrogel.

a

Resource Provider

- Forestry in state, institutional or private ownership. According to the Federal Forest Inventory, 3.6% of Germany's forests are owned by the federal government, 29% by the Länder, 19.4% by corporations and 48% by private owners.

Economy/Industry

- Solid wood products, wood-based materials, fibers, paper, nonwovens, textiles, chemical products, energy
- Forestry, sawmill industry, panel materials, furniture industry, interior design, pulp and paper industry, fibre industry and textile industry, technical textiles, adhesives industry, pharmaceutical industry, chemical industry, automotive industry, shipbuilding industry

Markets, Products

- Wood from cascading sustainable use yields potentially thousands of products. Depending on the disintegration stage, these can be end products (e.g. sawn wood products, wood-based materials) or intermediate products (fibres, chemically isolated wood components). The user industries are, for example, construction, furniture, pulp and paper, textiles, chemicals, energy, and in the future probably also automotive, architecture, health care, etc. This will be possible through increased research and development in materials and material conversion.

End-of-life-Management

- The duration of the life cycle depends on the respective product segments (these can be very different). Depending on the product segment, recycling systems range from very pronounced (paper > 70%) to non-existent (durable products such as furniture). As a rule, thermal recycling is the state of the art. This also applies to wood processing by-products from mechanical or chemical processes with a significant positive climate effect (e.g. black liquor combustion in the pulp process).

Organizations (nat. and int.)

- Forest based sector Technology Platform (FTP), DFWR, DHWR, Cluster Forst/Holz/Papier in various German states

Media

- Websites and reports of the above-mentioned actors

Consumers

- Population and special users as listed

NGOs

- For example: FSC, PEFC, B.A.U.M., WWF, Greenpeace

Sponsors, investors

- Federal and state research institutes, federal and state ministries, Charter for Wood 2.0, Bioeconomy Council

Politics, administration

- Federal and state research institutes, federal and state ministries, Charter for Wood 2.0, Bioeconomy Council

b

Competence centres (reg.)

- Thünen Institutes, Paper Technology Foundation (PTS), Institute of Wood Research Dresden (IHD), Fraunhofer Institutes for Applied Polymer Research (IAP), Wood Research Braunschweig (WKI)

Science

- Universities, Research institutions

Fig. 4.2 **a** System graphic. Part 1. (Source: Own representation). **b** System graphic. Part 2 (continuation of part 1). (Source: Own representation) coatings and pharmaceutical applications, among others. The textile sector can also benefit sustainably from wood bioeconomy, as new cellulose spinning processes (Tencel™) with significantly improved properties and a high sustainability effect have taken hold and are successfully establishing themselves on the market.[3] The development activities are mainly geared towards a continuous increase in the efficiency of wood utilization as well as improved environmental compatibility of the production processes.

4.2.5 Material Flows

The establishment of intelligent value chains and networks, including the associated main and side streams, is a major focus of research and development activities (see ◘ Fig. 4.6 in Box "Wood Development Pathways for Chemical Products").

4.2.6 Cascade Use

The aim of cascade use in the wood-based bioeconomy is to process the entire tree in effective, graduated disintegration steps. In contrast to all available fossil raw materials, wood is not only a raw material mass, but also has an intelligent inner structure that must be used. The wood-based bioeconomy therefore uses the raw material wood (trunk wood, crown wood, bark) ideally in a cascade. In this process, the raw material or products made from it are used as long, as often and as efficiently as possible in successive steps, and only at the end of the product life cycle are they energetically recovered. The material structure is disintegrated step by step. In order to achieve the goal of high raw material productivity, i.e. to increase the total benefit per unit of raw material, the cascade use of wood should include at least two material uses, and only at the end of the overall cascade is the residual material used as an energy source. The primary focus of a bioeconomically oriented use of wood is thus the use of the same unit of wood in as many stages as possible, for example for construction, housing, transport or packaging, as well as for heat generation. The cascade use of biomass is far superior to direct energy use in terms of ecological aspects and also has strong economic advantages, because it creates five to ten times the gross value added and employment effects for the same amount of biomass (Sauerwein, 2016). Cascade use begins with the felling of the tree and leads via its cutting and processing of individual components to the target products: The trunk is considered the most valuable part and is processed into sawn timber. Crown and residual wood from trunk processing is used in the wood-based materials, pulp and paper industries. As a rule, particle materials, fibre-based materials are produced from it. Residual wood assortments are mostly chemically decomposed for the fiber materials industry and for applications in chemistry and materials technology (including Fehrenbach et al., 2017). In this process, the wood is broken down into its chemical components:

- Lignin: incrusting substance of wood, responsible for its high stability, especially for its pressure stability – irregular macromolecule of substituted phenylpropane units
- Cellulose: highly ordered, linear molecule of ß-1,4-glycosidically linked glucose units with a pronounced supermolecular structure, which decisively determines the properties – here above all the tensile strength,
- Hemicelluloses: Group of carbohydrate macromolecules consisting of various sugar components (hexoses, pentoses)

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[3] For more information, see ► http://www.lenzing.com

with different functionalities; in wood, they represent the intermediary element between the cellulose fibrils and the lignin.
- accessory components such as terpenes (resin acids, turpentine oil), waxes and phytosterols, which form the basis for chemically modified, new materials and chemical products

Wood as semi-finished products in the form of sawn timber, wood-based panels, veneer and plywood, as well as wood pulp and cellulose, have traditionally been extremely important for the production of finished goods in the paper, construction, furniture and packaging industries (FNR, 2018).

In the field of energy use, wood is also used to generate heat and electricity.

4.2.7 Procedure

The disintegration of the wood primarily serves to produce fibre material with favourable properties for processing. For this purpose, processes with primarily mechanical, chemical-mechanical or chemical process steps are used:

- Mechanical pulping produces a still lignified, i.e. lignin-containing, pulp by cutting and crushing, which – depending on the fineness of the pulping – is used in the production of fiberboards (medium-density fiberboard – MDF, high-density fiberboard – HDF), molded fiberboard parts or paper and board. In addition to purely hydro-mechanical defibration, numerous process variants have been developed, relating to greater variability in the raw material (wood chips instead of logs), higher energy efficiency (thermo-mechanical pulp – TMP) and/or complementary improved fibre properties (chemical-thermo-mechanical pulp – CTMP with various technological variants, for example integrated bleaching). Today, TMP and CTMP production are of particular economic importance, as they have the best quality-efficiency ratio of all primarily mechanical disintegration processes.
- In chemical pulping, the wood is not only disintegrated but also broken down into its main chemical components cellulose, hemicelluloses, lignin and other accessory components (for more information, see Fengel & Wegener, 2003, among others). It is thus primarily used to obtain delignified cellulose fibres for paper and regenerated fibre production.[4]
- Today, approx. 181 million tonnes of pulp are produced worldwide. Increasingly, lignin extraction is (again) gaining importance for further chemical processing. In addition, the use of terpenes, phytosterols and waxes for chemical products and pharmaceuticals is playing an increasingly important role in research. From these substances, a whole range of chemical substances can be built up on a platform, from which, among other things, polymers can be produced. Furthermore, the carbohydrate components can be chemically as well as biotechnologically degraded to monomeric sugars or other platform chemicals such as lactic acid, succinic acid, glycols and other compounds. Thus, they potentially serve as raw materials for numerous products. Examples include polylactide for packaging, monoethylene glycol for polyester, phenolic components for resins, or hemi-

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[4] Regenerated fiber: filament fiber produced from very pure cellulose via a chemical-physical dissolving process, which in turn consists of pure cellulose. In addition to the classic viscose fiber, very efficient textile fibers with a good environmental balance have been developed in recent years through new processes (TENCEL®, LYOCELL®).

celluloses for polyester.[5] Increasingly, the chemical decomposition of wood today is also aimed at recovering sugars and lignin for use in platform chemistry.

4.3 Degree of Organisation of the Sector

The forestry, wood and paper industries and other related sectors have efficient association structures and supporting institutions that represent the interests of the forestry, wood, paper and other economic sectors. For about 15 years, a significant growth of industry associations and the intertwining of a wide variety of structures have been noticeable:

4.3.1 Central Nodes

The central business associations and organisations (and their respective subdivisions) are the Association of German Chambers of Industry and Commerce (DIHK), the German Forestry Council (DFWR), the German Timber Industry Council (DHWR), the German Sawmill and Timber Industry Association (DeSH) and the German Chemical Industry Association (VCI). (DeSH), the Association of German Paper Mills (Verband Deutscher Papierfabriken e. V.) and the German Chemical Industry Association (Verband der Chemischen Industrie). Here, the interests of the respective industry are bundled – as well as concertedly on certain topics – and represented in the political and public arena. In addition, the timber industry is represented by numerous sector-related associations, such as those of carpenters and joiners, veneer manufacturers, furniture manufacturers, the wood-based materials industry, etc. On the initiative of the Federal Ministry of Food and Agriculture (BMEL), the “Charter for Wood 2.0” has been in force since 2018.[6] It combines climate protection, value creation and resource efficiency targets. On its basis, diverse stakeholders are brought together in various formats. In this way, their political, economic and social actions are to be interlinked and coordinated in the sense of a holistic approach.

A central European (and also national) network node for the sector is the Forest-based sector Technology Platform (FTP) with its national support groups (NSG). In addition, there are various clusters in the federal states that focus primarily or predominantly on the topics of forestry, wood and paper (► Chap. 13). Political, strategic issues from the sector to policy-makers and vice versa are communicated primarily through the Bioeconomy Council at federal level and bioeconomy councils in some of the German Länder.

4.3.2 Decentralized Nodes

Trade fairs such as LIGNA, Interzoom, ForumHolz, Holz-Handwerk or Zellcheming as important communication venues for the development of the industry(ies) are further, decentralised hubs of the industry.

4.3.3 Certifications

The degree of organisation in the sector can also be seen in the increase in certification systems. This is the result of society’s

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[5] For more information, see ► www.upmpaper.com and ► www.bioeconomy.de

[6] For more information, see ► www.charta-fuer-holz.de

increased sensitivity regarding the treatment of forests as an economic and social asset. In recent years, several globally recognised certification systems have been introduced. Among others:

- Forest Stewardship Coucil (FSC): Founded in 1990 as an international NGO with the aim of identifying the sustainability of forest management through appropriate certificates for wood. The certification process is based on the sustainability concept of the "Brundtland Report" (UN-WCED, 1987) and includes economic, social and ecological criteria in the assessment. Today, products *(chain of custody)* are also increasingly included in the assessment. Among other things, recycling is also assessed.
- Programme for the Endorsement of Forest Certification Schemes (PEFC): Founded in 1990 as a pan-European system for the certification of forest management systems, including by the German Timber Council (DHWR). PEFC claims to be the largest institution for ensuring and marketing sustainable forest management through an independent certification system. 68% of Germany's forest area, i.e. approx. 7.6 million ha and 7653 farms and associations in Germany, are PEFC-certified.[7]
- NGOs related to forestry: among others B.A.U.M., World Wildlife Fund WWF, Naturschutzbund Deutschland NABU.[8]

4.3.4 Education

In Germany, there are many academic training institutions for the various branches of the wood-based bioeconomy. Corresponding courses of study are currently offered at the University of Hohenheim as well as the Straubing Campus of the Technical University of Munich.[9] Forestry, partly in combination with wood economics and wood technology, can be studied in Germany today at the Universities of Hamburg, Göttingen, Dresden, Freiburg, Munich (Weihenstephan) as well as the Rosenheim University of Applied Sciences. Wood management is also offered at the University for Sustainable Development in Eberswalde and the Universities of Applied Sciences in Rottenburg (wood management) and Lemgo (wood technology). In addition, the pulp and paper industry can be studied at the Technical Universities of Darmstadt and Dresden and the Universities of Applied Sciences in Munich and Karlsruhe (Duale Hochschule). In addition, the growing importance of the bioeconomy over the past 5 years has led to a change in academic training profiles, which is expected to result in new courses of study in the coming years.

4.3.5 Research

Research on the topic of wood in Germany is largely funded by the European research programme "Horizon 2020" and subsequently, from 2021, by "Horizon Europe". Here, in the years 2015–2017 alone, around €460 million was made available for research and innovation projects in the forest-based sector (FTP, 2019). At the national level, the Agency for Renewable Resources (FNR) as a departmental body of the BMEL is primarily responsible for research funding and coordination. In addition, the Project Management Organisation Jülich (PtJ) is important as a competent partner for the public sector in science, industry and politics.[10] Within European funding, the BBI JU (Bio-Based Industry Joint Undertaking)

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[7] For more information, see ▶ www.pefc.de

[8] For more information, see ▶ www.baumev.de, ▶ www.wwf.de, ▶ www.nabu.de

[9] For more information, see ▶ www.uni-hohenheim.de, ▶ www.tum.de

[10] For more information, see ▶ www.ptj.de

plays an outstanding role for the circular bioeconomy. 3500 direct and 10,000 indirect jobs are expected only by the so-called flagship projects; the funding from the BBI JU for this amounts to € 228 million with a private investment volume of € 1.3 billion.[11]

4.4 Innovations

4.4.1 Requirements

As a rule, previous decisive waves of innovation were always based on the availability of new resources such as steel or oil, among others, on which economic structures were built. Ultimately, the intensive exploitation of these resources under scale-economic aspects was the decisive innovation feature (Nefiodow, 2006) of industrial development since the middle of the nineteenth century. Thus, today's class of materials, polymer materials, arose primarily from the inexpensive and mass availability of coal products and later petroleum as a platform chemical.

However, an innovation push based on wood follows other basic requirements. Although large wood reserves are available worldwide and wood is a renewable resource, it is nevertheless limited and its cultivation as well as its use are linked to sustainability criteria. Value creation is therefore mainly triggered by innovations that reduce the use of resources or produce high-quality products (Radermacher, 2011).

In contrast to all resources exploited on an industrial scale to date, wood represents a special material whose properties are determined not only by its chemical composition but also by its hierarchical structural levels. Its inhomogeneous structure and anisotropic behaviour with respect to[12] the three main directions of wood[13] make it an extremely complex material (Wagenführ & Scholz, 2018), whose structure and morphology must be taken into account in exploitation strategies. Innovation based on wood is not primarily due to the availability of material in categories of quantity or mass. The special value results from the intelligent linking of structure and material in use, coupled with resource efficiency and circular economy. (For examples of innovations, see Infoboxes "Paper-Like Valuable Materials for Folding and Honey Wagon Sandwich Cores" and "High-Strength Synthetic Fibre Made from Pure Cellulose"). The provision, extraction, processing, distribution and recycling of resources must be as CO_2-efficient as possible. With this in mind, modern and decentralised cultivation, extraction, production and recycling technologies and processes should be used. Innovations in the field of digitalisation can have a supporting effect here. The German government's sustainability and high-tech strategy is based in part on similar considerations (BMEL, 2009).

4.4.2 Current Developments and Potentials

Recent concrete developments show the as yet untapped potential of the renewable raw material wood as a heterogeneous, highly

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[11] Philippe Mengal, Executive Director, Bio-based Industries Joint Undertaking; World Bioeconomy Roundtables, 18.05.2021, ► https://wcbef.com/events/upcoming-events/world-bioeconomy-roundtables/

[12] A material exhibits anisotropic behaviour if its physical, mechanical and chemical properties are direction-dependent. For example, the material behaviour of wood is anisotropic because its elongation behaviour and strength are completely different parallel or transverse to the direction of the fibres (► https://baulexikon.beuth.de/ANISOTROPES.HTM).

[13] The three main directions are: "longitudinal" along the axis of the log (parallel to the grain), "radial" at 90 degrees to the growth ring position, and "tangential" as a tangent along the growth rings.

complex polymer. In this respect, the main utilisation paths of the material are to be assigned or considered from a chemical point of view in a strongly structure-related manner. (Cf. Infobox "Development Paths from Wood for Chemical Products").

In order to implement the example products shown in ◘ Fig. 4.2a, many of which have yet to be researched, the main task is to develop and provide complex manufacturing technologies, including biochemical ones. In this context, the wood components mentioned must be processed on an industrial scale in order to later ensure the use of functionalised raw materials and materials on a large scale. This includes first and foremost efficient decomposition technologies as well as corresponding *downstream processes* for the separation and extraction of necessary chemical semi-finished products and end products.

Assuming this is the case, materials development in the top segment is aimed at using native wood to develop and produce processing and finishing products for construction and other areas. Harvesting and processing waste still offer the advantage that the complex wood structures can also be found in it, so that the fiber is available as a valuable material. This can be processed into fibre products such as papers, nonwovens, boards or moulded parts and composites. Only the processing or recycling residues of these products or assortments specially grown for this purpose on plantations offer the sensible economic prerequisites for producing simple platform chemicals, bioenergy sources or directly energy from them.

It can be deduced from this that innovation processes based on the renewable raw material wood must focus on the value of structure formation in natural wood synthesis and its use to the greatest possible extent if an overall economic advantage is to arise. This utilisation concept, known as the utilisation cascade, represents the main innovation gain for society alongside the climate-relevant effects and should be understood as a context.

4.4.3 Innovations in the Individual Sub-sectors

4.4.3.1 Silviculture and Timber Construction

Through wood modifications, material combinations (mixed construction), innovative structural solutions (for example bionically inspired) among others, an increase in wood use is seen in coordination with forestry (climate change, forest conversion, increase in raw materials, among other things through short rotation plantations), but also the use of wood in new fields of application is made possible (for example, energy industry: towers and rotor blades of wind turbines). Wood is not only an important CO_2 absorber in the growth phase, but also a significant CO_2 store through material recycling, especially in the construction industry. This will help to achieve the German and global climate protection targets by 2050.

4.4.3.2 Wood Materials

Here, the construction industry (for example, fire protection panels based on wood or paper) can be positively influenced across all sectors. A new area of application, the use of wood/wood-based materials/wood composites in mechanical and plant engineering, including vehicle and aircraft construction, can be developed on a new design basis. In addition to the lightweight construction aspect, the climate aspect in particular comes into play here (replacement of metals such as steel and aluminium by the

CO_2-neutral renewable raw material wood). An important aspect here is an economically viable recycling economy (cascade use), which requires, among other things, the separability of the material composites in the recycling process.

4.4.3.3 Pulp/Paper/Nonwovens/Textiles

Major innovation effects are seen in cellulose and fiber-based new technologies and products with high value-added potential, for example in *composite production* for applications in lightweight construction, in the packaging industry and the like. In addition, applications are conceivable in fields such as architecture and construction, medical technology and health care, living and working, food production in urban areas, and energy storage technology. The paper industry's future study "Fibre & Paper 2030" (PTS, 2015) provides a comprehensive approach.

4.4.3.4 General

Hybridisation, functionalisation and the lightweight construction approach have high value creation potential in the various construction and materials due to the interdisciplinary solution approaches, where wood in industrial processing or use is superior to other materials not only in terms of material properties over the CO_2 emission life cycle, but also in terms of sustainability, CO_2 balance and recyclability. Products that can be substituted by wood products with a long (construction sector) and medium service life (wood-based materials, furniture) therefore have the greatest effect on achieving climate protection targets. This also applies to recycling.

This is complemented by other innovations with high value-added potential:

- Material development in high-end applications
- Recycling
- Material development with focus on raw material separation at the end of the life cycle
- Concepts for material separation at the end of the material life cycle
- Use of hardwood in areas previously dominated by softwood or other materials (e.g. glued laminated timber (glulam) made of beech or pipes made of wood).
- High degree of material utilisation, in particular by-product utilisation for chemical product development

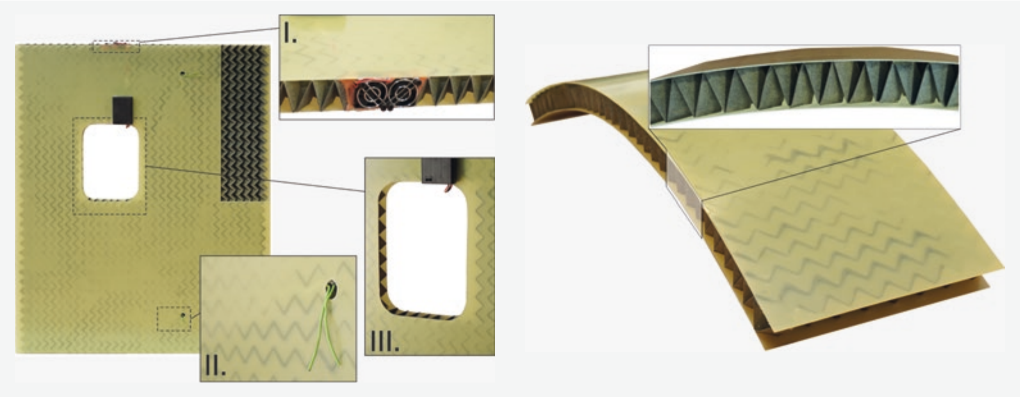
The pharmaceutical and medical sectors see billions in potential in the bioeconomy by substituting limited raw materials with renewable ones (Organobalance GmbH, 2015).

4.4.3.5 Paper-Like Materials for Folding and Honeycomb Sandwich Cores

In several research projects, adapted paper-like materials for folding and honeycomb cores in sandwich structures were developed for use in lightweight structures. This material has a significantly expanded field of application and can be used in a variety of ways for innovative products in the field of lightweight sandwich structures or 3D formable structures. This core material can experimentally and numerically demonstrably improve its weight-specific properties (◘ Figs. 4.3 and 4.4).

4.4.3.6 High Strength Synthetic Fibre Made from Pure Cellulose

The research group led by Daniel Söderberg (KTH Stockholm) has synthesised the strongest cellulose fiber ever produced. Its strength properties are similar to those of carbon fibres and it was synthesised by joining individual cellulose chains from nanofibrillated cellulose (Mittal et al., 2018) (◘ Fig. 4.5).



■ **Fig. 4.3** Paper-like materials for folding and honeycomb sandwich cores. (Source: PTS, n.d., o. S.)

■ **Fig. 4.4** 3D honeycomb for furniture construction. (Source: Lippitsch et al., 2019)

4.4.3.7 Development Paths from Wood for Chemical Products

The targeted product range for new chemicals and materials fully includes the material basis of wood – cellulose, hemicellulose, lignin and accessory components.

Thus, for cellulose-based developments, the already preformed linear structures are primarily used in order to be able to realise high tensile strengths. The field of development begins with the direct use of cellulose from the native cell in the form of fibers for paper, nonwovens and composite materials that can be built from it. In addition, new filaments are developed through chemical-physical forming processes, which are used in the textile sector for clothing as well as in technical applications and processes.

Hemicelluloses are chemically more diverse and can be isolated in relatively pure form. Here, the focus of developments is primarily on starting materials for bioplastics and food and feed supplements as well as cosmetics and pharmaceutical products. For example, the oil furfural, which is a by-product of some wood chemical processes, is an ideal platform chemical for biopolyesters. All carbohydrate fractions of wood are also starting materials for the production of bioethanol or bioglycols as feedstock chemicals or energy carriers.

Lignin as a natural source of aromatics offers a wide field of application for synthetic resins and adhesives – starting with phenolic resins and extending to polyurethanes. A particularly high added value would be achieved by the development of carbon fibers from lignin, which is being worked on intensively. In addition, lignin provides a good basis for carbon black and other technical products. The use of polymeric lignin with the incorporation of nitrogen as a soil conditioner and organic fertilizer without eutrophication potential is also interesting (■ Fig. 4.6).

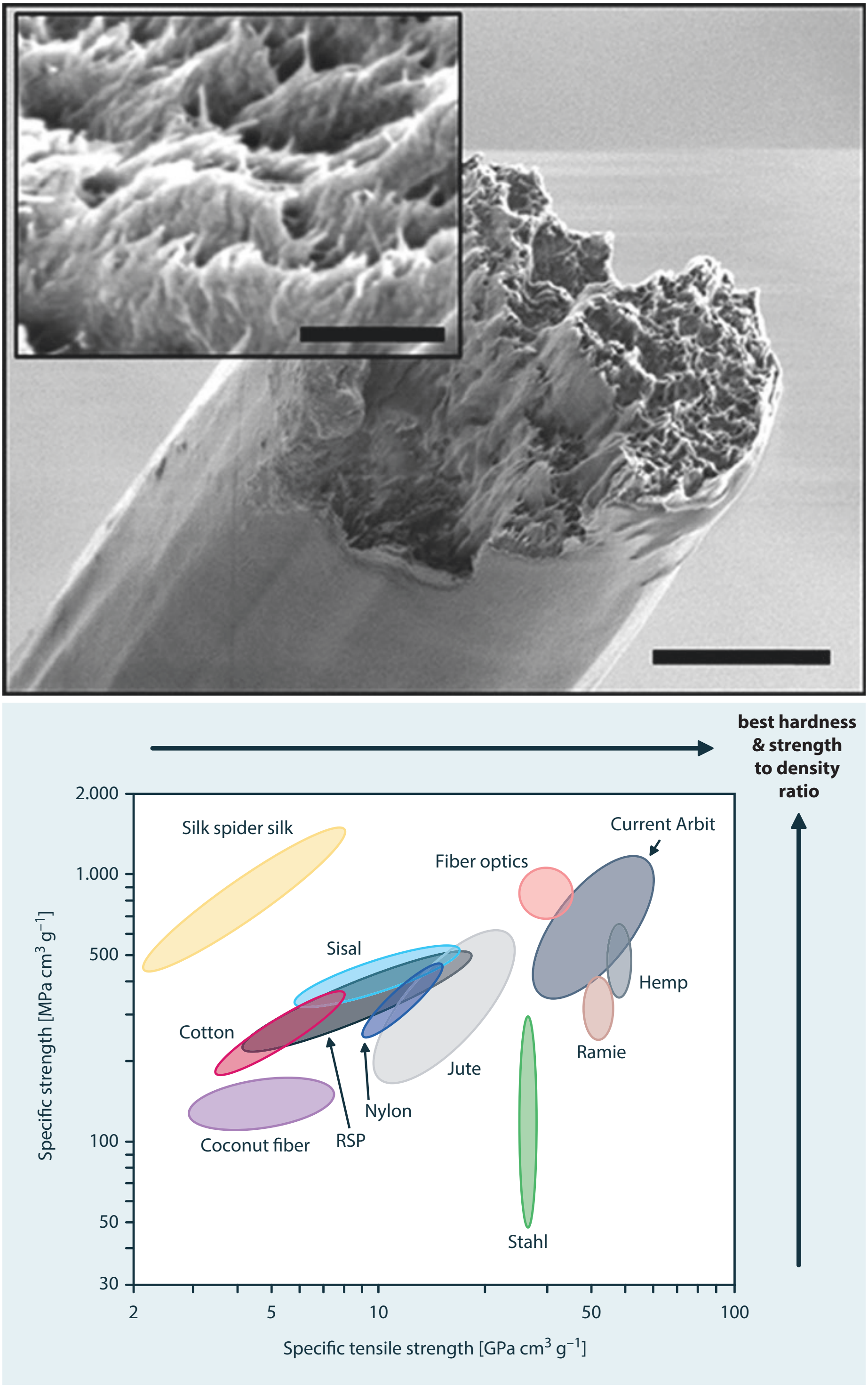


Fig. 4.5 High-strength fibers made from pure cellulose. (Source: Mittal et al., 2018, p. 6370 et seq.)

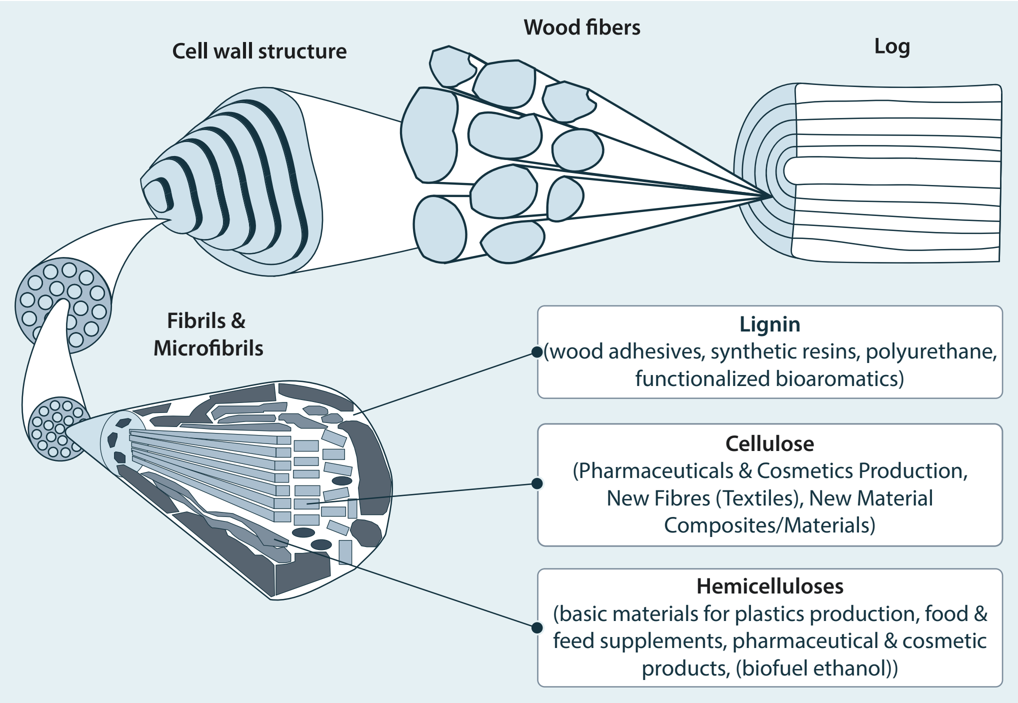


Fig. 4.6 Variety of materials made of wood. (Source: Own representation)

4.5 Conflicting Objectives

In order to make the conflicting goals comprehensible and capable of productive interpretation, let us first make a preliminary remark on the innovation approach: forests have at all times been a point of intersection of the most diverse interests and uses, and this continues to this day. As an economic factor, the forest and its use are already exposed to numerous competing interests. Thus, timber extraction and productivity have long been at the centre of economic activity. Sustainable management under the conditions of climate change are today's important issues and pose enormous challenges to forestry. In addition, the recreational and leisure value of forests has increased, resulting in specific demands and conditions. Here, above all, the nature conservation role of the forest has to be redeveloped under the aspect of the preservation of biodiversity, water balance and air renewal in connection with responsible resource management. The clash between emotionally charged opinions and fact-based facts requires productive moderation and explanation.

4.5.1 Competing Uses of Energy and Materials

According to the Federal Statistical Office (Destatis, 2019), consumption as energy wood increased from 13 to 19% of the timber harvest from 2006 to 2017, which corresponds to 9.9 million fm.[14] This quantity is withdrawn from valuable material use,

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[14] fm = solid cubic metre. A spatial measure used in the forestry and timber industry for round timber. It corresponds to one cubic metre of solid wood mass, i.e. it does not take into account the cavities between the logs.

among other things also under the aspect of the storage of fixed CO_2.

Nevertheless, wood does not play a dominant role in the area of energy generation. In the first half of 2018, approximately 23 TWh of electricity was generated from biomass, which indicates a decline. By comparison, the figure for photovoltaics is 22.3 TWh – with an upward trend. However, the energetic use of wood through combustion (domestic fire) is popular and at the same time problematic with regard to dust generation and sustainable energy efficiency: in 2010, of 135.4 million fm of available wood raw material in Germany, 33.9 million fm were used for domestic fire alone, and in total 64.8 million fm were used for energy generation or energy products, which corresponds to 50.5% of the volume (Mantau, 2012). However, the environmental impact does not end with the energy use. For example, it is predicted that domestic heating in Europe could contribute 41% of $PM_{2.5}$ particulate matter emissions and 69% of soot emissions in 2030 (Clean Heat, 2018). Deutsche Umwelthilfe estimates that the short-term environmental damage from widespread and regional soot emissions could consume or even exceed the benefits of the sustainable fuel (DUH, 2019).

In order to be able to correctly assess the potential for conflict, however, the producer side, the forestry sector, must also be considered. It is precisely due to the demand for energy that timber prices have improved in recent years to such an extent that adequate forest management has become attractive again, not least because of the ranges that can now be sold and which are primarily used for pellet production. In this respect, it is not the use of wood for energy in general that is at issue, but rather its allocation to the appropriate assortment. In addition, growth in Germany is still greater than wood use, so that serious raw material bottlenecks have not yet occurred (BMEL, 2014).

4.5.2 Forest Restructuring

From the point of view of use, the so-called forest conversion underway away from coniferous wood monocultures towards more site-appropriate deciduous and mixed deciduous stands with a higher proportion of natural forest and corresponding management guidelines is also an area of conflict that primarily affects material and material recycling (BMEL, 2014). It is also important to understand here that forest conversion is by no means only a political demand, but derives primarily from the necessities of future forest stability (Bolte et al., 2016). Under changed climatic conditions and the resulting stress caused by severe weather events, a tendency towards increasing drought, increased pest infestation and the loss of “hope tree species” due to insufficient robustness, the requirements are formulated. Thus, considerable stand losses of oak, ash and chestnut are expected. This is an economically and ecologically significant problem of the highest complexity.

4.5.3 Wood Utilisation

There is still a considerable need for research in order to make the predicted future high proportion of beech wood accessible for sensible and high-quality use. For this reason, among others, the establishment of a “Hardwood Technical Centre” is currently being pursued in Baden-Württemberg (Lehner, 2018), in addition to other activities in other federal states.

The key to conflict resolution lies in strengthening the options for utilisation: Only a secure demand for high-quality products by corresponding processing companies ensures a sustainably maintained and productive forest. To this end, as well as to further develop cascade use under market-economy conditions – i.e. also without subsidising certain utilisation paths – coordinated authoritative steps involving all potential and real partners are still required. Here, politics should take on a moderating role with the simultaneous use of subsidies in order to be able to achieve the social goals.

References

BFS (Bundesamt für Statistik). (2018). Holzernte 2017. Schweizerische Forststatistik. https://www.bfs.admin.ch/bfs/de/home/aktuell/neue-veroeffentlichungen.assetdetail.5708707.html. Accessed: 26.08.2019.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2009). Aktionsplan der Bundesregierung zur stofflichen Nutzung nachwachsender Rohstoffe. https://www.bmel.de/SharedDocs/Downloads/Broschueren/AktionsplanNaWaRo.pdf?__blob=publicationFile. Accessed: 26.08.2019.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2014). Der Wald in Deutschland. Ausgewählte Ergebnisse der dritten Bundeswaldinventur. https://www.bmel.de/SharedDocs/Downloads/Broschueren/Bundeswaldinventur3.pdf?__blob=publicationFile. Accessed: 26.08.2019.

BMNT (Bundesministerium für Nachhaltigkeit und Tourismus). (2018). Holzeinschlagsmeldung über das Kalenderjahr 2017. https://www.bmnt.gv.at/dam/jcr:76a1a1da-ba38-4ebe-ab9c-4c471dafde8d/Holzeinschlag%202017.pdf. Accessed: 26.08.2019.

Bolte, A., Börner, J., Bräsicke, N., Degen, B., Dieter, M., Saake, B., & Schneider, B. U. (2016). Perspektiven der Forst- und Holzwirtschaft in Deutschland. Bioökonomierat. https://biooekonomierat.de/fileadmin/Publikationen/berichte/Hintergrundpapier_Forstwirtschaft_280416__final.pdf. Accessed: 26.08.2019.

Clean Heat. (2018). Heizen mit Holz: Umweltfolgen und Lösungsansätze. https://www.clean-heat.eu/de/aktivitaeten/infomaterial/download/hintergrundpapier-heizen-mit-holz-1.html. Accessed: 26.08.2019.

Domínguez, G., Köhl, M., & San-Miguel, J. (2015). Part II: European forests: Status, trends and policy responses. In FOREST EUROPE: State of Europe's Forests 2015 (S. 65–220). Ministerial Conference on the Protection of Forests in Europe. https://www.foresteurope.org/docs/fullsoef2015.pdf. Accessed: 26.08.2019.

Destatis (Statistisches Bundesamt). (2019). Land- & Forstwirtschaft, Fischerei. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Fischerei/_inhalt.html. Accessed: 26.08.2019.

DUH (Deutsche Umwelthilfe). (2019). Clean heat. http://www.clean-heat.eu. Accessed: 11. Juni 2019.

EC (European Commission) (2019). Green growth and circular economy. c.europa.eu/environment/green-enowth/ingrowth/index_en.htm. Accessed: 09.09.2019.

FNR (Fachagentur nachwachsende Rohstoffe e. V.). (2018). Rohstoffmonitoring Holz. Erwartungen und Möglichkeiten. https://www.fnr.de/fileadmin/allgemein/pdf/broschueren/Broschuere_Rohstoffmonitoring_Holz_Web_neu.pdf. Accessed: 26.08.2019.

Fengel, D., & Wegener, G. (2003). *Wood: Chemistry, ultrastructure, reactions*. De Gruyter. ISBN 3 11 0084813.

Fehrenbach H., Köppen, S. Kauertz, B., Wellenreuther, F., Baur, F., Wern, B., & Breitmayer, E. (2017). BIOMASSEKASKADEN – Mehr Ressourceneffizienz durch stoffliche Kaskadennutzung von Biomasse – von der Theorie zur Praxis. Umweltbundesamt. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-06-13_texte_53-2017_biokaskaden_anlage.pdf. Accessed: 02.09.2019.

FTP (Forest-based sector Technology Platform). (2019). FTP Database. db.forestplatform.org. Accessed: 26.08.2019.

Lehner, L. (2018). Technikum Laubholz. Ergebnisse einer Machbarkeitsstudie. In 3. Bioökonomietag Baden-Württemberg, Stuttgart, 22.11.2018. https://biooeconomie.uni-hohenheim.de/uploads/media/3.Biooekonomietag_Flyer.pdf. Accessed: 09.09.2019.

Lippitsch, S., Korn C., Wagenführ A. & Lippert F. (2019). FlexCore – 3D Waben für den Möbelbau. Poster zu den 12. Internationalen Möbeltagen 2019 in Dresden.

Mantau, U. (2012). Holzrohstoffbilanz Deutschland, Entwicklungen und Szenarien des Holzaufkommens und der Holzverwertung 1987 bis 2015. Zentrum Holzwirtschaft. https://literatur.thuenen.de/digbib_extern/dn051281.pdf. Accessed: 26.08.2019.

Mantau, U. (2018). Holzrohstoffbilanzen und Stoffströme des Holzes – Entwicklungen in Deutschland 1987 bis 2016. Zitiert in: Schlussbericht. Hamburg.

Mittal, N., Ansari, F., Gowda, K. V., Brouzet, C., Chen, P., Larsson, P. T., Roth, S. V., Lundell, F., Wagberg, L., Kotov, N. A., & Söderberg, D. (2018). Multiscale control of nanocellulose assembly: Transferring remarkable nanoscale fibril mechanics to macroscale fibers. *ACS Nano, 12*, 6378–6388.

Nefiodow, L. A. (2006). *Der sechste Kondratieff: Wege zur Produktivität und Vollbeschäftigung im Zeitalter der Information*. Rhein-Sieg-Verlag.

Organobalance GmbH. (2015). Pressemitteilung – Milliarden-Potenzial für Bioökonomie in Medizin und Pharmazie. http://biotechnologie.de/posts/1511-milliarden-potenzial-fuer-biooekonomie. Accessed: 09.09.2019.

PTS (Papiertechnische Stiftung). (n.d.). Papierartige Werkstoffe für Falt- und Honigwaben-Sandwichkerne. https://www.ptspaper.de/?status=details&news_id=1877&id=2809. Accessed: 02.09.2019.

PTS (Papiertechnische Stiftung). (2015). Faser & Papier 2030 Nachwachsende Zukunft gestalten. www.faser-papier-2030.de. Accessed: 26.08.2019.

Radermacher, F. J. (2011). *Welt mit Zukunft. Überleben im 21. Jahrhundert* (2. Aufl.). Murmann.

Sauerwein, P. (2016). Chancen und Hemmnisse für die Holzwerkstoffindustrie. Vortrag auf dem Workshop der acatech und der Sächs. Akademie der Wissenschaften zu Leipzig, 07.12.2016. Nicht veröffentlicht.

Teischinger, A. (2016). Bioökonomie in Österreich. In A. Wagenführ (Hrsg.), *Tagungsband des 17. Holztechnologischen Kolloquiums Dresden*, 28–29 April 2016. Schriftenreihe Holz- und Papiertechnik (S. 11–17). Dresden: Institut für Holz- und Papiertechnik der TU Dresden. ISBN 978-3-86780-476-9.

UNECE (United Nations Economic Commission for Europe). (2018). UNECE Statistical Database. Forestry (FOREST EUROPE/UNECE/FAO). https://w3.unece.org/PXWeb2015/pxweb/en/STAT/STAT__26-TMSTAT1/. Accessed: 01.10.2018.

Wagenführ, A., & Scholz, F. (2018). *Taschenbuch der Holztechnik* (3. Aufl.). Hanser: Murmann.

WCED (World Commission on Environment and Development). (1987). Unsere gemeinsame Zukunft. Der Brundtland-Bericht der Weltkommission für Umwelt und Entwicklung. : .

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Livestock-based Bioeconomy

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Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_5

5.1 Introduction

As the world population continues to grow unabated, the demand for food will continue to rise (FAO, 2018; Searchinger et al., 2018; Smith, 2018). This also involves a massive increase in global demand for food of animal origin, especially meat, which is considered a "traditional symbol of prosperity". On the other hand, there are already more than 800 million people (about 11% of the world's population) suffering from chronic hunger, about 2 billion people have to live with food insecurity (FAO, 2019). According to FAO recommendations (FAO, 2013), adults should consume about 20 g of protein of animal origin per day to have a balanced diet. This amount is reached as a global average (23.9 g/day), but it varies between 1.7 (Burundi) and 69 g (USA; Germany: 52.8 g/day). This comparison reveals the enormous inequality in the supply of the world's population with quality food, which is likely to worsen in the future.

Moreover, livestock feeding takes up a significant proportion of agricultural land. While in 1970, about 0.38 ha were available per inhabitant at a global scale, the value had decreased to 0.24 ha in 2000, and in 2050, it will probably have dropped to only about 0.15 ha. In Germany, currently about 0.22 ha are available per inhabitant. Smith (2018) considers this to be one of the greatest challenges facing humanity. Accordingly, the keeping of livestock for the purpose of producing high-quality food, especially food containing protein, is increasingly being discussed with view to the associated consumption of resources (land, water, energy) and the accompanying emissions, particularly in the current "agrifood system" (Diaz, 2019; Flachowsky et al., 2019, for example). On the other hand, livestock and the food of animal origin produced thereof are also an important economic factor, especially in industrialised countries. Germany, for example, has more livestock than people (12 million cattle, 25 million pigs and almost 180 million poultry alone). They generate about twice as much agricultural production value in the form of raw milk, eggs and live animals for slaughter than crop production (in Germany, 53 vs. 23 billion euros in 2018; Kohlmüller & Koch, 2019).

This chapter examines the agricultural background of current livestock farming. Special attention is paid to the intensive interconnectedness of the mass flows between livestock farming and the agricultural production of plant biomass, including the return of large quantities of by-products from the industrial processing of primary plant products to the agricultural cycle of materials via livestock feeding. This leads to limitations, but also creates new opportunities regarding the ways agricultural animal husbandry could respond to the current and future challenges in Germany in the context of livestock-based bioeconomy.

5.2 System Description

5.2.1 The Role of Livestock in the Agricultural Food Production System

In the system of agricultural food production, livestock play a central role as biomass transformers. While fully maintaining the mass balances, the ingested biomass is transformed, via digestion and metabolism, into excreta (faeces, urine), gases (CO_2, with ruminants also CH_4) as well as into an increase in body substance, milk or eggs – i.e. mainly into the build-up of proteins, fats and carbohydrates.

As is shown in ▪ Fig. 5.1, only a small part (approx. 10–20%) of the agrarian plant biomass reaches human consumption at all. The main reason for this is the fact that most

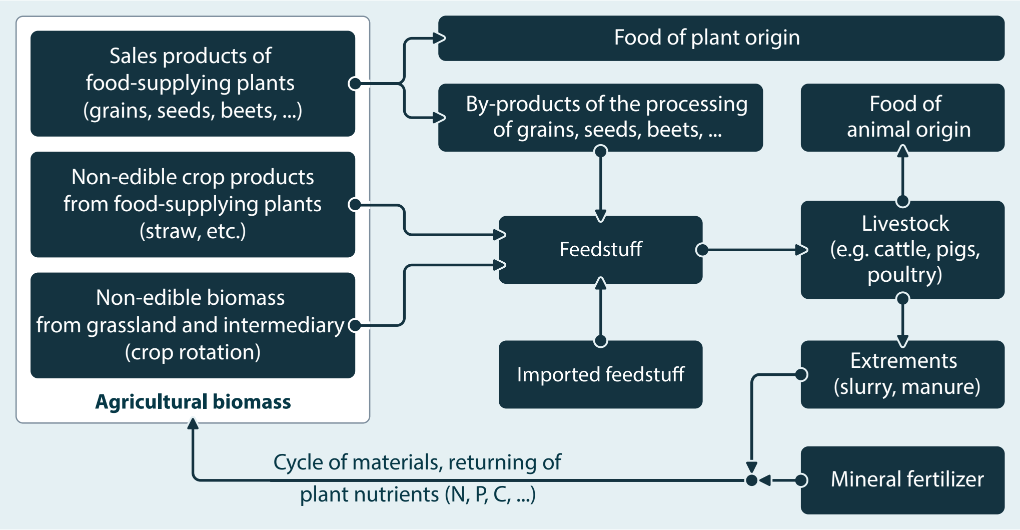


Fig. 5.1 Schematic flow of biomass and the contained plant nutrients between agricultural crop and livestock production. (Source: authors' own illustration)

of the agricultural biomass is, in principle, unfit for human consumption, such as biomass from grassland or from intermediate crops. This type of biomass is an inevitable part of the overall agricultural production of biomass, as the sustainable cultivation of food-supplying crops requires a crop rotation that also includes non-edible intermediate crops. In addition, a significant share of agricultural land can only be used as grass land, for geographical or environmental reasons (topography, remoteness, rainfall, temperature, groundwater, proximity to water sources, etc.). But even with food-supplying plants (e.g. cereals), not even half of the biomass harvested is suitable for further use as food (e.g. grains versus straw). This biomass from grassland, intermediate crops and crop residues accounts for more than half of the total agricultural biomass and serves as the primary feed basis for ruminants in particular. However, plant breeders have made little effort to develop the feed value of this type of biomass. Progress in this area will be of great importance for the livestock-based bioeconomy in the future. Great hopes are placed in modem breeding methods such as genome editing of feed value-determining traits of crops in particular (National Academy of Sciences Leopoldina et al., 2019).

The industrial processing of plant products into foodstuffs such as flour, sugar or cooking oil, or energy sources such as biodiesel and bioethanol, or into other valuable industrial materials, produces even more by-products in considerable quantities. Often, the by-products significantly exceed the quantity of the actual target product: for soy, for example, the ratio is 2:1, for rapeseed 1.5:1. These residues from the industrial processing of plant products usually serve as high-quality feedstuffs that are not, or to a limited extent only, fit for human consumption. They are mainly used for feeding poultry, pigs and high-yielding ruminants and account for almost half of the compound feed traded globally. Thus, the "modern" production of food of animal origin is fundamentally based on the intensive interconnectedness of the biomass processing industry with agriculture.

The feeding of livestock generates excrements which, in the form of manure, return a large proportion of the plant nutrients fixed in the biomass (nitrogen, phosphorus, etc.) to the agricultural land in a highly available form. Through this, livestock are fundamentally involved in maintaining the agricultural nutrient cycle and can replace mineral fertilizers to a considerable extent. Therefore, they need to be included in the bioeconomic assessment of the agricultural production of biomass as a general rule. Conversely, a livestock-based bioeconomy would be incomplete without considering its fundamental effects on the agricultural production of plant biomass.

A prerequisite for the efficient transformation of biomass through livestock is that the feed is of high quality and fully balanced with regard to all essential nutrients. For this purpose, livestock farmers often purchase additional feedstuff, for example protein feeds such as soya and rapeseed meal or mineral feeds containing phosphorus, for example. These feedstuffs, too, are subsequently transformed into manure by the livestock. This indirect import of plant nutrients through purchased feed need not be viewed negatively per se, as it can compensate for the export of plant nutrients through the sale of agricultural products.

Only when import rates are high the nutrient cycle between animal husbandry and primary plant production will become unbalanced. Where this threshold lies depends on the efficiency with which the plant nutrients bound in the feed biomass are transformed into sales products of animal origin. Apart from the quality of the biomass available as feed, this is also a question of the livestock species, the kind of output (meat, milk, eggs), the performance level and, in particular, the conceptual design of the livestock feeding regime which implements the current state of knowledge of animal nutrition.

5.2.2 Assessment of the Transformation of Biomass into Edible Protein

The assessment of the consumption of resources by livestock and their environmental impact is usually made in a generalised manner in relation to a sales product (for example, one kilogram of meat). However, this perspective severely limits the differentiated consideration of the diverse livestock groups (e.g. poultry, fish, pigs, ruminants) and output categories (meat, milk, eggs) as well as the high variability of output levels. For this reason, various authors (for example Flachowsky & Kamphues, 2012; Nijdam et al., 2012) have attempted to compare the wide range of production methods of food of animal origin by means of objective parameters. The amount of edible protein of animal origin that ultimately reaches the consumer is particularly suitable as a common basis. Species, production specialisation, performance level and other factors have a considerable influence on the formulation of the ration and the feed intake of livestock as well as the amount of edible protein produced daily. Among other things, ruminants (e.g. cattle, sheep, goats) are able to use cell wall-rich feedstuffs such as grass or straw for energy production with the aid of the microorganisms living in their forestomach system (▶ Sect. 5.2.1). Therefore, their rations contain far more non-edible biomass than those of non-ruminants such as pigs or poultry (◘ Fig. 5.2). Besides, the microorganisms of the forestomach system use non-protein nitrogen compounds (e.g. urea) to produce large quantities of high-quality protein. This means that ruminants are largely independent of the supply of protein via the feed ration, or even completely independent at low performance

Protein source	Level of performance (per animal per day)	Dry matter intake (kg per animal per day)	Ratio of roughage[1] to concentrates[1] (in % of DM)	Edible protein (per g/animal per day)	Land footprint (m^2/kg edible protein)[4, 5, 6]	Water footprint (m^3/kg edible protein)[6]	Carbon footprint (kg CO^2equ/kg edible protein)[6]
Milk	5 kg	10	95/5	163	33 – 135	16.0	50
	10 kg	12	90/10	323	22 – 88	10.9	30
	20 kg	16	75/25	646	15 – 68	10.5	16
	40 kg	25	50/50	1,292	15 – 70	12.3	12
Beef	500 g LWG[1]	6.5	95/5	48	72 – 295	34.0	110
	1000 g LWG	7.0	85/15	95	41 –180	24.7	55
	1500 g LWG	7.5	70/30	143	35 – 155	24.5	35
Pork	500 g LWG	1.8	20/80	45	36 – 176	35.8	16
	7	2	10/90	63	30 – 148	31.3	12
	10	2.2	0/100	90	24 – 120	26.1	10
Poultry	40 g LWG	0.07	10/90	4.8	14 – 68	14.4	4
	60 g LWG	0.08	0/100	7.2	12 – 60	11.8	3
Eggs	50 % LP[2]	0.10	20/80	3.4	28 – 122	26.5	7
	7	0.11	10/90	4.8	26 – 105	22.5	5
	9	0.12	0/100	6.2	20 – 95	20.8	3

1) Roughage: fresh or preserved biomass from grassland and intermediary crops, rich in fiber, non-edible concentrates: high-quality mixtures of grains and by-products, low in fiber, partially edible
2) Live weight gain per day
3) Laying performance
4) Some authors calculated LFP without permanent grassland in non-ruminant feeding
5) High fluctuations due to different yield levels (Flachowsky et al. 2017) and different shares of by-products in the rations
6) Values can be massively influenced by reproductive performance, diseases, animal losses and other factors (Özkan et al. 2016)

Fig. 5.2 Feed intake, edible protein yield and *footprints* (FP) per kilogram of edible protein of animal origin for different animal species/categories and different performance levels (data on feed in dry matter (DM)). (Source: Own representation based on Flachowsky et al., 2017)

levels, and are therefore on principle no food competitors of humans. Increased methane formation with a relatively high greenhouse gas factor (GHG; about 23 × CO2; IPCC, 2006) is one of the negative effects of this microbial colonisation of the forestomachs.

High-yielding dairy cows produce the largest quantities of edible protein (approx. 1 kg/day). However, in terms of live weight (LW), laying and growing poultry are clearly superior to dairy cows. The lowest protein yield per kg LW is produced by growing ruminants, followed by fattening pigs (Fig. 5.2). For each kilogram of edible protein, the land, water and carbon footprints (FP) become smaller at higher outputs (see also Niemann et al., 2011; Windisch et al., 2013), while the amount of concentrates required increases (Fig. 5.2). The high ranges of variation in the land FP result from different influencing factors in the corresponding calculations (see footnotes).

With regard to water FP (WFP), there is currently a controversial debate. For the calculations in ◘ Fig. 5.2 only “blue” water was considered, i.e. water from reservoirs, lakes or rivers. It is the only water supplied to plants by human activity, and the consumption is measurable (Tom et al., 2016). According to the data shown in ◘ Fig. 5.2, beef production is particularly costly in terms of land and water FP. It also has by far the highest carbon FP per amount of protein produced. On the other hand, this is also the branch of production that can use the largest quantities of high-fibre, non-edible biomass.

Another topic to be critically discussed in connection with the production of food of animal origin is the competition for food between humans and animals. According to FAO statistics, about 85% of the world’s soya harvest and about one third of the world’s cereal harvest is used for animal feed. However, a high proportion of this biomass could also be consumed directly by humans. In view of the increasing limitation of arable land on which this biomass is produced and the rising world population, the competition for use between feed and food will increase sharply in the future. Particularly affected are those livestock that consume a lot of “concentrated feed” – for example, non-ruminants such as pigs, fattening poultry and laying hens (◘ Fig. 5.2), i.e. precisely those production sectors that are characterised by a high transformation efficiency in the production of edible protein and comparatively low footprints. This reveals a fundamental dilemma of livestock feeding: high efficiencies and low environmental impacts require predominantly high-quality feed, which in turn increases the food competition with humans. While non-edible biomass generates more emissions, limits the performance level of the animals due to the lower feed quality and is therefore less efficient overall, it can be transformed into edible protein without any food competition. Against this background, the often criticised production of beef and milk is certainly sustainable, especially since the footprints of milk production hardly differ from those of monogastric livestock.

In the future, increasing food competition will promote livestock systems with a high potential for utilising non-edible biomass. This includes ruminants, which can digest non-edible biomass by means of their forestomachs, but also monogastric livestock (pigs, poultry; see also Hendriks et al., 2019), provided they are fed, for example, lower-quality by-products of the industrial processing of primary plant products (e.g. from the processing of cereals or rapeseed).

◘ Figure 5.3 shows the proportion in various feedstuffs that is edible for humans (human edible fraction, hef). The respective hef data are to be interpreted as ranges of values, since no clear boundary can be drawn between edible and non-edible biomass. Many primary plant products such as cereals, maize, soya etc., which are often generally referred to as “foodstuffs”, contain considerable amounts of components worth feeding.

Such data help to make the discussion about food competition between humans and animals more objective. Van Zantem et al. (2016) propose to specify the production of edible animal protein per hectare of agricultural land, taking into account the use of by-products. Along similar lines, Nie et al. (2018) have developed a so-called food energy water-nexus for various feed or animal husbandry systems. Overall, the data show the great potential of by-products from the industrial processing of plant raw materials and their growing importance in the production of food of animal origin.

Feedstuff	hef (%DM)		
	Low	Medium	High
Barley	40	65	80
Maize	70	80	90
Wheat	60	80	100
Soya beans	50	92	93
Rapeseed	30	59	87
Wheat bran	0	10	20
Maize silage	19	29	45
Other[1)]	0	0	0

[1)] Other by-products (e.g. dried pulp, brewer's grains, distillers wash) and roughage (e.g. grass, silage from grass and legumes, hay, straw)

◘ **Fig. 5.3** Fraction edible by humans in different feeds (hef, in % of DM). (Source: Own representation based on Ertl et al., 2015)

5.3 Prospects for a More Efficient and Sustainable Production of Food of Animal Origin

Improving the transformation efficiency of biomass in the system of modern agricultural livestock production has two main objectives:

(a) Minimize the consumption of biomass for non-productive life processes in relation to total consumption (see also Niemann et al., 2011) and
(b) optimize the efficiency of the transformation within the productive processes.

Even non-productive life processes, such as maintenance metabolism, consume energy and nutrients and cause emissions. Breeding animals for higher performance has consistently reduced the share of maintenance requirements in total nutrient requirements. However, the gain in efficiency follows a dilution function and is therefore degressive. In modern high-performance breeds, the increases in transformation efficiency to be expected from simply breeding for even higher performance are relatively small. The situation is different when it comes to feed costs and the environmental impact of maintaining the livestock systems. For example, a female bovine must be raised for 24–30 months before it can begin to produce milk. Given that the average number of productive years of dairy cows in Germany is less than four, optimising the rearing period and increasing the lifetime yield, for example by increasing longevity, has a significant impact on the transformation efficiency and environmental impact of the entire production system. This principle applies to all types of livestock husbandry.

Approaches to improve the utilisation of biomass for productive life processes (growth, production of eggs and milk) basically cover two areas,

(a) the digestive tract and
(b) the metabolism beyond the intestinal barrier.

As is shown in ◘ Fig. 5.4, the ingested biomass is broken down by the body's own digestive enzymes and microorganisms into

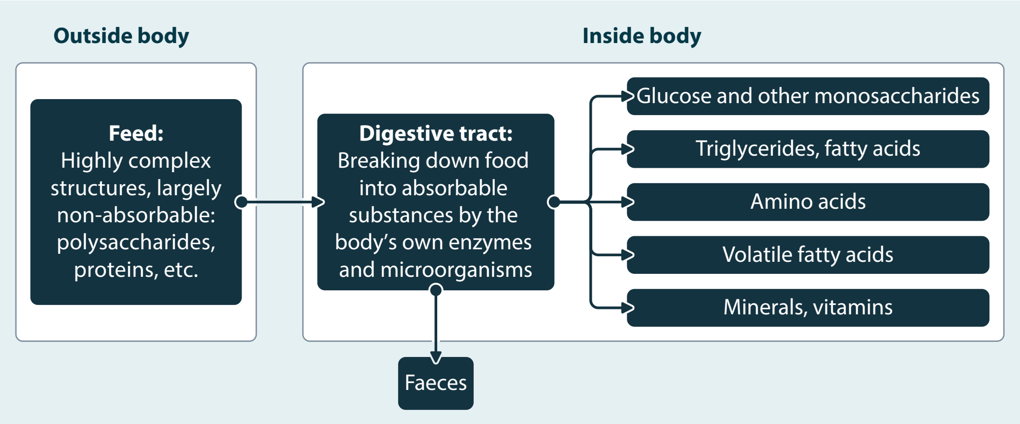


Fig. 5.4 Schematic of the flow of biomass from feed via the digestive tract into the metabolism. (Source: author's own illustration)

low-molecular nutrients, which are supplied to the metabolism beyond the intestinal barrier through absorption. The extent to which this is achieved depends on how well the composition of the feed biomass matches the digestive capacity of the livestock species concerned. For example, ruminants can digest high-fibre, non-edible biomass well, whereas monogastrics can only do so to a limited extent (▶ Sect. 5.2).

Beyond the intestinal barrier, the composition of the absorbed nutrients differs only marginally between the various livestock species and also humans. The subsequent metabolic processes are also very much evolutionary conserved in their biochemical nature. It is certainly possible to shift the regulation of metabolism through breeding or pharmacological interventions – such as the application of growth hormone – and to steer the flow of absorbed nutrients in a certain performance direction. However, the efficiency of the processes involved is largely determined and will be achieved when all essential nutrients (limiting amino acids, for example) are available in the metabolism in an optimal ratio.

The actual efficiency of nutrient transformation in the metabolism therefore depends primarily on the extent to which the optimal supply of the metabolism with the various nutrients is achieved by appropriate feeding. These interactions between the digestive tract and metabolism provide several starting points for increasing the efficiency and sustainability of the production of food of animal origin.

5.3.1 Increasing the Quantity and Quality of Forageable Biomass

A conservative approach to increasing the quantity of biomass aims to minimise losses along the route from the field through harvesting and preservation (drying, ensiling) to feeding. With regard to the quality of the biomass in terms of its suitability as animal feed, there are essentially three limiting aspects;

(a) the presence of antinutritive or toxic ingredients,
(b) high proportions of components with low digestibility and
(c) the coupling of high and low feed value sub-fractions in the same feedstock.

Antinutritive or toxic ingredients in otherwise high-quality biomass are very significant bottlenecks regarding its use as potential feed. For example, former rapeseed varieties naturally contained such high levels of toxic or highly antinutritive substances (erucic acid in the oil, glucosinolates in the water-soluble components of the dry matter) that it could not be used at all, or to a very limited extent only, both as food (edible oil) and as animal feed (e.g. by-products of the extraction of rapeseed oil). However, the massive reduction of these critical ingredients through plant breeding about two decades ago led to a triumphant success of the protein-rich by-products of oil extraction from rapeseed in livestock feeding and fundamentally changed the profile of circular economy of rapeseed. Cotton seed is another very interesting candidate in terms of quantity as regards the diminution of strongly antinutritive ingredients, especially the so-called gossypol. Significant breeding and genetic engineering successes have already been achieved in reducing the gossypol content, which have considerably expanded the possible uses of cotton seed as a high-protein feedstuff in livestock feeding (for example Sunikumar et al., 2006). These examples show the great potential of plant breeding and genetic engineering to improve feed quality and thus to specifically influence the bioeconomy of the connection between agricultural crop and livestock production, including the by-products of the industrial processing of agricultural biomass (see also Flachowsky, 2013; Flachowsky & Meyer, 2015; NASEM, 2016; ► Chap. 3).

Biomasses with very high contents of lignocellulose such as straw are only suitable as animal feed, if at all, for ruminants, because lignin can hardly be degraded in the forestomachs and also strongly impedes the microbial digestion of the associated cellulose structures. This caging effect of lignin is the reason why wood itself is not suitable as feed for ruminants, even though the cellulose per se would have a considerable nutritional value. The degradation of lignin structures in biomass would thus massively expand the portfolio of potential feeds, both quantitatively and qualitatively (Blümmel et al., 2018). The feasibility of such approaches was demonstrated decades ago (for example, Kerley et al., 1985) and also temporarily implemented in practice with cereal straw, for example (Sundstol & Owen, 1984; Flachowsky, 1987), although technical and economic difficulties at the time prevented widespread use. However, with new developments in the circular economy of lignocellulosic biomass such as wood, these largely forgotten approaches could become interesting again. Another approach would be to separate the valuable from the value-reducing sub-fractions of the biomass. Options range from the mechanical coarse separation of plant material (for example leaves versus stems) to the extraction of high-quality protein from press juices of green biomass or from residues of (bio-)technological processes (for example from distillers grain solubles of bioethanol production). In principle, this is nothing but the consistent extension of food and feed technology processes to non-edible biomass or by-products.

5.3.2 Expanding the Digestive Capacity of Livestock

Apart from the volume of the digestive tract, the limitation of the digestive capacity of humans and animals is based mainly on a limited endowment with endogenous digestive enzymes. The supply of exogenous enzymes is an established method to widen this bottleneck. It can be used to strengthen existing capacities, with proteases supporting protein digestion, for example, or to introduce fundamentally new biological degradation capacities into the digestive tract (► Chap. 6). A prominent example are phytases from biotechnological production (usually based on genetically modified microorganisms). They compensate the inability of animals and humans to endow their body with digestive enzymes to release phosphorus from the phytic acid found in grains and seeds. However, the list of enzymes available so far is still very limited. This area holds an enormous potential for innovation, as it would be possible to adapt the digestive capacity of livestock to a variable composition of biomass through the targeted supplementation of enzymes. Of particular interest would be additives that enable monogastric livestock to digest non-starch polysaccharides enzymatically. Overall, the development and large-scale production of enzymes as feed additives for livestock nutrition holds an enormous potential of expansion for the bioeconomy of microorganisms (► Chap. 6).

An indirect improvement of the digestive capacity is achieved by all measures that improve gut health (application of organic acids, probiotics, phytogenic additives, exogenous enzymes to break down non-starch polysaccharides) (Gonzalez-Ortiz et al., 2019).

One of the visions for future ruminant husbandry is shifting the microbial degradation of cellulosic dietary fibre from acetic acid fermentation towards propionic acid. In addition to reducing the emission of climate-damaging methane, this would result in a massive increase in the yield of nutritional energy from a non-edible feed substrate, as the calorific value of methane remains chemically bound in the propionic acid and is available to the animal's metabolism as absorbable nutritional energy. However, microbial digestion of dietary fibre is closely linked to the formation of methane. Measures to reduce the formation of methane – for example, by means of broadly acting feed additives (herbal extracts, antimicrobial substances, etc.) – therefore often also inhibit fibre digestion and thus reduce the feed intake of the animals. Recently, however, additives have been developed that highly specifically block only the last enzymatic step of methane formation and therefore cause less collateral damage to the fermentation ability of the forestomachs (Duin et al., 2016).

5.3.3 Optimising of the Metabolism

As has been described earlier, this aspect is not about increasing the efficiency of individual metabolic processes, but about avoiding an inadequate supply of nutrients, including both deficiencies and surpluses. This requires very precise concepts for determining the metabolic demand for nutritional energy and nutrients as well as the delivery capacity of biomass for the respective livestock species and categories. With regard to meeting the demand for essential ingredients, plant breeding can certainly make a contribution, for example by increasing the shares of limiting essential amino acids in plant protein (see also Flachowsky & Meyer, 2015; NASEM, 2016). The targets for plant breeding can only be formulated relatively roughly, though, as the specific demand patterns vary according to animal species, kind of output and performance level. Fine-tuning of the supply of limiting nutrients, on the other hand, is achieved by supplementing the feed with pure, synthetically or biotechnologically produced substances (e.g. crystalline amino acids, vitamins). They play a fundamental role in modern diet formulation and are indispensable instruments for minimising environmentally relevant emissions from livestock farming. The consistent supplementation of the feed of pigs and poultry with limiting amino acids, for example, allows for a reduction of the crude protein content of the feed by several percentage points and, as a consequence, lowers nitrogen emissions by approximately one third compared to rations without amino acid supplementation (Flessa et al., 2012; Sajeev et al., 2018).

5.3.4 Novel Biomasses and Livestock

New (bio-)technological processes will generate new types of residues, which may well be suitable as feed for livestock. With view to a cascading use, the nutritional potential of these by-products must always be taken into account and, if necessary, already considered in the primary production process. In the future, more and more plants will be cultivated which have so far been hardly or not at all considered for livestock nutrition. Many plants from tropical and subtropical regions, for example opuntia, have high potentials for animal nutrition. In this context, plant biomass of aquatic origin appears to be particularly interesting, as it does not compete with other terrestrial biomasses for limited agricultural land. Examples of such aquatic biomasses are macroalgae and microalgae. The latter are mainly discussed for the extraction of protein (partly also fat) and will be examined in detail in ▶ Chap. 7. Macroalgae, on the other hand, provide carbohydrates, above all, and in a form that is largely enzymatically indigestible for terrestrial livestock (Brugger et al., 2019). Not even fish (for example in aquaculture) possess suitable endogenous digestive enzymes. In contrast, aquatic molluscs do possess digestive enzymes adapted to the specific carbohydrates from macroalgae (Michl et al., 2014). This example shows that the use of novel types of biomass is often accompanied by the search for novel animals capable of digesting this biomass – such as molluscs as potential transformers of macroalgae.

This basic principle of matching as closely as possible the characteristics of the biomass and the digestive capacity of the transformers in question also applies to the discussion of insects as a potential novel type of livestock. Many of the insects currently being considered for use are food competitors of both humans and conventional livestock (EFSA, 2015). They generally require highly digestible biomass for efficient transformation, indicating a limited digestive capacity analogous to monogastric livestock. In fact, the digestive capacity of individual insect species remains largely unexplored, although this knowledge is essential for the sustainable use of insects as novel transformers of biomass.

In principle, even excrements can be considered potentially usable biomasses. The feeding of nitrogen-rich excrements, for example sterilised poultry manure, has a certain tradition as a source of crude protein for the microorganisms in the forestomachs of ruminants. Especially in regions with roughage low in crude protein (e.g. grass land in the tropics), these microorganisms benefit from the additional supply of nitrogen, which they can use to build up microbial protein, which in turn serves the ruminant as an important source of protein. Another example is the use of manure to breed black soldier flies, which can then be used as protein feed for livestock. However, the use of excrements in animal feed is prohibited in many regions for reasons of hygiene and food safety. In the European Union, for example, excrements in livestock feed are among the list of prohibited substances.

5.4 Conflicting Objectives

As outlined above, the global demand for food of animal origin is expected to increase massively. This will create an enormous future market for animal production – especially for production methods with a high transformation efficiency (for example poultry meat). Associated relative advantages regarding the environmental impact (◘ Fig. 5.2) will accelerate this trend. Thus, it is not surprising that the consumption of poultry meat has increased massively in recent decades and has almost overtaken pork as the global leader in meat consumption (OECD/FAO, 2018). However, these highly efficient production methods are the ones causing the highest food competition. The core of the conflict of objectives between production efficiency, environmental impact and food competition lies primarily in the shrinking availability of agricultural land (▶ Sect. 5.1), which is used for the production of food, feed, energy sources and other industrial valuable substances of plant origin. The circular economy of agricultural plant and animal production and the downstream industrial processing of the respective products are inextricably linked via the factor of agricultural land and thus enter into direct competition with each other. The production of animal feed is not fundamentally at stake, though. In the future, considerable amounts of non-edible biomass will continue to accrue from grass land and from co-products from cultivated plants, intermediary crops and as by-products of the industrial processing of plant products, which can be transformed into high-quality foodstuffs by means of appropriate production systems (above all ruminants). The resulting manure supports the agricultural cycle of plant nutrients and thus indirectly promotes the production of food of plant origin. Alternatively, the non-edible biomass could also be utilised energetically in biogas plants and the residues returned to the cycle of plant nutrients in the same way as the excrements of livestock. But apart from losing high-quality food, biogas plants work much more slowly than the forestomachs of ruminants. The half-life of microbial degradation of organic matter in the forestomachs of ruminants is less than 1 day, but in biogas plants it takes about 5 days (ranging between 3 days and 2 weeks, depending on the quality of the fermentation substrates (Dandikas et al., 2018)). The disadvantages of the targeted use of non-edible biomass lie in the lower transformation efficiency and the associated higher emissions (e.g. methane). Other negative effects that are often mentioned, such as the consumption of land and water, do not have an impact here, as long as only the use of non-edible biomass accruing anyway is concerned and no additional agricultural land (especially arable land) is used for the cultivation of animal feed. However, the quantities of food of animal origin that can be produced in this way lie significantly below the current and particularly the future demand and would require a massive change in dietary habits (for example, Schader et al., 2015).

Apart from the limited availability of non-edible biomass, another factor limiting its transformation into food of animal origin are food safety aspects. In principle, this applies to waste of any kind. In contrast to by-products from the industrial processing of agricultural raw materials, waste materials are indeterminate and uncontrolled in their origin. Accordingly, they hold the risk of entering undesirable substances into and threaten the hygienic standard of the food chain. A similar assessment can be made for excrements such as those considered for producing insects (for example, black soldier fly on manure) (see also EFSA, 2015). As a matter of principle, non-edible biomass, too, should come exclusively from regular agricultural land or the controlled processing of its products. This is the only way to guarantee a high level of food safety.

Another conflict of objectives touches on the ethical aspects of livestock production. Livestock are increasingly perceived as fellow creatures, with people questioning the animals' "exploitation" for their own nutrition purposes. Accordingly, the discussion about artificial meat, among other things, has gained considerable momentum. No livestock need to be killed for it, the cell cultures grow very efficiently, there is no slaughter waste, and a very high level of hygiene can be obtained. However, the latter requires antibiotics, which again pose a risk to food safety. The real bottleneck in this production of valuable food lies in the need for the highest quality nutrients to "feed" the cell cultures, though. These nutrients have to be generated through primary agricultural production and/or costly industrial processing. This means that such production methods inevitably come into conflict with the objectives of environmentally relevant emissions, consumption of agricultural land and competition for food. The extent to which they actually promote circular economy in comparison to conventional livestock farming can only be determined by means of comprehensive *live cycle assessments*.

5.5 Images of the Future

Apart from a growing population and rising temperatures (IPCC, 2019), increasing urbanisation and growing global affluence are considered to be major changes that will strongly influence and, in part, challenge the current role of livestock in providing food to humans in the future (Mottet et al., 2017). The result is a call for more livestock products and an expansion of agricultural land, partly through irrigation using non-renewable water supplies and through deforestation. Further, the food competition between humans and livestock – especially non-ruminants – will continue to intensify (Bryan et al., 2015) and climate-relevant greenhouse gases caused by livestock production will continue to increase (Lesschen et al., 2011). All these developments are heading in an unsustainable direction and require countermeasures. In essence, the aim is to produce the unavoidable additional demand for food associated with the growing number of people with fewer resources and emissions overall ("sustainable intensification") and, in addition, to search for alternatives to conventional food production. Plant breeding – in particular on the basis of genome editing – is of primary importance here (e.g. adaptation to higher temperatures, drought, higher atmospheric CO_2-concentrations, salt water, etc.) (Weigel & Manderscheid, 2012; NASEM, 2016; Bailey-Serres et al., 2019; National Academy of Sciences Leopoldina et al., 2019), followed by innovative cultivation techniques, plant protection measures, as well as harvesting and preservation methods (HLPE, 2019).

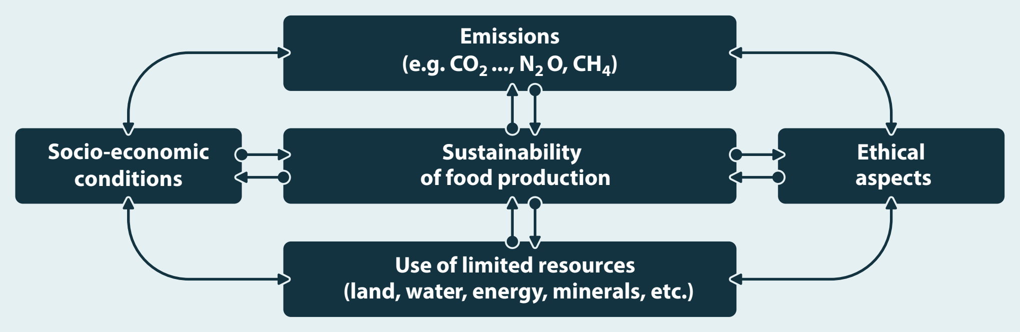
But the need for sustainable intensification will also require considerable changes in the way livestock are kept. First and foremost is the avoidance of food competition between humans and livestock, and in two directions:

- it is necessary to map out the perspectives and potentials of ruminants using grass land, co-products from cultivated plants and intermediary crops in the course of crop rotation as well as by-products. But monogastric livestock have considerable potential in the utilisation of non-edible biomass, too. Pigs, in partiular, have been fed almost exclusively on non-edible biomass since their domestication and have only recently become a food competitor to humans as a result of breeding for high performance. These "archaic" abilities of monogastric livestock need to be reactivated.
- Non-edible biomass from crop production must be regarded as a valuable raw material to an even greater extent than in the past. As it will be the basis for the production of food of animal origin in the future, it must also be intensified in a sustainable manner as regards quantity and quality. Here, too, plant breeding and genetic engineering (e.g. with regard to antinutritive or toxic ingredients), cultivation techniques and, in particular,

innovative harvesting and preservation methods are required to maintain the feed value of the usually perishable biomass. In addition, the by-products of the processing of plant products must be consistently returned to the feeding cycle.

However, the demand for a strict avoidance of food competition between humans and livestock will only be implemented to a limited extent in the foreseeable future. This is due to the fact that the expected demand for food of animal origin can hardly be met on the basis of non-edible biomass alone. The price for this food would be very high and the supply of food to people would follow the global wealth gap even more than before. As is shown in ■ Fig. 5.5, these socio-economic conditions are just as important for the kind and scope of future animal production as are resource consumption, environmentally relevant emissions and, increasingly, ethical aspects. It is therefore to be hoped that people's nutritional habits will change in the future and that a limited intake of food of animal origin will become generally accepted. In order to support this development, a consistent further development of life cycle assessments, which allow for objective comparisons of the overall effects of measures and alternative proposals for the production of food, is required.

Finally, the question arises whether the future will bring a form of agriculture without livestock. After all, farm animals are no longer needed in large numbers as working animals. Moreover, the complete renunciation of food of animal origin would eliminate all ethically motivated reservations concerning livestock. For humans, this would not be a fundamental nutritional problem either, as long as other high-quality foods and, if necessary, supplements such as amino acids or vitamins are always sufficiently available. With view to the enjoyment value, plant-based imitations already exist or have long had a firmly anchored cultural identity (for example, tofu versus cheese). They are complemented by products from new technological approaches, which are referred to collectively as cellular agriculture or meat alternatives and are already being discussed at scientific level (for example, Grieve et al., 2019). However, such products tend to be relevant for industrialised countries only, while the nutrition of underdeveloped regions will continue to depend largely on livestock. Herds of cattle and flocks of sheep, for example, basically do not require any technical infrastructure such as roads, electricity, and so on. The question of the dispensability of livestock rather touches on the basic principle of primary agricultural production based on crops. In addition to the actual "food"



■ **Fig. 5.5** Sustainability in the production of edible protein of animal origin as a balance between limited available natural resources, emissions, socio-economic conditions and ethical aspects. (Source: authors' own illustration) components, these always contain considerable amounts of non-edible biomass as well, which must be degraded to plant nutrients and returned to the agricultural land (▣ Fig. 5.1). Livestock perform this function in a way that has been established for thousands of years, generating highest-quality food for humans (and they also used to serve as working animals). The abandonment of livestock without alternative would therefore not only result in an absolute loss of food but would also reduce the productivity of crop cultivation or require an increased use of mineral fertilizers.

References

Bailey-Serres, J., Parker, J. E., Ainsworth, E. A., Oldroyd, G. E. D., & Schroeder, J. I. (2019). Genetic strategies for improving crop yields. *Nature, 575*, 109–118. https://doi.org/10.1038/s41586-019-1679-0

Blümmel, M., Teymouri, F., Moore, J., Nielson, C., Videto, J., Kodukula, P., Pothu, S., Devulapalli, R., & Varijakshapnicker, P. (2018). Ammonia fiber expansion (AFEX) as spin of technology from 2nd generation biofuel for upgrading cereal straws and stovers for livestock feed. *Animal Feed Science and Technology, 236*, 178–186. https://doi.org/10.1016/j.anifeedsci.2017.12.016

Brugger, D., Buffler, M., Bolduan, C., Becker, C., Zhao, J., & Windisch, W. (2019). Effects of whole plant brown algae (Laminaria japonica) on zootechnical performance, apparent total tract digestibility, fecal characteristics and blood plasma urea in weaned piglets. *Archives of Animal Nutrition*. https://doi.org/10.1080/1745039X.2019.1672479

Bryan, B. A., Crossmann, N. D., Nolan, M., Li, J., Navarro, J., & Connor, J. D. (2015). Land use efficiency: Anticipating future demand for land-sector greenhouse gas emissions abatement and managing trade-offs with agriculture, water, and biodiversity. *Global Change Biology, 21*(11), 4098–4114. https://doi.org/10.1111/gcb.13020

Dandikas, V., Heuwinkel, H., Lichti, F., Eckl, T., & Drewes, J. E. (2018). Correlation between hydrolysis rate constant and chemical composition of energy crops. *Renewable Energy, 118*, 34–42. https://doi.org/10.1016/j.renene.2017.10.100

Diaz, O. (2019). Is it the agri-food-system adequated to our present needs? *EC Nutrition, 14*(1), 31–33.

Duin, E. C., Wagner, T., Shima, S., Prakash, D., Cronin, B., Yáñez-Ruiz, D. R., Duval, S., Rümbeli, R., Stemmler, R. T., Thauer, R. K., & Kindermann, M. (2016). Mode of action uncovered for the specific reduction of methane emissions from ruminants by the small molecule 3-nitrooxypropanol. *PNAS, 113*(22), 6172–6177. https://doi.org/10.1073/pnas.1600298113

EFSA (European Food Safety Authority). (2015). Risk profile related to production and consumption of insects as food and feed. *EFSA Journal*. https://doi.org/10.2903/j.efsa.2015.4257

Ertl, P., Zebeli, Q., Zollitsch, W., & Knaus, W. (2015). Feeding of by-products completely replaced cereals and pulses in dairy cow and enhanced edible feed conversion ratio. *Journal of Dairy Science, 98*, 1225–1233. https://doi.org/10.3168/jds.2014-8810

FAO (Food and Agriculte Organization of the United Nations). (2013). Dietary Protein Quality Evaluation in Human Nutrition. FAO food and nutrition paper, 92. http://www.fao.org/ag/humannutrition/35978-02317b979a686a57aa4593304ffc17f06.pdf. Accessed: 02.09.2019.

FAO (Food and Agriculte Organization of the United Nations). (2018). The state of the world. 2018: The state of food security and nutrition in the world – Building climate resilience for food security and nutrition. http://www.fao.org/3/i9553en/i9553en.pdf. Accessed: 02.09.2019.

FAO (Food and Agriculte Organization of the United Nations). (2019). The state of food security and nutrition in the world – Safeguarding against economic slowdowns and downturns. https://reliefweb.int/sites/reliefweb.int/files/resources/ca5162en.pdf. Accessed: 02.09.2019.

Flachowsky, G. (1987). *Stroh als Futtermittel (S. 255)*. Landwirtschaftsverlag.

Flachowsky, G. (2013). *Animal nutrition with transgenic plants (S. 234)*. CAB International.

Flachowsky, G., & Kamphues, J. (2012). Carbon footprints for food of animal origin: What are the most preferable criteria to measure animal yields? *Animals, 2*(2), 108–126. https://doi.org/10.3390/ani2020108

Flachowsky, G., & Meyer, U. (2015). Challenges for plant breeders from the view of animal nutrition. *Agriculture, 5*(4), 1252–1276. https://doi.org/10.3390/agriculture5041252

Flachowsky, G., Meyer, U., & Südekum, K.-H. (2017). Land use for edible protein of animal origin – A review. *Animals, 7*(3), 1–19. https://doi.org/10.3390/ani7030025

Flachowsky, G., Südekum, K. H., & Meyer, U. (2019). Protein tierischer Herkunft: Gibt es Alternativen? *Züchtungskunde, 91*(3), 178–213.

Flessa, H., Müller, D., Plassmann, K., Osterburg, B., Techen, A. K., Nitsch, H., Nieberg, H., Sanders, J., Olaf Meyer zu Hartlage, O., Beckmann, E., & Anspach, V. (2012). Studie zur Vorbereitung einer effizienten und gut abgestimmten Klimaschutzpolitik für den Agrarsektor. Landbauforschung vTI Agriculture and Forestry Research. ISBN 978-3-86576-087-6.

Gonzalez-Ortiz, G., Bedford, M. R., Bach Knudsen, K. E., Courtin, C. M., & Classen, H. L. (2019). *The value of fibre – Engaging the second brain for animal nutrition (S. 383)*. Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-893-3

Grieve, B. D., Duckett, T., Collinson, M., Boyd, L., West, J., Yin, H., Arvin, F., & Pearson, S. (2019). The challenges posed by global broadacre crops in delivering smart agri-robotic solutions: A fundamental rethink is required. *Global Food Security, 23*, 116–124. https://doi.org/10.1016/j.gfs.2019.04.011

Hendriks, W. H., Verstegen, M. W. A., & Babinsky, L. (2019). *Poultry and pig nutrition – Challenges of the 21th century (S. 424)*. Wageningen Academic Publishers.

HLPE (High Level Panel of Experts of the FAO). (2019). Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the HLPE of the FAO, July 2019. http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Reports/HLPE-Report-14_EN.pdf. Accessed: 02.09.2019.

IPCC (International Panel of Climate Change). (2006). IPCC guidelines for national greenhouse gas inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/. Accessed: 02.09.2019.

IPCC (International Panel of Climate Change). (2019). Climate change and land. Approval plenary; 02.–06. August 2019. https://www.ipcc.ch/site/assets/uploads/2019/08/Fullreport-1.pdf. Accessed: 09.09.2019.

Kerley, M. S., Fahey, G. C., Jr., Berger, L. L., Gould, J. M., & Baker, F. L. (1985). Alkaline hydrogen peroxide treatment unlocks energy in agricultural by-products. *Science, 15*, 820–822. https://doi.org/10.1126/science.230.4727.820

Kohlmüller, M., & Koch, T. (2019). *Markt Bilanz – Vieh und Fleisch*. In *AMI (Agrarmarkt Informationsgesellschaft)*. Medienhaus Plump GmbH & Agrarmarkt Informations-Gesellschaft mbH.

Lesschen, J. P., van den Berg, M., Westhock, H. J., Witzke, H. P., & Oenema, O. (2011). Greenhouse gas emission profiles of European livestock sectors. *Animal Feed Science and Technology, 166–167*, 16–28. https://doi.org/10.1016/j.anifeedsci.2011.04.058

Michl, S. C., Windisch, W., & Geist, J. (2014). Function of the crystalline style and first detection of laminarinase activity in freshwater mussels of genus Andota. *Journal of Molluscan Studies, 80*(2), 198–200. https://doi.org/10.1093/mollus/eyt053

Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., & Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food dabate. *Global Food Security, 14*, 1–8. https://doi.org/10.1016/j.gfs.2017.01.001

NASEM (National Academies of Sciences, Engineering and Medicine). (2016). *Genetically engineered crops: experiences and prospects; Committee on Genetically Engineered Crops: Past Experience and Future Prospects, Board on Agriculture and Natural Resources; Division on Earth and Life Studies; National Academies of Sciences, Engineering, and Medicine*. The National Academies Press.

Nationale Akademie der Wissenschaften Leopoldina, Deutsche Forschungsgemeinschaft & Union der deutschen Akademien der Wissenschaften. (2019). Wege zu einer wissenschaftlich begründeten, differenzierten Regulierung genomeditierter Pflanzen in der EU/Towards a scientifically justified, differentiated regulation of genome edited plants in the EU. Halle (Saale). https://www.leopoldina.org/uploads/tx_leopublication/2019_Stellungnahme_Genomeditierte_Pflanzen_web.pdf/. Accessed: 06.12.2019.

Nie, Y., Avraamidon, S., Lie, J., Xiao, X., & Pistikopoulos, N. (2018). Land use modeling based on food – energy- water nexus: A case study on crop-livestock systems. *Computer Aided Chemical Engineering, 44*, 1939–1944. https://doi.org/10.1016/B978-0-444-64241-7.50318-9

Niemann, H., Kuhla, B., & Flachowsky, G. (2011). Perspectives for feed-efficient animal production. *Journal of Animal Science, 89*(12), 4344–4363. https://doi.org/10.2527/jas.2011-4235

Nijdam, D., Rood, T., & Westhoek, H. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy, 37*(6), 760–770.

OECD/FAO. (2018). OECD-FAO agricultural outlook. OECD agriculture statistics (database). https://doi.org/10.1787/agr-outl-data-en/. Accessed: 06.12.2019.

Sajeev, E. P. M., Amon, B., Ammon, C., Zollitsch, W., & Winiwarter, W. (2018). Evaluating the potential of dietary crude protein manipulation in reducing ammonia emissions from cattle and pig manure:

A meta-analysis. *Nutrient Cycling in Agroecosystems, 110*, 161–175. https://doi.org/10.1007/s10705-017-9893-3

Schader, C., Muller, A., Scialabba, N. E., Hecht, J., Isensee, A., Erb, K. H., Smith, P., Makkar, H. P. S., Klocke, P., Leiber, F., Schwegler, P., Stolze, M., & Niggli, U. (2015). Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. *Journal of the Royal Society, Interface, 12*(113), 1–12. https://doi.org/10.1098/rsif.2015.0891

Searchinger, T., Waite, R., Hanson, C., Ranganathan, J., Dumas, P., Matthews, E. (2018). Creating a sustainable food future: A Menu of solutions to feed nearly 10 billion people by 2050. WRR (World Resources Report) Synthesis Report by the World Bank and the UN. https://wrr-food.wri.org/sites/default/files/2019-07/WRR_Food_Full_Report_0.pdf. Accessed: 03.06.2019.

Smith, P. (2018). Managing the global land resource. *Proceedings of the Royal Society B, 285*(1874), 1–9. https://doi.org/10.1098/rspb.2017.2798

Sundstol, F., & Owen, E. (1984). *Straw and other fibrous by-products as feed. Developments in animal and veterinary sciences 14 (S. 604)*. Elsevier Amsterdam.

Sunikumar, G., Campbell, L. M., Puckhaber, L., Stipanovic, R. D., & Rathore, K. S. (2006). Engineering cottonseed for use in human nutrition by tissue-specific reduction of toxic gossypol. *PNAS, 103*(48), 18054–18059. https://doi.org/10.1073/pnas.0605389103

Tom, M. S., Fischbeck, P. S., & Hendrickson, C. T. (2016). Energy used, blue water footprint and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. *Environmental System Decisions, 36*(1), 92–103. https://doi.org/10.1007/s10669-015-9577-y

Van Zantem, H. H. E., Mollenhorst, H., Klootwijk, C. W., van Middelaar, C. E., & de Boer, I. J. M. (2016). Global food supply: Land use efficiency of livestock systems. *International Journal of Life Cycle Assessment, 21*(5), 747–758. https://doi.org/10.1007/s11367-015-0944-1

Weigel, H.-J., & Manderscheid, R. (2012). Crop growth responses to free air CO_2 enrichment and nitrogen fertilization: Rotating barley, ryegrass, sugar beet and wheat. *European Journal of Agronomy, 43*, 97–107. https://doi.org/10.1016/j.eja.2012.05.011

Windisch, W., Fahn, C., Brugger, D., Deml, M., & Buffler, M. (2013). Strategien für eine nachhaltige Tierernährung. *Züchtungskunde, 85*(1), 40–53.

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(born 1944) studied agricultural sciences at the Friedrich Schiller University of Jena, obtained his doctorate there and habilitated at the University of Leipzig. He conducted research in the field of nutritional sciences with a focus on animal nutrition and resource economics. He was appointed Professor of Nutritional Physiology at the University of Jena in 1989. He then headed the Institute of Animal Nutrition at the Friedrich-Loeffler-Institute (FLI) in Braunschweig from 1994 to 2009. Since then he has been working there as a Senior Visiting Scientist. He was a member of various panels of the European Food Safety Authority for 18 years. As Chairman of the Nutritional Standards Committee of the Society of Nutritional Physiology, of which he is currently Honorary Chairman, he makes significant contributions to advancing knowledge in this field.

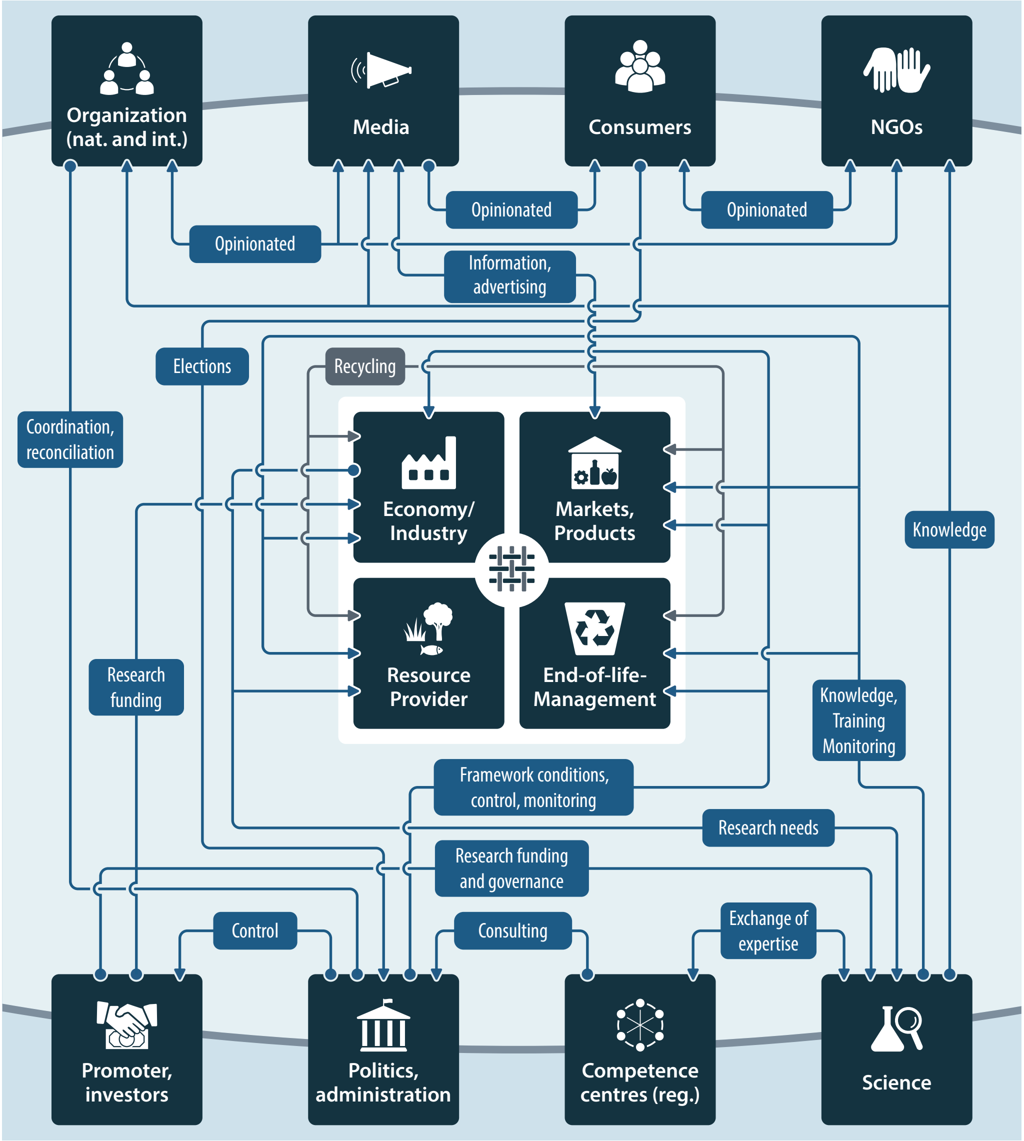
Bioeconomy of Microorganisms

Manfred Kircher

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_6

6.1 Overview Graphic



Resource providers

- Sugar refineries, oil extraction companies, private and municipal waste companies

Economy/Industry

- AB-Enzymes (Darmstadt), BRAIN AG (Zwingenberg), c-LEcta GmbH (Leipzig), CropEnergies AG (Zeitz), Covestro AG (Leverkusen), Evonik Industries AG (Essen), EW Biotech GmbH (Leuna), Subitec (Stuttgart)

End-of-life-Management

- Private and municipal waste management companies

Organization (-nat. and int.)

- BIO Deutschland e.V. (Berlin). BioBall e.V. (Bioeconomy in the metropolitan area e.V.) (Frankfurt am Main), BioPro Baden-Württemberg GmbH (Stuttgart), CLIB-Cluster (Cluster industrial biotechnology) (Düsseldorf), IBB Netzwerk GmbH (Industrielle Biotechnologie Bayern Netzwerk GmbH) (Planegg), VAAM (Association for General and Applied Microbiology e.V.) (Münster), EuropaBio (Brussels), Food and Agriculture Organization of the United Nations (FAO) (Rome)

Media

- TV, newspaper, radio, social media, specialist literature

Consumers

- final consumers (end products), companies along the production supply)chain (raw materials, intermediate products), waste management (after-use products)

NGOs

- Greenpeace, Bund für Umwelt und Naturschutz Deutschland e.V. (BUND) - Friends of the Earth Germany

Funding institutions, investors

- Companies, venture capital banks, foundations, state and federal ministries, European Commission

Politics, administration

- Politics and administration at local, state, federal and EU level

Competence centres (reg.)

- Cluster and technology transfer centres, business promotion institutions

Science

- Research Centre Jülich of the Helmholtz Society (FZ Jülich) (Jülich), Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB (Stuttgart), Leibniz Institute DSMZ-German Collection of Microorganisms and Cell Cultures GmbH (DSMZ) (Braunschweig), Max Planck Institute for Terrestrial Microbiology (Marburg), Phillips-Universität Marburg (Marburg), Technical University of Munich (Munich and Straubing), University of Hohenheim (Hohenheim), University of Applied Sciences Aachen (Jülich), Thünen Institute (Braunschweig), BioSC (Bioeconomy Science Center) (Jülich)

6.2 System Description

6.2.1 Introduction

The term microorganisms covers (mostly) unicellular organisms, which microbiology divides into microalgae, bacteria, fungi, archaea, protozoa (and the cell-free viruses). They play a central role in the natural carbon cycle. Microalgae, like plants, photosynthetically sequester carbon from the atmosphere and build biomass. Bacteria, fungi, archaea and protozoa, on the other hand, convert biomass or degrade it and return the carbon bound in it to the atmosphere. These microbial metabolic activities can also be used in technical processes for the production of commercial products. Microalgae, fungi and bacteria are mainly used in industry. This combination of microbiology and process engineering is known as biotechnology. It is involved in the production of biobased raw materials, but mainly in their conversion and the recycling of residual materials and waste. The result is an enormously diverse range of products for an equally broad spectrum of applications. Microbial products serve, among others, the large markets of nutrition, chemicals and pharmaceuticals, energy and fuels and, last but not least, waste recycling. With these markets, the economy comes into play and the combination of biotechnology and economy leads to the bioeconomy.

6.2.2 Definition

Microorganisms are part of the production system based on renewable raw materials, produce intermediate and end products in technical processes for a variety of markets and contribute to recycling residual materials and products after use. They therefore play a central role in the entire utilisation cascade of renewable raw materials and are therefore of systemic importance for the bioeconomy as a whole.

6.2.3 The Development of Biotechnology in the Bioeconomy

The power spectrum of microorganisms has been used by humans since time immemorial: Soils are worked in such a way that the interaction of plants, animals and microorganisms creates humus and thus fertile soils through biological weathering. Plant biomass is microbially preserved and fermented into foodstuffs such as beer, sauerkraut and yoghurt. Microorganisms were unknowingly used in this way for thousands of years. Only since the nineteenth century have they been recognised as biocatalysts and have been used specifically in technical processes since the middle of the twentieth century. Combined with the necessary process engineering, this marked the birth of biotechnology, which has since established itself as a basic technology of the bioeconomy.

An early milestone in biotechnology was the use of microorganisms as a so-called pure culture, because these unicellular organisms always occur in natural ecosystems as a community of different species. Isolating one species from all others therefore requires a special effort. With the help of microbiological methods, this has now been achieved for numerous species of microorganisms. The German Collection of Microorganisms and Cell Cultures in Braunschweig (DSMZ), one of the world's most important collections, stores around 50,000 living microorganism strains from which scientists in research and industry can establish new cultures.

These strains are both "wild types" isolated from nature and mutants and genetically modified microorganisms. Mutants have a randomly altered genome compared to the wild type, i.e. they have desirable changes and often additional secondary mutations. Until the 1980s of the twentieth century, the selection of mutants was the standard method of strain development used to modify microorganisms for a technical process. Since then, genetic engineering has established itself as a significant procedure. On the one hand, it enables targeted modifications while avoiding unintended side mutations, and on the other hand, it expands the possibility of exchanging genes across species. Since then, biotechnology has become increasingly important in the pharmaceutical industry because it enables microorganisms to produce human insulin, for example.

With the progressive development of DNA sequencing and processing, the original genetic engineering has evolved into *genome editing*. Today, the microbial genome can be modified with pinpoint accuracy so that the modified cell produces a defined metabolic product. Furthermore, strain development combines methods of genetics with information technologies that enable the processing of the large data volume of the genetic material. In this way, biosynthetic pathways can be planned for which, after translation into the genetic code, the corresponding DNA sequence is produced in the laboratory. In so-called “synthetic biology”, these gene building blocks are introduced into specially prepared cells. Such cells can carry out completely new syntheses or produce products that are unknown in nature. Microbial cells can thus be used technically as biocatalysts that carry out precisely planned reactions and are thus gaining importance in the chemical industry.

These advances in strain development are accompanied by methods of process engineering for the various microorganisms and applications (◘ Fig. 6.1). Microalgae can photosynthetically build up algal biomass starting from carbon dioxide and sunlight, which is further processed for a wide variety of purposes. If perishable plant biomass is assumed, it can be preserved, i.e.

Value-added stage	Raw material	Commercial products	Status
Structure	Atmospheric CO_2	Food, chemistry, fuel, biomass	State of the art
Preservation	Vegetable biomass	Silage	
Conversion	Sugar	Nutrition, chemistry, pharmaceuticals, fuel, enzymes	
	Woody residues (lignocellulose)	Fuel	
	Biological and synthetic precursors	Pharmaceuticals, chemicals	
Recycling	Biomass, industrial and municipal waste	Biogas, compost, sewage sludge	
	CO_2-emission	Food, chemistry, fuel, biomass	
		Energy, fuel	Demo scale
		Chemistry	in development

◘ **Fig. 6.1** Raw materials and microbial products at different stages of the bioeconomy value chain. (Source: Own representation) made storable, by microbial ensiling (acidification). Alternatively, sugar is obtained from biomass, which can be stored well. It can be fermentatively converted into a diverse range of microbial products, mainly for the food, chemical and fuel industries. Especially in the chemical and pharmaceutical sectors, microorganisms are also offered biotechnological or synthetic product precursors for conversion. New processes are expanding the spectrum of possible raw materials beyond sugar, still the most important carbon source, to include woody biomass contained in agricultural and forestry residues and in industrial and municipal waste. Recently, processes that accept gaseous carbon sources such as carbon dioxide have also entered industrial practice. They require other energy sources instead of sunlight and thus establish a link to the energy sector. Microorganisms are thus involved in all value creation stages of the bioeconomy, namely in the construction, conservation and conversion of biological raw materials and the recycling of waste.

All these services are based on the enormous diversity of microorganisms. ◘ Figure 6.2 provides an overview of processes for microalgae, bacteria and fungi, as well as exemplary products and their markets. For the biosynthesis of these products, microorganisms need raw materials, both as a source of carbon and for the extraction of energy. Some obtain carbon and energy from the same raw material, others from different sources.

Microalgae utilise atmospheric carbon dioxide with light as an energy source. Depending on requirements, they are cultivated in translucent tube systems or also in open basins and used, for example, for the production of high-quality food and feed dyes (for example carotenoids). The algal biomass can be used as animal feed; this also applies to almost all other processes. Fungi include yeasts, as used in the production of wine and beer, but also bioethanol. They rely on sugars as a carbon and energy source, the decomposition of which in the absence of air (anaerobic) emits significant amounts of carbon dioxide. With very small exceptions (for example, carbon dioxide for the beverage industry), this emission is not used; it goes into the atmosphere. This also applies to fermentation under aeration (aerobic), with which, for example, Aspergillus fungi produce enzymes. In this case, genetically modified organisms (GMOs) are usually used. Their biomass is not permitted as animal feed and is disposed of.

Bacteria are mostly cultivated aerobically with sugar as a carbon source. However, some bacteria can also convert other carbon and energy sources such as methane (methane is the main component of biogas and natural gas). They produce food and feed additives as well as pharmaceutical and chemical products. Often, microbial products are further processed chemically, leading to biobased plastics, for example. One example is lactic acid, which is used both as a preservative for food and as a starting material for the biopolymer polylactide (PLA). Clostridia, which have the particular ability to metabolise carbon monoxide and carbon dioxide, have only recently come to the fore. While carbon monoxide can provide the necessary energy, the utilisation of carbon dioxide requires hydrogen as an energy source. This opens up the possibility of also utilising the by-product carbon dioxide with the help of microorganisms (Graf et al., 2014). Thus, certain microorganisms can produce methane from carbon dioxide and hydrogen. If the anaerobic biogas fermentation is followed by this step of biological methanation, the methane yield can be increased and the carbon dioxide emission reduced. However, because the production of hydrogen is energy-intensive, the process is only viable if surplus energy can be used.

In the industrial practice of fermentation, bacteria and fungi are usually cultivated in an aqueous nutrient solution called fermentation broth. Each cell has a surface area of about three millionths of a square

Procedure	**Microorganism**	**Carbon source**	**Energy source**	**Target product** ***By-product***	**Market for target product** ***Market for by-product***
Algae					
Algae cultivation	*Chlorella*	CO_2	Light	Carotenoids	Pet food, nutrition
				Algal biomass	Pet food
Mushrooms					
Anaerobic fermentation	Yeast	Sugar		Beer, wine	Drinks
				Bioethanol	Fuel, chemistry
				Fermentation residue	*Feed*
				CO_2	*without use*
Aerobic fermentation	*Aspergillus*			Enzymes	Chemistry, diagnostics, etc.
				GMO digestate	*Waste management*
				CO_2	*without use*
Bacteria					
Anaerobic fermentation	*Corynebacterium*	Sugar		Amino acids	Feed, nutrition, pharma
				GMO digestate	*Waste management*
				CO_2	*without use*
	Escherichia			Insulin	Pharma
				GMO digestate	*Waste management*
				CO_2	*without use*
	Lactobacillus			Lactic acid	Nutrition, chemistry
				Fermentation residue	*Pet food*
				CO_2	*without use*
	Methylococcus	Methane		Biomass	Pet food
				CO_2	*without use*
Anaerobic gas fermentation	*Clostridia*	CO_2 CO	H_2	Bioethanol *fermentation residue*	Fuel *Waste management* *without use*

Fig. 6.2 Biotechnological processes, target and by-products and markets. (Source: Own representation)

Procedure	Microorganism	Carbon source	Energy source	Target product *By-product*	Market for target product *Market for by-product*
Mixed crops					
Silage	Mixed culture	Agricultural biomass		Silaged biomass	Pet food Biogas fermentation
Biogas fermentation		Solid and liquid biowaste		Methane	Energy
				Fermentation residue	Fertilizer
				CO_2	*without use*
Composting				Compost	Fertilizer
				CO_2	*without use*
Wastewater treatment				Water	Water supply
				Sewage sludge	Energy
				Methane	Energy
				CO_2	*without use*

Fig. 6.2 (continued)

meter to absorb nutrients and release carbon dioxide. Cultivation takes place in vessels (fermenters) that can reach a volume of up to 800,000 litres. Around five trillion cells are then active in one litre, which together have an exchange surface area of 15,000 m^2/l. In addition to the potential of microbial metabolism, it is this huge exchange area that makes microbial processes so powerful.

Mixed crops are used in the preservation of plant biomass (silage) and recycling. Important applications of silage are the storage of green fodder (grass, forage maize, beet leaves, etc.) for animal breeding and raw material for biogas fermentation (including energy maize). The mixed culture of biogas fermentation results in biogas, which consists of the energy source methane (60%) and carbon dioxide (40%). Wastewater treatment and landfilling also produce a similarly composed gas (sewage gas, landfill gas). The former two processes also produce microbial residues (digestate, sewage sludge) that can be spread as fertiliser. In Germany, the methane from both sources is used as an energy source. For the sake of completeness, it should be noted that composting is also a process essentially based on microorganisms. Here, too, carbon dioxide is emitted.

Microbial conversion therefore always produces several products: the target product, microbial biomass, carbon dioxide and by-products of microbial metabolism. It is therefore one of the economic and ecological challenges for the bioeconomy to develop a value-added use for all process products.

6.2.4 The Main Commercial Goods of the Bioeconomy

Figure 6.3 provides an overview of commercially important microbial products, and it will be seen that microbial products contribute to value creation in virtually all sectors of the economy.

Market	Raw material	Product examples	Market development, status
Food	Sugar	Alcoholic beverages, starter cultures, citric acid, vitamin C food additives	Growing with the market
Feed		Feed additives, amino acids, enzymes microbial biomass	
Enzymes		Enzymes for syntheses,- feed, digestion of lignocellulose, household chemistry etc.	
Bioenergy		Bioethanol	Market according to admixture obligation
	Lignocellulose sugar	Bioethanol	Growing market. Few plants in the EU, not in Germany
	Algae oils	Biodiesel	Niche market, pilot plants
	Residual flows, energy corn	Biogas	9,000 Plants
	CO, CO_2	Bioethanol Fine and specialty	Niche market, production plant under construction in Belgium
Chemistry	Sugar, vegetable oils	chemicals	7% of the market
		Basic chemistry	<1% of the market
	Lignocellulose sugar, CO, CO_2	Basic chemistry	Pilot plants in Germany
Pharma	Sugar	Antibiotics, insulin	Growing
Waste management	Residual flows	Biogas (electricity, heat, bio-methane)	Growing

Fig. 6.3 Commercially important products and their carbon source. (Source: Own representation)

6.2.4.1 Food and Feed Additives

The alcoholic fermentation of wine and beer, the microbial acidification of yoghurt and sauerkraut, the leavening of dough by means of yeasts and starter cultures in meat processing are proof of the ancient role of microorganisms in food processing. In meat processing, for example, citric acid, which is purely accessible by fermentation, and vitamin C, for the production of which bio- and chemocatalytic steps are combined. In order to compensate for the lack of certain amino acids in animal feed, these amino acids are produced fermentatively and added to the feed.

The main carbon source for the products listed here is sugar. The markets for food and feed additives are growing in line with the population and increasing prosperity in emerging countries.

6.2.4.2 Chemistry

The German chemical industry processes around 2.7 million t of renewable raw materials annually; this corresponds to a raw material share of 13%. Sugar (156,000 t) and starch (336,000 t), part of which is processed microbially and enzymatically, still account for 18% among the biological raw materials (VCI, 2019). Microbial products are particularly relevant in the area of high-quality skin care and household chemicals (detergents). The most important carbon source here is agriculturally produced sugar; the use of wood residues, carbon monoxide and carbon dioxide is under development.

6.2.4.3 Pharmaceuticals

Among the top 100 pharmaceutical products, biopharmaceuticals account for 49% of global sales (Statista, 2018b). These include antibiotics produced by the fungi *Penicillium* and *Cephalosporium*. One example of a transgenic product is microbially produced human insulin, for which Germany has one of the world's most important production sites in Frankfurt. The turnover for this product alone is €4.7 billion (2016) (FNP, 2016). Sugar is used as a carbon source.

6.2.4.4 Enzymes

The most economically important enzymes are carbohydrases, which break down starch into sugar for the beverage industry, and proteases, which can break down protein stains in detergents. Lipases (fat-splitting in detergents), polymerases (linking genetic building blocks, for example in diagnostics) and nucleases (DNA-degrading in research) are also relevant. An important application in animal nutrition is to increase the digestibility of feed by adding enzymes. In the textile industry, wool is enzymatically modified to make textiles felt-free (FCI, 2007). A growing area is the digestion of woody biomass for industrial use. Although this material, known as lignocellulose, consists of around 70% sugar, it is bound in such a complex structure that it is not directly accessible for biotechnological processes. Enzymes can break down this structure and release the sugar.

The enzyme world market is around US$8 billion (Allied Market Research, 2018), with around 64% of production in Europe, particularly Denmark, France and Germany (Biooekonomie.de, 2016). Due to the diversity of enzymes and their applications, a few large companies and numerous specialist suppliers have established themselves in the market worldwide.

6.2.4.5 Fuel

Microbially produced fuels contributed 1.3% to German fuel consumption in 2017. This is mainly bioethanol with 1.2 million tonnes and with a small share also biomethane (28,000 tonnes) (FNR, 2018). 64% of bioethanol is produced in Germany (BDB, 2017) on the basis of sugar (sugar beet) and starch (cereals, maize) (FNR, 2016); the rest is imported. Worldwide, 79 million tonnes of bioethanol were produced in 2017 (Crop. energies, 2017), mainly on the basis of sugar cane (Brazil) and corn (USA).

6.2.4.6 Biogas

In Germany, 9200 biogas plants were operated in 2018 (Statista, 2018a), producing around 9 billion m^3 of biogas. In terms of the methane it contains, this corresponds to 7% of natural gas and biogas consumption (Scarlat et al., 2018). In addition to waste, energy maize is mainly fermented. Biogas is used to produce electricity, heat and biomethane.

In Germany, 51.4 TWh of electricity are generated from biomass, of which 34.3 TWh are generated after microbial conversion of biomass (95% biogas, 5% sewage and landfill gas). This corresponds to a share of 5.2% of Germany's gross electricity generation (FNR, 2018). Overall, the share of renewable electricity in Germany in 2016 was 33%

of which 21% was bio-based (BMWi, 2019). Worldwide, biogas generates 353 TWh (Sapp, 2017).

Total heat consumption in Germany is around 2500 TWh (BDEW, 2017); of this, 19.2 TWh (0.8%) is based on biogenic gases (70% biogas, biomethane 18%, 11% sewage gas, 1% landfill gas). Among the renewable heat sources, these gases have a share of 11.2% (UBA, 2019).

In addition, biomethane from biogas is purified so that it can be fed into the natural gas grid. In 2016, almost 200 upgrading plants produced 9.4 TWh of biomethane (Neumann, 2018).

6.2.5 Framework for Action

How the economic importance of microbial processes will develop in the future depends not only on their performance, but also to a large extent on the general framework for action.

Politically, the industrial use of microorganisms is supported. The relevant guidelines for innovation in the field of microbial processes and products are set out in the National Research Strategy BioEconomy 2030 (BMBF, 2010) of the Federal Ministry of Education and Research (BMBF).

The economic framework conditions are set in particular by the Renewable Energy Sources Act (EEG), blending quotas for fuels, energy costs and indirectly also by the Emissions Trading Scheme (ETS). As a fuel, bioethanol is subject to the EU Renewable Energies Directive (EU, 2009). It defines the minimum target of 10% renewable energy to be achieved by 2020 as a share of the fuel market in all EU member states. Renewable electricity generated from biogas is (decreasingly) subsidised, which increasingly challenges plant operators. Although ETS only affects fossil carbon dioxide emissions in defined sectors, it also determines competitiveness with processes using renewable carbon sources. Unfortunately, ETS does not have an encouraging effect on the recycling of carbon dioxide because the emission is priced quite independently of the reuse. There are no supporting measures for bio-based products outside the energy sector.

6.2.6 System Boundaries

Achieving competitiveness with fossil-based products is fundamentally difficult – especially in the current transition phase to the bioeconomy, in which fossil-based and bio-based raw materials are processed in parallel and are in direct competition. For products that are exclusively biotechnologically accessible or are offered biobased due to consumer demand (pharmaceuticals, food and feed additives, skin care products), competitiveness is given. However, these products are produced in comparatively small volumes, so they have little effect on the general raw material change. By contrast, bio-based alternatives cannot (yet) compete in terms of cost with fossil-based fuels and basic chemicals, which are produced in very large volumes. It remains to be seen whether it is sufficient to wait for competitiveness to emerge of its own accord as the extraction costs of fossil raw materials rise. At any rate, control instruments such as an expansion of the ETS system or the levying of a tax on fossil carbon dioxide emissions are currently being introduced.

A cost factor of microbial processes that has not yet been addressed is the limited carbon yield. It leads to the fact that only a part of the carbon from the raw material is bound in the target product. Thus, yeast can theoretically form a maximum of 51 kg ethanol and 49 kg carbon dioxide from 100 kg sugar (Sahm & Bringer-Meyer, 1987); in practice, the yield is usually lower. It could be increased by consistent use of all by-products.

The demand for renewable raw materials must also be viewed critically. In order to keep this and the associated land use change in check, microbial processes must be concentrated on those product areas that are dependent on carbon. These are usefully products of organic chemistry (including food and feed additives and pharmaceutical products) and sub-sectors of the fuel market (heavy duty, shipping and aviation). The energy sector, on the other hand, should give preference to carbon-free alternatives.

The foreseeable rather decentralised production infrastructure of microbial processes has a further impact. Such plants have a much smaller capacity compared to fossil-based production plants. This is due on the one hand to the complex logistics of bio-based raw materials, which require short transport routes, and on the other hand to the technical limits of microbial processes. In such plants, the economically relevant scale effect on investment and running costs has less of a cost-dampening effect, which leads to fundamentally higher production costs.

The issue of employment addresses a significant social implication of microbial processes. As an export nation, Germany will also have a large demand for raw materials in the bioeconomy and will be dependent on raw material imports. Whether this will be unprocessed biomass or a biomass fraction (for example sugar) or an early processing stage (for example ethanol), or whether entire production chains will shift to global biomass regions, is an open question. In any case, the broad switch to microbial processes will also have an impact on local industrial centres, whether through partial relocation of production to biomass regions in Germany or to other parts of the world.

6.3 Innovations

The diversity of applications of microorganisms corresponds to the innovation potential, which ranges from new processes and products to mechanical and plant engineering and process organization. In the following, these fields of innovation will be explained and concrete examples will be used to show how innovations are realised by industry – and equally by young start-ups and established large companies. It should be emphasised that an economically important innovation does not necessarily have to be scientifically sophisticated. Sometimes, even rather inconspicuous developments have a major impact.

Process innovations concern all process steps; starting, for example, with the enzymatic digestion of wood, the development and optimization of microbial strains and enzymes, microbial and enzymatic conversion processes, and processing and product purification.

One example of an innovative strain development company is SenseUp. The start-up, spun off from Jülich Research Centre in 2015, supports the development of microbial production strains. To select the best cells, millions of genetic variants may need to be tested. SenseUp has developed an automated process that tests up to 50,000 cells per second (SenseUp Biotechnology, 2019), reducing costs by speeding up testing. With this offering, SenseUp has successfully established itself as a service provider in the market.

Covestro AG is a large-scale chemical company that is developing a microbial process for the production of a biobased basic chemical product. An important raw material used by Covestro is aniline, of which the company consumes more than one million tons per year for the production of polymers. In fact, a process to bio-aniline linking microbial- and chemical catalysis is promising and currently under pilot (Jäger, 2018). The innovation here lies in the raw material and process change for a product that is known in itself.

Lanzatech (founded in New Zealand in 2005; now USA) is currently scaling up the world's first gas fermentation to production level. The technology draws on the research work of Professor Peter Dürre (University of Ulm), among others, to establish a biotechnological process that can utilise gaseous carbon sources. A carbon monoxide-based ethanol production plant is currently being built in Ghent (Belgium); it will use carbon monoxide from a steelworks as a feedstock (ArcelorMittal, 2018). The innovation here lies at three levels: in the fermentation process, in the plant technology of the bioreactor and in the cross-sector cascade use of the emission from a steelworks.

Product innovation can lie both in the novel use of a product that is known per se and in a new product for an application that is known per se. For example, the business potential of Ectoin, a protective molecule of microorganisms living under extreme conditions, was recognized at the private University of Witten/Herdecke. In 1993, bitop AG (Dortmund) was founded and is now the only producer of Ectoin worldwide. Its protective effect can be transferred to many applications and is used for the relief of skin diseases, colds, allergies, lung diseases and dry epithelia, in supportive care for cancer patients and in cosmetics as an anti-aging agent and in sun protection formulations. The success of bitop is thus based on the commercial use of the natural treasure trove of microorganisms. Recognizing the application potential of Ectoin and developing a microbial manufacturing process for it is innovative.

c-LEcta, a company founded in Leipzig in 2004, focuses on the product field of enzymes. The company now generates more than 70% of its sales with self-developed enzymes (c-LEcta, 2019). The focus is on the food and pharmaceutical markets, which are considered particularly demanding due to the numerous regulations. The innovation here is to recognize the often very specific problems of such markets and to offer an economically viable solution.

With new processes, mechanical and plant engineering is also challenged. In gas fermentation, for example, it is necessary to overcome the low solubility of gaseous carbon sources in the aqueous nutrient solution. Innovative aeration equipment is therefore required here. One example is the already mentioned Lanzatech.

There is also potential for innovation in the organization of process flows. The aim is to coordinate plants and processes in such a way that the raw materials are utilized as completely as possible. The process organization required for this is the coupling of process flows, the cascade use of raw materials, for example along the decreasing processing capability, and recycling. This can apply to material flows both within an industrial site and between different companies, and also across sectors.

For example, the medium-sized company BioWert Industrie GmbH in Brensbach (Hesse) operates a biorefinery that processes all components of meadow grass. The grass fibres are used to produce insulation and composite materials. Proteins, aromas and cosmetic active ingredients are extracted from the pressed juice produced during the processing of the grass. Materials that can no longer be used for other purposes serve as fertilizer or are microbially fermented into biogas (BioWert, 2019). The biogas is used to supply the plant with energy. The innovation here lies in an economically viable coupling and cascade use of all components of a raw material, in this case grass.

Infraserv GmbH & Co. Höchst KG, the operator of the Frankfurt Höchst industrial site, offers a similar example. One of Europe's largest biogas plants is operated there as a central element of cascade utilization. Annually, 500,000 t of waste can be fermented into 11 million m^3 of biogas (Industriepark Höchst, 2019). Industrial by-products generated at the site and waste from the surrounding area are accepted as raw materials. The resulting biogas generates heat and electricity for the site on the one hand and is fed into the municipal natural gas grid on the other. What is innovative here is the organization of the complex waste utilization from mutually independent sources.

6.4 Images of the Future

The fact that the raw material transition from fossil to biobased carbon sources is necessary and must be largely completed by 2050 has been bindingly recognised by well over 50 countries in the Paris Climate Agreement. With their central position in the bioeconomy, microbial processes and products therefore have very good economic potential, depending on the framework conditions.

▪ Agriculture

The foreseeable increase in demand for biobased raw materials with the bioeconomy opens up growing business areas for agriculture and forestry – not only for established products such as sugar, but also for by-products such as straw and forestry waste. In Germany, energy and industrial crops were grown on 2.445 million ha in 2018. The fact that 66% of this area production is processed with the participation of microorganisms is evidence of the importance of microorganisms (◘ Fig. 6.4) (FNR, 2019).

▪ Food Industry

Microbial processes and products are already well established in the food, beverage and feed sectors, and the economic potential is expected to grow with the market. Above-average growth can be expected for global meat production – both for conventional meat and for alternatives. For alternative meat products, this may result in increasingly valuable business options in the medium term. For example, the young company Impossible Food (USA) uses fermentatively produced phytohemoglobin to give soy products meat flavor (Impossible Food, 2019).

▪ Chemical Industry

Biobased chemical products are already established on the market if they can be produced exclusively by biotechnology or if they meet a particular customer demand. This applies in particular to the fine and spe-

Crops	Use	Area under cultivation (1,000 ha) (according to FNR 2019)	Predominant processing	Bio-catalysis share
Energy crops	Biogas	1,350	Bio-catalysis	55.3 %
	Biodiesel	560	Chemo-catalysis	
	Bioethanol	246	Bio-catalysis	10.1 %
	Solid fuels	11	Burn	
Industrial Plants	Industrial starch	129	Chemo-catalysis	
	Industrial oils	120	Chemo-catalysis	
	Medicinal substances and dyestuffs	12	Chemo-catalysis	
	Industrial sugar	12	Bio-catalysis	0.5 %
	Plant fibers	2	Chemo-catalysis	
		2,442		**65.9%**

◘ **Fig. 6.4** Share of biocatalysis in crop processing. (Source: Own representation, based on FNR, 2019) cialty chemicals segments. For basic chemical products that are produced in comparatively large volumes, bio-based alternatives are not yet competitive. Nevertheless, there is potential in the long term, because basic chemicals must also face up to the raw material change by 2050.

- **Pharmaceutical Industry**

In 2017, for the first time, more biological active ingredients were approved in Germany than chemosynthetically produced ones, with 23 biopharmaceuticals. This demonstrates the growing importance of bio-based pharmaceuticals, many of which are produced microbially. Overall, sales of biopharmaceuticals by German companies reached €10.2 billion, a share of 26% among all pharmaceutical products (VFA, 2018).

- **Fuel Economy**

Given the political pressure towards zero-emission mobility, the market for biofuels is expected to decline. For aircraft, ships and heavy-duty transport, it can be assumed that fuels of high energy density, as offered by carbon-based fuels, will continue to be needed. In these sub-sectors, long-term markets may develop for biofuels (Kircher, 2015).

- **Construction Industry**

Microbial products can also contribute to the construction industry. For example, microorganisms are used to bond rock particles by calcium carbonate precipitation to form road surfaces or dyke pavements (BioCement, 2016) and to repair cement damage to bridges, for example (Basilisk, 2019). With the increasing need for low-emission construction, the market for such technologies can be expected to grow.

- **Waste Management**

Technically, biogas will be able to play an increasing role in waste management, because this methane-containing gas can be produced from biobased side streams from all production sectors, can be used in many ways to produce heat and electricity, as a fuel and as a basic chemical, and can use the existing infrastructure for natural gas.

In addition, a further source is available through the aforementioned methanation of carbon dioxide. When consuming excess electricity from volatile energies (wind, solar), the methane produced in this way would act as an electricity storage facility, for which an extensive infrastructure is already available in the form of the existing natural gas grid. Microorganisms catalysing methanation would thus contribute to the integration of the bioeconomy and the energy sector.

6.4.1 Possibility of Adding Value

◘ Figure 6.5 shows the relationship between functionality, value creation and market size. Value creation is crucially dependent on the functionality of a product. It is very high for pharmaceuticals that are expected to produce a highly specific response in a very specific indication. However, the market size of such a highly specific product is relatively limited. Products for nutrition (food and feed), are also value-added and are produced in larger volumes. They are partly identical to chemical products, which have a wide range. High-value cosmetic ingredients such as microbially or enzymatically produced emollients, with their relatively low production volume, are included in the fine chemicals market. Specialty chemicals include building blocks for plastics such as microbially produced polyhydroxyalkanoates (PHA). Biobased basic chemicals can be, for example, methanol and ethanol, i.e. molecules of low functionality but large production volume. These two products already indicate the overlap between basic chemicals and energy carriers, which is also expressed in terms of value. Naturally, raw materials have the largest production volume. However, their value is still greater

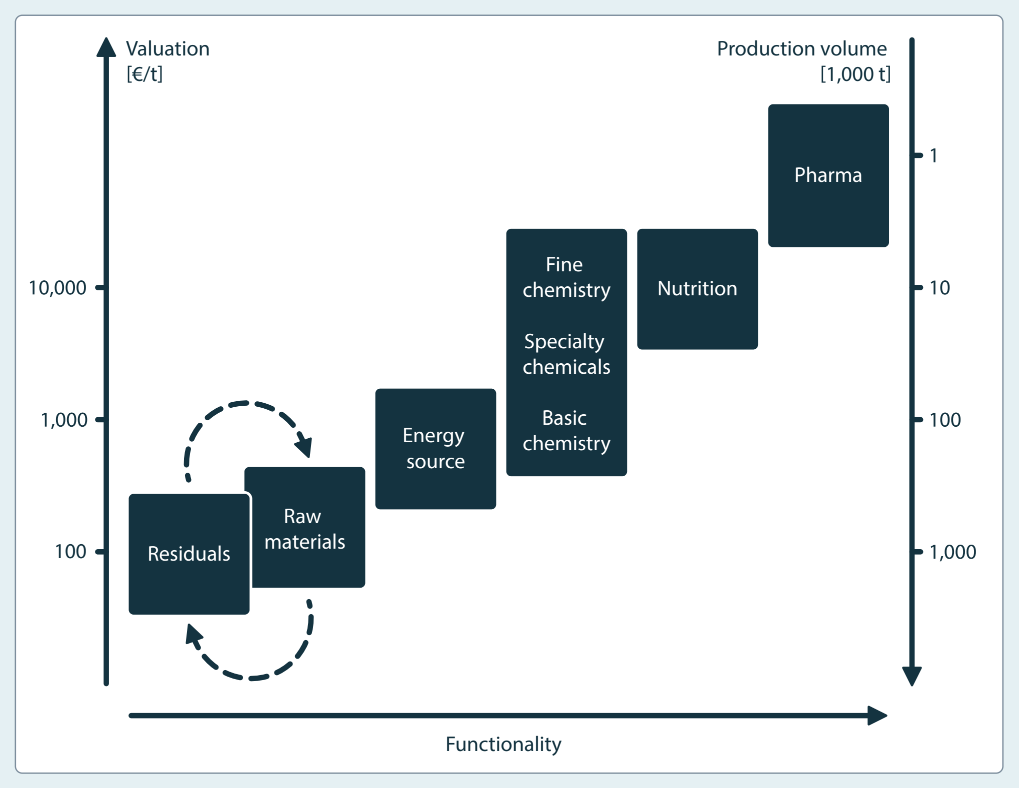


Fig. 6.5 Value, functionality and production volume of microbial raw materials and product groups. (Source: Own representation)

than that of residual materials, which in turn can be recycled at least in part as raw materials. This cascade of uses, from raw and residual materials to energy and pharmaceuticals, also brings with it new options in the coupling of material flows, which are increasingly attracting research interest. This also includes the use of residual materials such as municipal waste (brown bin), urban green waste, sewage sludge, carbon dioxide, etc. for materials, i.e. not almost exclusively for energy, as has been the case up to now. (Provadis University, 2019). New value-added options thus also reach the waste industry and, in the case of carbon dioxide recycling, the energy industry. Overall, this increases raw material efficiency. That is, a higher proportion of raw material carbon is converted into value-added products, or the loss in residual materials decreases (Kircher, 2018). However, this can only succeed if consumers make their share of residual materials available in the "brown bin" in such a way that it remains recyclable. It is therefore important to continue to raise awareness of the fact that residual materials are valuable raw materials.

6.5 Conflicting Objectives

From an economic point of view, the competitiveness of biobased products is of primary importance. Compared to fossil fuels, bio-based raw materials are expensive and their microbial processing is multi-step and complex. Biobased fuels and in particular large-volume base chemicals have therefore only become established in niches to date.

The ecological balance of biobased products is ecologically advantageous over the entire production and use cycle. Nevertheless, their ecological footprint should not be underestimated. The production of the raw materials and their conversion are accompanied by the emission of greenhouse gases. These must be reduced and, if possible, also recycled.

Microbial conversion processes convert only part of the carbon of the raw materials into a target product. The remainder usually remains as residual material, the use of which would often be technically possible, but is omitted for economic reasons. The framework conditions should therefore support the complete utilisation of biomaterials through coupling and cascade utilisation or recycling.

A political conflict of objectives arises from the focus of the raw material change on renewable energies. Here, support measures have been taken that have led, for example, to the desired investments in biogas plants, but also to considerable land use changes. The area of bio-based chemicals, on the other hand, remains without support.

Another political conflict of objectives is that the development and implementation of microbial processes is generally only supported if biogenic raw materials are used. Research into the utilisation of carbon dioxide of fossil origin is only supported if only renewable energies are used. However, in the current transitional phase of the raw material change, fossil and biogenic carbon sources will continue to be processed in parallel for decades. The industrial optimisation of such processes would therefore be accelerated if the framework conditions were to simplify the use of microbial processes for fossil raw materials as well.

Conclusion

Microorganisms have a central function in the bioeconomy; be it in the provision of raw materials, the conversion into products of all sectors of the bioeconomy and the recycling of residual materials. The value spectrum of the products ranges from low-value raw materials to high-priced pharmaceuticals. The scientific competence to develop microorganisms into efficient biocatalysts and to develop and operate the corresponding technical processes and plants is crucial for the transition to the bioeconomy and is fundamentally available. In the transition to the bioeconomy, the economy should increasingly adapt to the processing of diverse raw materials ranging from agricultural biomass to municipal waste and carbon-containing gases. Overall, it will be important to convert significant sectors of industries that are successful in Germany to microbial processes and to adapt regional, supraregional and international supply chains for biobased raw materials accordingly.

References

Allied Market Research. (2018). Enzymes market type (protease, carbohydrase, lipase, polymerase and nuclease, and other types), source (microorganisms, plants, and animals), reaction type (hydrolase, oxidoreductase, transferase, lyase, and other reaction types), and application (food and beverages, household care, bioenergy, pharmaceutical and biotechnology, feed, and other applications) – Global opportunity analysis and industry forecast, 2017–2024. https://www.alliedmarketresearch.com/enzymes-market. Accessed: 18.06.2019.

ArcelorMittal. (2018). ArcelorMittal and LanzaTech break ground on €150million project to revolutionise blast furnace carbon emissions capture. https://corporate.arcelormittal.com/news-and-media/news/2018/june/11-06-2018. Accessed: 18.06.2019.

Basilisk. (2019). Website. Basilisk self-healing concrete. http://www.basiliskconcrete.com/%3FLang%3Den. Accessed: 18.06.2019.

BDB (Bundesverband der deutschen Bioethanolwirtschaft). (2017). Die deutsche Bioethanolwirtschaft in Zahlen. https://bdbe.de/daten/marktdaten-deutschland. Accessed: 18.06.2019.

BDEW. (2017). Endenergieverbrauch nach Sektoren. https://www.bdew.de/service/daten-und-grafiken/foliensatz-waermeverbrauchsanalyse/. Accessed: 01.09.2019.

BioCement. (2016). What is biocement? http://www.biocementtech.com/solutions/#what-is-biocement. Accessed: 18.06.2019.

Biooekonomie.de. (2016). Enzyme – die Supertalente der Bioindustrie. https://biooekonomie.de/enzyme-die-supertalente-der-bioindustrie. Accessed: 18.06.2019.

SenseUp Biotechnology. (2019). Website. The screening company for the biotech industry. http://www.senseup.de. Accessed: 18.06.2019.

BioWert. (2019). Website biowert. https://biowert.com. Accessed: 18.06.2019.

BMBF (Bundesministerium für Bildung und Forschung). (2010). Nationale Forschungsstrategie Bioökonomie 2030. Unser Weg zu einer biobasierten Wirtschaft. https://www.bmbf.de/upload_filestore/pub/Nationale_Forschungsstrategie_Biooekonomie_2030.pdf. Accessed: 18.06.2019.

BMWi (Bundesministerium für Wirtschaft und Energie). (2019). Erneuerbare Energien. https://www.bmwi.de/Redaktion/DE/Dossier/erneuerbare-energien.html. Accessed: 18.06.2019.

c-LEcta. (2019). c-LEcta: Financial figures for 2018 underscore successful transformation into a product company. c-LEcta Newsletter. https://www.c-lecta.com/newsroom/news/view/entry/c--lecta-financial-figures-for-2018-underscore-successful-transformation-into-a-product-company/. Accessed: 18.06.2019.

Crop.energies. (2017). Bioethanol as a growth market. http://www.cropenergies.com/Pdf/en/Bioethanol/Markt/Dynamisches_Wachstum.pdf. Accessed: 18.06.2019.

EU (2009). Richtlinie 2009/28/EG „Erneuerbare Energien" mit den Änderungen der Änderungsrichtlinie 2015/1513/EU. https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32009L0028&from=DE. Accessed: 02.09.2019.

FCI (Fonds der chemischen Industrie). (2007). Textilchemie. https://www.vci.de/vci/downloads-vci/textilchemie-textheft.pdf. Accessed: 18.06.2019.

FNP (Frankfurter Neue Presse). (2016). Pharmaunternehmen Sanofi: Der Weltmeister der Insulinproduktion. https://www.fnp.de/wirtschaft/pharmaunternehmen-sanofi-weltmeister-insulinproduktion-10441370.html. Accessed: 18.06.2019.

FNR (Fachagentur Nachwachsende Rohstoffe). (2016). Bioethanol. https://biokraftstoffe.fnr.de/kraftstoffe/bioethanol/. Accessed: 18.06.2019.

FNR (Fachagentur Nachwachsende Rohstoffe). (2018). Basisdaten Bioenergie Deutschland 2018. Festbrennstoffe, Biokraftstoffe, Biogas. http://www.fnr.de/fileadmin/allgemein/pdf/broschueren/Broschuere_Basisdaten_Bioenergie_2018_web.pdf. Accessed: 18.06.2019.

FNR (Fachagentur Nachwachsende Rohstoffe). (2019). Entwicklung der Anbaufläche für nachwachsende Rohstoffe in Deutschland. https://mediathek.fnr.de/grafiken/daten-und-fakten/anbauflache-fur-nachwachsende-rohstoffe.html. Accessed: 18.06.2019.

Graf, F., Krajete, A., & Schmack, U. (2014). Abschlussbericht. Techno-ökonomische Studie zur biologischen Methanisierung bei Power-to-Gas-Konzepten. Abschlussbericht- DVGW Karlsruhe. https://www.researchgate.net/profile/Frank_Graf/publication/278031528_Techno-okonomische_Studie_zur_biologischen_Methanisierung_bei_PtG-Konzepten/links/557aa2c808aeb6d8c0207c8f.pdf. Accessed: 18.06.2019.

Impossible Food. (2019). Heme and science. https://impossiblefoods.com/heme/. Accessed: 18.06.2019.

Industriepark Höchst. (2019). Biogas generation: Cutting-edge energy recovery from biowaste. https://www.industriepark-hoechst.com/en/stp/menu/powered-by-infraserv/services/disposal/biogas-generation/. Accessed: 18.06.2019.

Jäger, G. (2018). Alternative feedstocks for the polymer industry: Status and outlook, CIC2018 17.01.2018–18.01.2018, Düsseldorf. https://www.clib2021.de/veranstaltungen/cic2018. Accessed: 2.09.2019.

Kircher, M. (2015). Sustainability of biofuels and renewable chemicals production from biomass. *Current Opinion in Chemical Biology*. https://doi.org/10.1016/j.cbpa.2015.07.010

Kircher, M. (2018). Implementing the bioecoomy in a densily populated and industrialised country. *Advances in Industrial Biotechnology*. https://doi.org/10.24966/AIB-5665/100003

Neumann, H. (2018). Die Rolle von Biogas ändert sich fundamental. Topagraronline 3.4.2018. https://www.topagrar.com/energie/news/rolle-von-biogas-aendert-sich-fundamental-9591564.html. Accessed: 18.06.2019.

Provadis-Hochschule. (2019). BioBall – Bioökonomie im Ballungsraum. https://www.provadis-hochschule.de/angewandte-forschung/innovationsraum-bioball/. Accessed: 18.06.2019.

Sahm, H., & Bringer-Meyer, S. (1987). Ethanol-Herstellung mit Bakterien. *Chemie Ingenieur Technik, 59*(9), 695–700.

Sapp, M. (2017) State of biogas in the world: 2017. Clean energy solutions center. http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2017_events/9_GBEP_WGCB_30_November_2017/GBEP_CESC_biogas_report.pdf. Accessed: 18.06.2019.

Scarlat, N., Dallemand, J.-F., & Fahl, F. (2018). Biogas: Developments and perspectives in Europe. *Renewable Energy*. https://doi.org/10.1016/j.renene.2018.03.006

Statista (2018a). Anzahl der Biogasanlagen in Deutschland. https://de.statista.com/statistik/daten/studie/167671/umfrage/anzahl-der-biogasanlagen-in-deutschland-seit-1992/. Accessed: 18.06.2019.

Statista (2018b). Marktanteil von Biopharmazeutika am weltweiten Arzneimittelumsatz der Top 100-Präparate* in den Jahren von 2006 bis 2024. https://de.statista.com/statistik/daten/studie/311766/umfrage/biotech-produkte-anteil-an-den-top-100-praeparaten-der-pharmaindustrie-seit-2006/. Accessed: 18.06.2019.

UBA (Umweltbundesamt). (2019). Erneuerbare Energien in Zahlen. https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen#waerme. Accessed: 18.06.2019.

VCI (Verband der chemischen Industries). (2019). Rohstoffbasis der chemischen Industrie. https://www.vci.de/vci/downloads-vci/top-thema/daten-fakten-rohstoffbasis-der-chemischen-industrie.pdf. Accessed: 18.06.2019.

VFA (Die forschenden Pharmaunternehmen). (2018). Pressemitteilung. Biopharmazeutika legen zu: mehr Präparate, mehr Umsatz, mehr Arbeitsplätze. https://www.vfa.de/de/presse/pressemitteilungen/pr-02-2018-biopharmazeutika-legen-zu.html. Accessed: 18.06.2019.

Dr. Manfred Kircher

(born 1953) brings to his consulting work more than 30 years of experience in the chemical industry and the development of an internationally active bioeconomy cluster with companies and research institutes. His career spans biotechnology research and development (Degussa AG, Germany), manufacturing (Fermas s.r.o.; Slovakia), venture capital (Burrill & Company; USA) and partnering and branding (Evonik Industries AG; Germany). As a delegate of Evonik, he was Chairman of the Board of the Industrial Biotechnology Cluster in Germany until 2012 and developed this cluster of German and international companies, research institutes and investors into a successful and recognised organisation for establishing bioeconomic value chains. Since 2014, he has been Chairman of the Advisory Board of the Industrial Biotechnology Cluster (CLIB-Cluster) and, since 2019, a member of the Board of the Bioeconomy in the Metropolitan Area Association (BioBall).

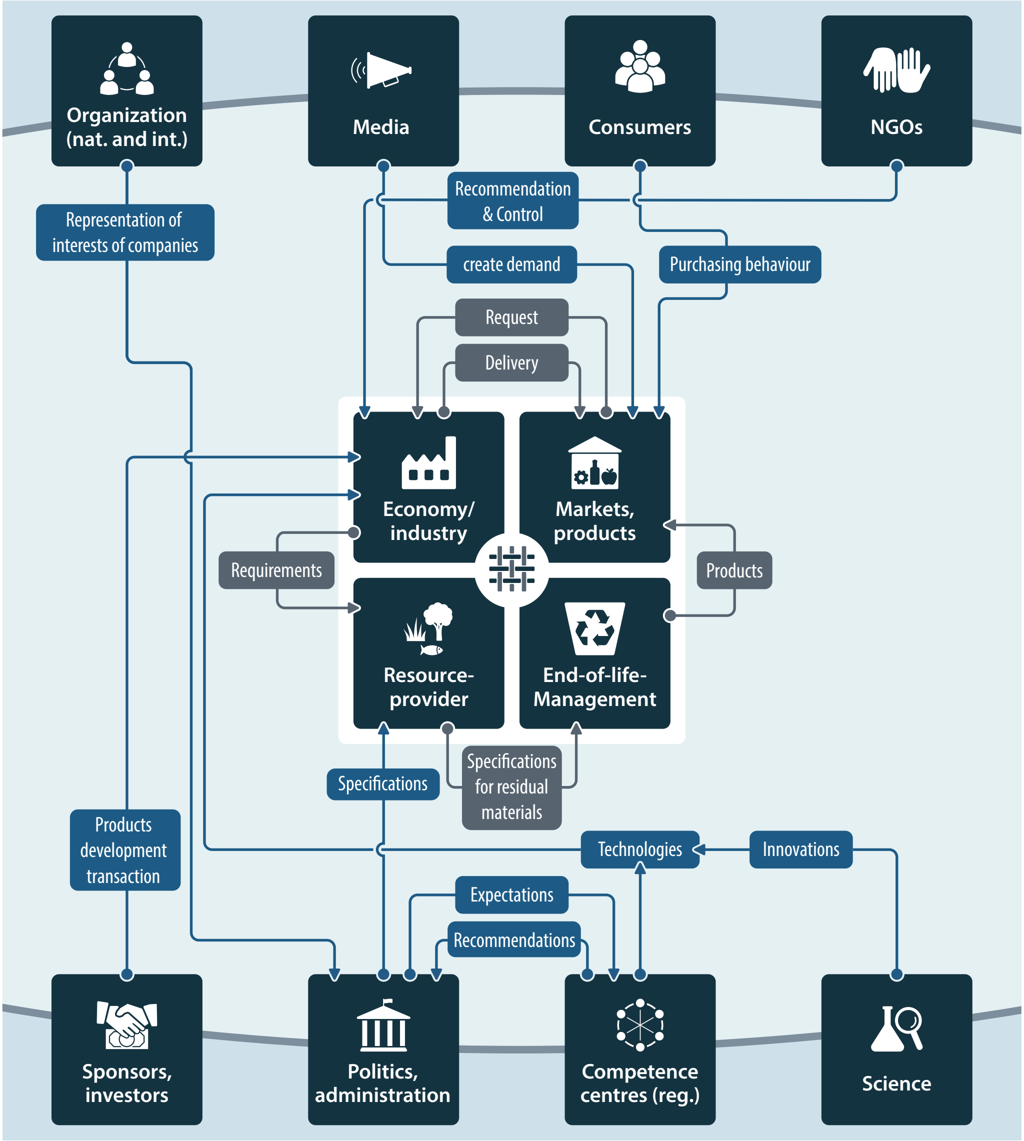
Marine Bioeconomy

Charli Kruse

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_7

7.1 Overview Graphic



Resource Provider

- Aquaculture operators in Germany are mainly small and medium-sized enterprises. They produce fish, crustaceans, mussels and algae, for example. Worldwide, they have been showing growth rates of approx. 6% for years.
- Bioreactor plants are operated by various biotechnology companies using both marine and other microorganisms and therefore cannot be categorized.

Economy/industry (examples)

- Food: Deutsche See GmbH, Sylter Algenfarm GmbH & Co. KG, Viva Maris GmbH
- Medical products: aktivmed GmbH, IVF Hartmann AG, M+W Dental, Kerecis
- Cosmetics: oceanBasis GmbH, Biomaris GmbH & Co. KG
- Fibres: smartfiber AG
- Biomolecules: ALGOPACK, Queisser Pharma GmbH & Co. KG

Markets, products (examples)

- Food: fish, crustaceans, shellfish, algae
- Medicine: wound dressings, dental impression compounds, medicines
- Cosmetics creams, oils, foams
- Consumer goods: fabrics, leather, plastics
- Environmental protection: e.g. the targeted cultivation of aquatic plants and articial reefs for coastal protection and biodiversity preservation

End-of-life-Management

The duration of the life cycle depends on the respective production systems:

- In aquaculture recirculation systems: stocking of the system → biomass propagation → fishing, harvesting, collection → processing to end product → end consumer → recirculation (biogas/organic nutrients).
- In bioreactors: Filling the reactor → biomass propagation → purification, concentration → processing to the final product → end user → return to the cycle (see above).

Organizations (nat. and int.)

- e.g.: BIO Deutschland e. V., Bundesverband Aquakultur e. V., SUBMARINER Network for Blue Growth EEIG

Media

- Print and online publications of the actors

Consumers

- Population and special users as listed

NGOs

- e.g.: DECHEMA e. V., Life Science Nord, ScanBalt BioRegion, environmental and consumer protection associations

Sponsors, investors

- R&D funding (EU, German Federation and The Länder), foundations

Politics, administration

- Federal and state research institutes, federal and state ministries

Competence centres (reg.)

- e.g.: Fraunhofer-Einrichtung für Marine Biotechnologie und Zelltechnik (FhG-EMB, Lübeck), mariCube - Kompetenzzentrum Blaue Biotechnologie

Science

- Universities, research institutions

Type of institution	**Institution**
Clusters and associations	BIO Deutschland e. V., BioCon Valley GmbH, Bundesverband Aquakultur e.V., DECHEMA e. V., Kompetenznetzwerk Aquakultur (KNAQ), SUBMARINER Network for Blue Growth EEIG, Life Science Nord Management GmbH
Science: Helmholtz Association	Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI), GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung GmbH, Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum (GFZ)
Science: universities and universities of applied sciences	Ernst-Moritz-Arndt-Universität Greifswald, Forschungs- und Entwicklungszentrum Fachhochschule Kiel GmbH, Hochschule für Technik und Wirtschaft des Saarlandes, Meeresbiologische Wattstation Carolinensiel der Universität Münster, Technische Universität Bergakademie Freiberg, Technische Universität Hamburg-Harburg, Universität Bremen, Universität Hamburg, Universität Oldenburg, Universität Rostock, Universität zu Kiel
Science: Federal and state institutions	Bundesamt für Seeschifffahrt und Hydrographie, Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Bundesanstalt für Gewässerkunde, Bundesanstalt für Wasserbau, Abteilung Küste (BAW-AK), Johann Heinrich von Thünen-Institut, Wehrtechnische Dienststelle für Schiffe und Marinewaffen der Bundeswehr, Maritime Technologie und Forschung, Landesforschungsanstalt für Landwirtschaft und Fischerei Mecklenburg-Vorpommern, Common Wadden Sea Secretariat
Science: Other institutions	Deutsche Gesellschaft für Meeresforschung, Deutsche Hydrographische Gesellschaft e. V., Deutscher Wetterdienst, Deutsches Klimarechenzentrum GmbH, Institut für Marine Biotechnologie e. V., Deutsches Institut für Lebensmitteltechnik e. V., Gemeinschaft zur Förderung von Pflanzeninnovation e. V., Gesellschaft für Marine Aquakultur (GMA) mbH, Institut für Fisch und Umwelt
Science: Fraunhofer Society	Fraunhofer-Einrichtung für Marine Biotechnologie und Zelltechnik (EMB), Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik (IGB), Fraunhofer-Institut für Molekularbiologie und Angewandte Oekologie (IME)
Science: Max-Planck-Society	Max-Planck-Institut für Marine Mikrobiologie (MPI-MM), Max-Planck-Institut für Meteorologie (MPI-M)
Science: Leibniz Association	Leibniz Institut DSMZ-Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, Leibniz-Institut für Ostseeforschung Warnemünde, Leibniz-Zentrum für Marine Tropenforschung (ZMT) GmbH, Senckenberg am Meer, Senckenberg Biodiversität und Klima Forschungszentrum
Industry – production	Sylter Algenfarm GmbH & Co.KG, algova UG, Aquacopa GmbH, Aquazosta GmbH, BlueBioTech GmbH, BromMarin GmbH, CRM – Coastal Research & Management GbR, CrustaNova GmbH, EURODUNA Rohstoffe GmbH, Evonik Industries AG, Förde Garnelen GmbH & Co. KG, FRESH Völklingen GmbH, Garnelen Farm Grevesmühlen GmbH & Co. KG, Garnelenhof Schäfer GmbH & Co. KG, Köster Marine Proteins GmbH, Marine Aquaculture Consulting, Microganic GmbH, neomar GmbH, oceanBASIS GmbH, Phytolutions GmbH, Polyplan GmbH Ingenieurbüro für Energie und Umwelttechnik, Ratz Aquakultur GmbH, Scherbrings Bio-Garnelen, Sea & Sun Technology GmbH, SeaKult - sustainable futures in the marine realm, SubCtech GmbH, Subitec GmbH, Union Agricole Holding AG, W42 Industrial Biotechnology GmbH, smartfiber AG, BIQ GbH, SSC GmbH, MINT-Engineering GmbH, Cara Royal, Sylter Algenfarm GmbH & Co. KG

7.2 System Description

7.2.1 Overview of Central Elements of the System

The **resource base** consists of renewable raw materials of marine origin, essentially multicellular organisms (fish, evertebrates, vascular plants, macroalgae), unicellular organisms and microorganisms. The **resources** are usually **provided** by the technical systems of aquaculture recirculation systems and bioreactors. The **main products of** the marine bioeconomy are food, medical products, ingredients for cosmetics, fibres (clothing and composite materials) and biomolecules, which are used in the following **markets**: Medicine (wound dressings, medicines), food (fish, evertebrates (mussels, crabs, etc.)), algae, food ingredients, consumer goods (detergents, alginate, agarose, etc.), and environmental protection (coastal protection, biodiversity conservation). The length of the **life cycle** depends on the products in question. In aquaculture recirculation systems, a life cycle mainly consists of the elements stocking of the system – biomass multiplication – fishing, harvesting, collection – processing into the final product – end user – return to the cycle. In bioreactors a life cycle is characterized by the elements filling of the reactor biomass multiplication – purification, concentration – processing to the final product – end user – return to the cycle. All biological residual waste, both from aquaculture recirculation systems and from bioreactors, can, provided they have not accumulated toxins, ultimately be returned to the biological cycle as fertilizer. The **system boundaries** that also determine the framework for action in the marine bioeconomy are, for example: the costs and technical challenges for land-based seawater plants, insufficient knowledge of the physiology and ecology of marine organisms, the need to develop new processes, enabling the use of natural systems under ecological constraints, and government support for the development of the marine bioeconomy.

7.2.1.1 The Main Elements in Detail

The marine bioeconomy is based on the **sustainable use of** marine biological resources and has developed noticeably over the past 15 years. Currently, many economically important goods and raw materials are already being extracted from the sea, where they are increasingly harvested according to ecological principles. Their uses range from foodstuffs (fish, molluscs, crustaceans, algae, etc.) to medical products (wound dressings, medicines, excipients) and ingredients for cosmetics (algae ingredients, collagen) to raw materials for various branches of industry (enzymes, fatty acids).

In addition, the marine ecosystem also provides us with **services** whose artificial replication would incur high costs (Gelpke, 2017) and whose sustainable support must be part of the future bioeconomy. These are often services that are not directly perceived but have a monetary value and must therefore be taken into account for a marine bioeconomy. A distinction is made between supporting, regulating, providing and cultural ecosystem services, the financial benefits of which are very complex and difficult to capture in their entirety (ibid.). For example, according to the Federal Ministry of Food and Agriculture, around €160 million has been spent annually on coastal protection alone. Without the support provided by biological processes (coastal and marine organisms), costs would continue to rise.

The production processes that currently still primarily consume resources are to be converted into cycles as part of the biologisation of the economy. The German government is currently working on a corresponding "bio-agenda". Biotechnological processes are needed for this sparing use of the biosphere (Zuber, 2009), as these are generally based on renewable raw materials, which are indispensable for a sustainable economy.

The use of marine biotechnology for marine bioeconomic production processes is very diverse. The products manufactured using this technology can be found in various sectors, which is why it is difficult to narrow down this area of the bioeconomy precisely. These industries include: Food industry, medicine, cosmetics industry, energy industry, material development, environmental protection, etc. At the same time, marine biotechnology is only just beginning to develop, so that its potential applications cannot yet be assessed. Although two-thirds of the earth's surface is covered by water, this is much less researched than the terrestrial areas of our planet. Nevertheless, it is generally assumed that many marine resources will be available for new biotechnological processes in the future (Fraunhofer, 2017; Stieber, 2015; Vondracek, 2012). The ERA-NET Marine Biotechnology[1] coordinates and promotes activities and developments in the field of marine biotechnology or bioeconomy at European level. Here, too, the focus is on the broad use of marine resources, from biomolecules of marine organisms to the complete use of organisms.

The above-mentioned provision of resources can take place via various biological agents (organisms, materials):

- multicellular organisms (fish, evertebrates, vascular plants, macroalgae)
- unicellular organisms
- Microorganisms (especially cyanobacteria)
- cell cultures isolated from the organisms
- biomolecules isolated from cells (for example enzymes with low temperature optima)

The **multicellular organisms** required are produced primarily in aquaculture facilities. In 2016, there were already 80 million tonnes with a value of US$ 232 billion, which corresponded to 47% of global fish production. These facilities can be located in open waters, in which case care must be taken to ensure that the surrounding ecosystem is not affected. The issue is thus the development of zero-emission plants, as called for in various policy papers (Haas et al., 2015).

In Iceland, the entire marine management system is being restructured according to bioeconomic principles. For example, before fishing, the stocks are assessed by independent institutes according to their resilience. Young fish are protected and algae are only harvested to the extent that they have regenerated by the next harvest. In addition, many initiatives are emerging that process the resulting waste into further products – such as the use of fish guts for oil and enzyme production, the production of chitosan from shrimp remains, or the use of algae fibers and ingredients for the clothing and cosmetics industries (BIOCOM AG, 2018; Guðfinnsson et al., 2007).

An alternative to this is land-based aquaculture recirculation systems (ibid.). These can be controlled, they can be set up close to the processing industry and the products are not affected by external influences. For profitable use of such plants, their products must be more widely used in the future. Possibilities for this are given in ◘ Fig. 7.1.

Another possibility of providing multicellular organisms is the targeted propagation and removal of algae from the environment. Especially in eutrophic waters, CO_2 as well as excess plant nutrients could be removed from the system and thus contribute to the health of the ecosystem. It goes without saying that these procedures are only possible under close observation of the respective ecosystem in order to prevent a negative influence.

Single-cell eukaryotic and prokaryotic organisms as well as cell cultures are mainly

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[1] For more information, see ► http://www.marinebiotech.eu

Products from fish	Products from algae
Fish meat	Seaweed dishes
Fishmeal	Alginate
Fish oil	Agar
Fish cell cultures	Food colourings/antioxidants
Wound dressings made from fish collagen	Textile fibres
Fish leather	Cosmetic ingredients

Fig. 7.1 For improved added value, a greater variety of products can be manufactured from aquaculture organisms through further processing

used in bioreactors. Here they are propagated and the products they produce, such as fatty acids, enzymes and other biomolecules, are separated from the *batches* used in special technical processes. In particular, the use of biomolecules from marine organisms suggests that there are still many possible applications. Currently, for example, fluorescent or luminescent proteins are used to visualize cellular structures. A typical example is the green fluorescent protein (GFP) from the jellyfish *Aequorea victoria.* However, the search for pharmacologically useful natural substances from the sea is particularly intensive.

The use of microalgae in bioreactors is mainly with limnic algae, although systems with marine species are already being developed (Vondracek, 2012). The use of algae from these photobioreactors is still in its infancy, with the primary use being for the production of biofuels and omega-3 fatty acids. Furthermore, they are used for house facades as air purifiers (CO_2 uptake) and subsequently fed to further recycling (for example BIQ GmbH, SSC GmbH, MINT-Engineering GmbH).

The use of both **unicellular and multicellular marine algae** for biotechnology has many other advantages. For example, they produce many useful products for pharmaceutical, cosmetic or food products. A new development is investigating the production and use of fibres from marine macroalgae for the clothing industry (see smartfiber AG and SeaCell) and as a plastic substitute (Hermann, 2013).

The duration of the life cycle of the required feedstocks depends on the respective production processes and utilizations, as described for the example of aquaculture recirculation systems and bioreactors.

Ideally, the life cycle of the end products described above should be closed, as the required raw materials and products are permanently reproduced due to the intended circular economy. The resulting residual materials are further processed in a cascade or, for example, return to the biological cycle as nutrients. In this context, it is important to ensure that the life cycles and cycles of different products manufactured from the same resources (e.g. consumer goods and food from fish) are harmonised in order to avoid pure waste products.

The problem is briefly explained in ◘ Fig. 7.2 using the example of a multitrophic plant containing fish, mussels, algae and microorganisms. An integrated multitrophic aquaculture system is described. The possible end products here are highlighted in grey in the lower white box. Since they all have different lifetimes, their production must be continuously coordinated for an ideal circular economy so that no waste is produced.

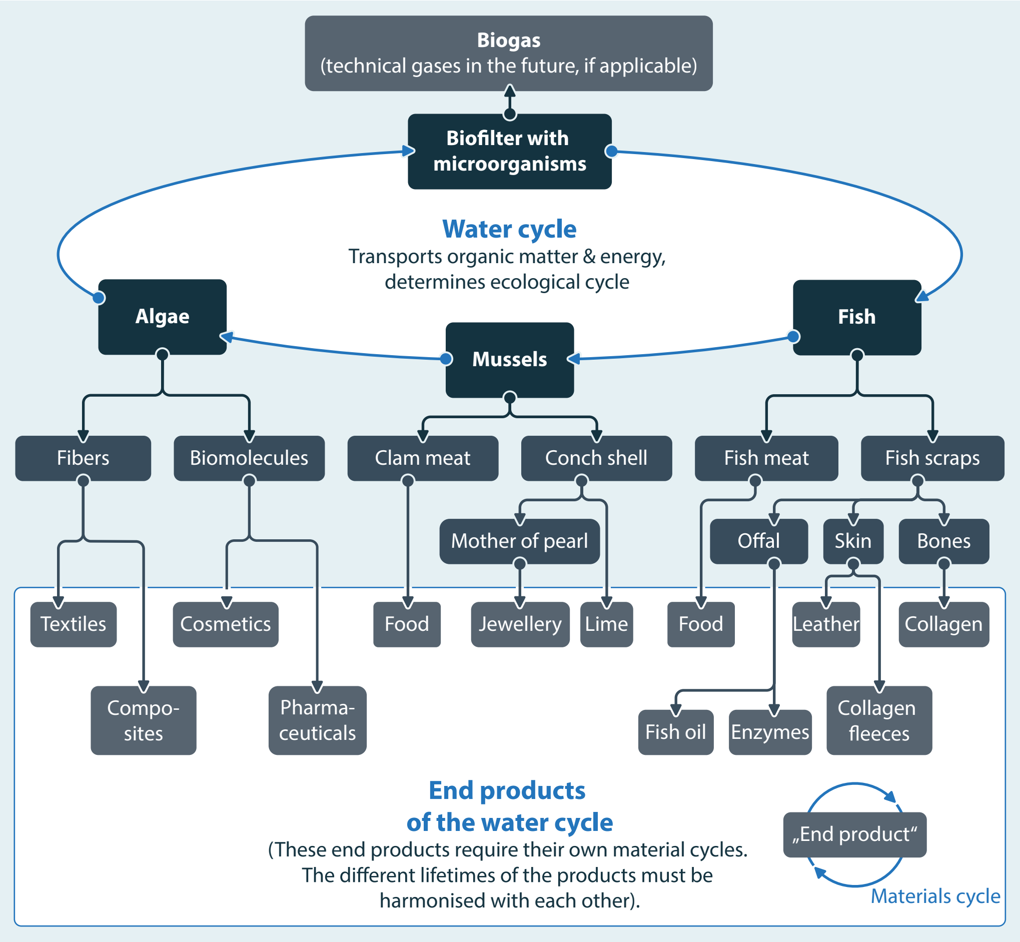

Fig. 7.2 Bioeconomic harmonization of the life cycles of various products in a cascade of production processes. (Source: Own representation)

So, for example, the fish produced can give rise to different products that have different life cycles. These are relatively short for food and collagen fleeces, while they are much longer for leather. For a perfect closed-loop system, these would have to be coordinated with each other. For example, in order not to flood the market with leather, other products have to be produced, such as collagen fleeces from the skin residues. On the other hand, more durable foodstuffs, such as canned fish, can ensure that the entire system is harmonised. This clearly shows how complex the problem of production in cycles is.

The most important players in the marine bioeconomy are summarised in the table in ▶ Sect. 7.1. Due to the explanation given that the area of the marine bioeconomy (biotechnology) is not reported separately, especially in larger companies, this compilation does not claim to be complete.

The limits of the marine bioeconomy currently arise primarily from the technical replication of the marine environment for the propagation of the required organisms in land-based aquaculture or bioreactor facilities – especially in those areas where the use of metals cannot be dispensed with. This primarily concerns measurement and control technology. Here, innovations must be supported that make it possible to operate these plants in the long term under salt water conditions without the instruments and equipment corroding. Plastics are increasingly being used instead of iron, with new biological plastics also being further developed in this area. The materials that are still required and are susceptible to corrosion must be protected to such an extent that corrosion is largely prevented in order to keep the investment costs of these plants as low as possible.

For aquaculture in open waters, zero-emission facilities are not yet available, so that there is still a risk of environmental pollution and damage to cultivated stocks. In some countries, however, intensive control and regulation measures have already brought them much closer to this goal. The main challenge is to prevent the input of nutrients into the environment and the exposure to pathogens from the existing environmental milieu. The second challenge is biofouling of the materials lying in the water. These have to be permanently cleaned, which leads to a burden on both the environment and the breeding organisms.

One of the greatest obstacles to the widespread introduction of marine breeding facilities, apart from the intensive training of operators, is the high cost of such facilities (Meyer et al., 2016), which is reflected in the products. This can be counteracted by reducing production costs on the one hand and increasing revenues on the other. To reduce costs, recirculation and aquaponics systems and, above all, integrated multi-trophic aquaculture systems (IMTA) must be intensively further developed and expanded. They allow the water to be used several times, for example for the parallel production of fish, mussels and algae. In this process, the water body undergoes additional purification from compartment to compartment, which reduces water consumption and lowers the water exchange rate. Aquaponics and recirculation systems are already being used commercially at present, although these are mainly small and medium-sized enterprises. Currently, the disposal of residual water is another cost factor. New solutions must be found for this, especially for desalination, so that the biofilter waste can then be disposed of in a conventional way, for example in biogas plants or as garden fertiliser. For the monitoring and control of the condition of the organisms used, more and more sensor-based automatic systems need to be developed and used in order to reduce costs due to losses and diseases also in this still very labour-intensive area (Stentiford et al., 2017). Finally, it is also imperative, especially for fish farming, to push the development of feeds that can avoid fishmeal from wild-caught fish (Davidson et al., 2016; Nagel et al., 2016; Michl et al. 2017). Plant proteins or evertebrates in particular are being investigated as substitutes, but cell cultures such as those used for the development of *in vitro meat* could also be used for this purpose.

The use of open waters, especially for algae harvesting, must be regulated and made possible under appropriate ecological precautions in order to remove excess biomass from the mostly eutrophic waters of the German coasts. This is already being practised in Iceland in an exemplary manner. To relieve the pressure on fish stocks in the open seas, it would also be necessary to designate defined areas for aquaculture. To this end, the development of integrated multitrophic systems must be accelerated to enable meaningful risk assessment and, as far as possible, zero-emission systems.

A basic prerequisite for the further development of the bioeconomy is government support for the development of appropriate production processes and for further research into marine organisms with a view to their biotechnological exploitation. After all, we can only use systems that we understand comprehensively – both at the biochemical-physiological and at the ecosystem level.

Furthermore, it is also a question of broad consumer education and information in order to reduce the scepticism that still exists in some cases about these new technologies and the products manufactured with them. To this end, a broad consensus should be established between producers and consumers in order to be able to react quickly to existing concerns, but also to needs.

7.3 Innovations

Crucial **technical innovations** in the marine bioeconomy are in the cultivation of aquaculture organisms from algae to fish. Only sustainable aquaculture can replace the removal of the requiredmarine organisms from the natural system. The development of land-based recirculating systems in particular is therefore making enormous progress. Fish, various evertebrates as well as macroalgae can now be produced in these. More and more development projects are being realized in which different organisms are kept together in IMTA facilities (Kleitou et al., 2018; Walker, 2016). In recent years, in addition to the expansion of offshore and nearshore aquaculture facilities, we have seen the development of autonomous, free-floating cage facilities that seek to circumvent the problem of localized concentration of organic matter and mimic the natural dispersal of organisms.[2]

The first bioreactors for the propagation of plant or animal single cells are also already being tested. These enable the production of specific cell types and the desired biomolecules they produce.

Many new ideas have also been implemented in the field of **product development**. For example, more and more algae are being used to produce fatty acids and oils, primarily food additives such as alginate, agar-agar or carrageenan, but also biofuels (Puri, 2017; Wibawa et al., 2018). The cellulose fractions of algae are used to develop fibers that are already used for textiles with particularly good skin-compatible properties.[3] The use of such fibres for composite materials is also currently being discussed.

At the Fraunhofer Research Institution for Marine Biotechnology and Cell Engineering, fish cells are being tested for their economic use (Rakers et al., 2010, 2011, 2014). A broad potential for the use of these cells is being tested. For example, fish cells can be used for the production of fish viruses such as the koi herpes virus and thus contribute to the production of vaccines. Furthermore, they can be used for the production of high-quality biomolecules such as enzymes, fatty acids and proteins that are rich in essential amino acids. It is also conceivable to use them for the production of fish cell meal as a substitute for fish meal or directly as food (for example finless foods). Further examples of the different uses of algae and fish are shown in ◘ Fig. 7.1. In addition to new pharmaceuticals, cosmetics and foodstuffs, activatable biomolecules such as marine enzymes will also gain in importance in the future, as these generally have a lower temperature optimum than those of terrestrial organisms. This can reduce energy costs for many industrial processes (Vondracek, 2012).

Marine molecules that are already being used include luminescent proteins or toxins from jellyfish and marine snails (*Aequorea victoria* and *Conus magus,* respectively), which have opened up completely new markets. Organisms in the sea have been able to

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[2] For more information, see ► https://www.innova-sea.com/

[3] For more information, see ► http://www.smartfiber.de/home/

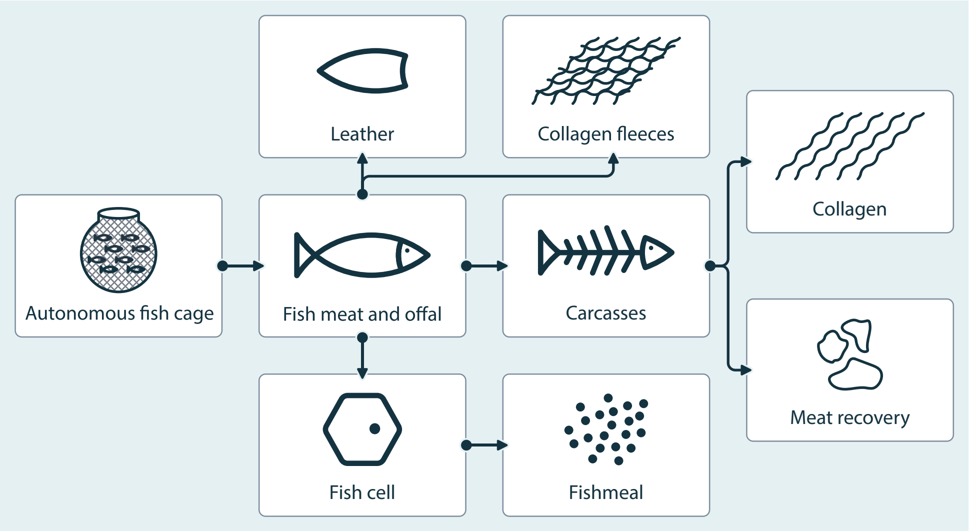

Fig. 7.3 Share Current innovations in fish production and processing. (Source: Own representation)

adapt to their ecological niches for many millions of years longer than terrestrial organisms, so that many new discoveries can be expected from marine research in the coming years. These could include, for example, biomolecules with technologically useful properties, the enrichment of rare substances in the sea by marine organisms, and the neutralization of harmful substances by marine microorganisms (Yakimov et al., 2007).

In the area of **production process innovation,** it is expected that integrated multitrophic marine aquaculture facilities on land will be developed to the point where they are profitable to manage. New bioreactors for fish cells should make it possible to industrially produce cell-based affordable food, so-called *in vitro meat*. This task will be solved in the next ten years, as the provision of high-quality protein will be essential for feeding humanity. Already, this development is moving from academia to industry (for example, Finless Foods). Recent market analyses predict corresponding developments in this new segment of food production, such as those by MarketsandMarkets.[4] Some of these innovations in the fish processing industry are shown in ◘ Fig. 7.3.

As a prerequisite for future innovations, it is necessary to conduct further and more in-depth research into the marine ecosystem, particularly in order to better understand the diverse ecological, physiological, molecular biological and biochemical processes. This will make it possible to make new organisms or products from known organisms usable for industry. Innovations in the public sector are to be welcomed here. Both the German government and the European Union have created new funding opportunities specifically for the area of the marine bioeconomy, for example the programmes “New biotechnological processes based on marine resources – BioProMare” and the ERA-NET Marine Biotechnology.

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[4] For more information, see ► https://www.marketsandmarkets.com/Market-Reports/cultured-meat-market-204524444.html

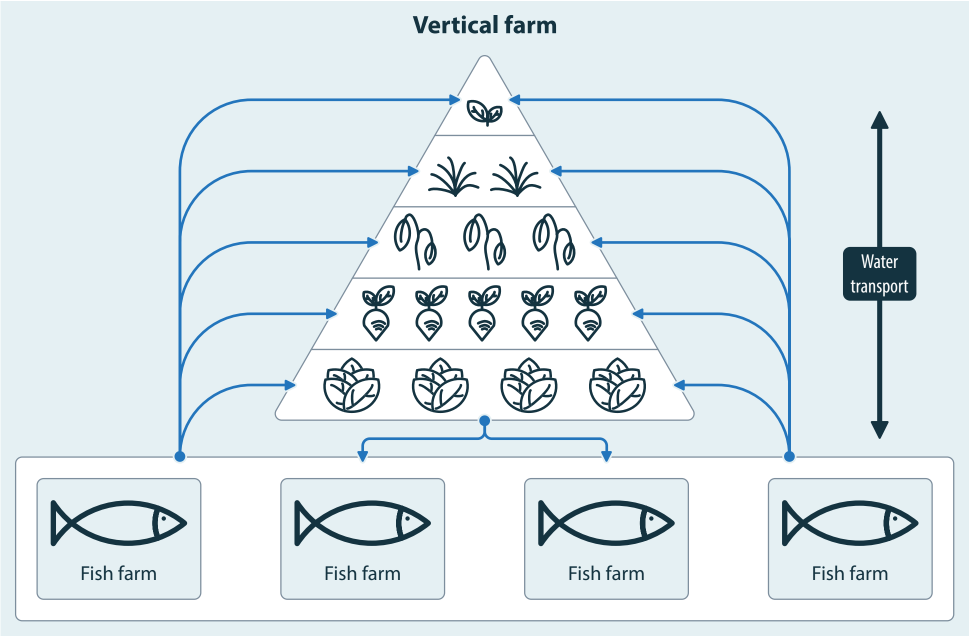

Fig. 7.4 Schematic representation of linking peri-urban vertical plant farms with recirculating aquaculture systems. (Source: Own representation)

7.4 Images of the Future

According to the Biotechnology Report 2004 published by the auditing firm Ernst & Young, marine or blue biotechnology accounts for only 1% of the biotechnologies used to date, which is significantly underrepresented in relationto limnic and terrestrial species compared with marine biodiversity. It is therefore generally assumed that marine biotechnology will become considerably more important as the basis for a marine bioeconomy in the coming years.

7.4.1 Complex Aquaculture Facilities

The largest growth is likely to be in the food economy. The gap between the demand for marine food and the available resources is widening (Chomo & De Young, 2015). This is the reason why the development of aquaculture facilities is ever increasing. In this regard, **facilities in open waters are** constantly faced with the challenge that they must not affect the ecosystem. Therefore, considerable efforts are being made to make land-based facilities more economically effective. In the limnic area, various pilot plants already exist that combine fish and plant cultivation, for example.[5] In the future, it will make sense to combine these with *verticallurban farming complexes* (Fig. 7.4). Something similar will also develop for marine facilities, as the demand for marine organisms is constantly growing (Richter & Betz, 2011). According to Wirtschaftswoche on 5 September 2018, in Germany alone, 2.6% more was spent on fish and seafood at retail in 2017 compared to the previous year

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[5] For more information, see ► www.fish-for-life.org; ► http://bundesverband-aquaponik.de/; ► https://www.igb-berlin.de/kloas

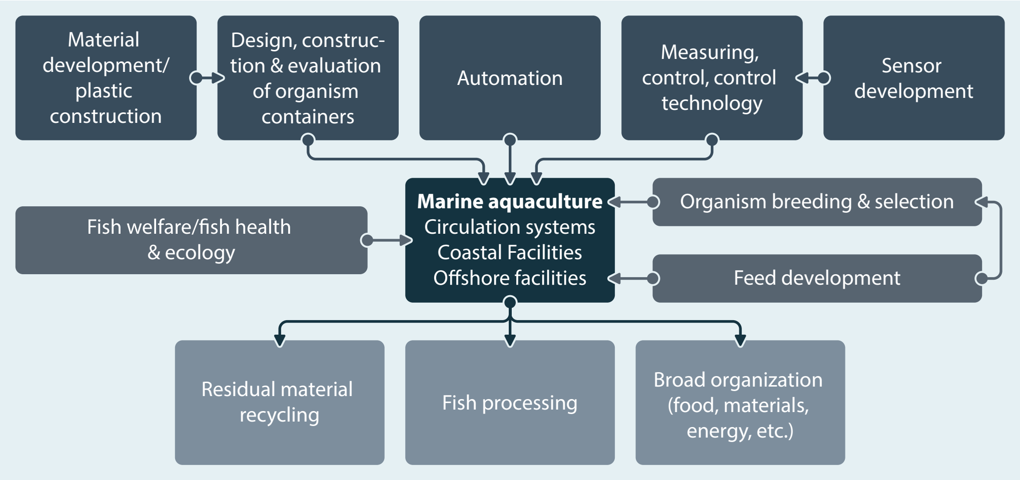

Fig. 7.5 Opportunities for adding value to the production and operation of modern aquaculture systems. (Source: Own representation)

(€3.9 billion). The average retail price for fish and fish products increased by 3.8% overall. German retailers sold around 413,500 t of fish and seafood in 2017, which was 0.7% more than in the previous year.

As shown in Fig. 7.4, in a vertical plant and fish farm, the nutrient-rich water from the fish water is used to irrigate and fertilize the plants and can thus be pre-clarified again more easily for use in the fish tank. Through such plants, food production can be brought closer to the cities, which saves long transport distances. In addition, valuable arable land is not required.

Combined **land-based systems** must be developed to relieve the pressure on open waters. In addition to the production of food from the various trophic levels (fish, mussels, algae, etc.), other organisms can also be included in these cycles in the future, for example to produce industrially usable biomolecules. Here, too, a combination with *vertical farming areas* would be desirable. However, this would require the cultivation of salt-resistant plants or the development of new desalination plants. This will be an essential prerequisite for a broad, sustainable establishment of the marine bioeconomy. The economic sectors to be involved in this process are very diverse, ranging from materials development to plastics engineering, measurement and control technology, the food industry and medicine (Fig. 7.5).

The still high costs are the decisive point of criticism of corresponding plants. Nevertheless, there are many efforts to make further progress in this field. Some successful approaches are already being developed (Meeresfischzucht Völklingen, Cara Royal, Sylter Algenfarm GmbH & Co. KG etc.). In addition, there is criticism that there is still too little meaningful data on integrated multitrophic aquaculture systems. Particularly in the area of studies of the species to be associated, little is known, although appropriate assumptions can be made for this from the known ecosystems.

7.4.2 Macroalgae Use

The use of macroalgae will also take on a new dimension. Ecologically accompanied cultivation of macroalgae in open waters can counteract the eutrophication of waters and the increase in CO_2. This means that, on the one hand, excess plant nutrients such as phosphorus and nitrogen compounds as well as carbon dioxide are absorbed and, at the same time, important products are generated for various branches of industry (food industry, cosmetics, pharmacology, materials industry) (Walter o. D., 2018). This form of marine use still meets with resistance in some quarters, as there are fears that it will have an impact on the marine ecosystem. A social consensus must be achieved here by informing consumers about the ecological benefits of this type of marine management. This is the only way to generate broad acceptance for appropriately manufactured products, which is essential for their sale. In Iceland, this is already being practiced in an exemplary manner, as described, for example, for the production of SeaCell™MT fibre.

The marginal seas are already heavily influenced by humans, and the input of plant fertilizers from agriculture in particular will be unavoidable in the coming years. Every effort should therefore be made to keep lasting changes to a minimum. Careful surface harvesting of the algae would be the method of choice. Nevertheless, it is imperative to carry out appropriate investigations beforehand with regard to possible negative effects on the environment.

One source of raw material that is still unexploited is the beach flotsam or driftwood that accumulates on the beaches every year. Various studies have already been carried out on its use, either as insulation material or as animal feed (see “POSIMA” project). Unfortunately, these studies have so far only been able to clarify partial aspects of the use. Further extensive research would also be necessary in this area. For example, large quantities of seaweed are washed up on the beaches, especially in autumn, and it has very good properties as an insulating material, as it burns poorly and is resistant to mould and vermin (see, for example, the seaweed trade).

7.4.3 Microalgae Use

In recent years, the use of microalgae for the production of biodiesel has also been discussed time and again (Irmer, 2015). Here, too, there are various efforts on the part of both industry and public agencies to identify new possibilities. As a rule, however, these are limnic algae species and only rarely marine species. For the latter case, the various photobioreactors already available need to be adapted to marine systems, mainly in terms of material resistance and salt disposal. The problem of fuel production from algae is discussed very controversially. On the one hand, propagation in photobioreactors, which are relatively easy to produce, is an enormous advantage over the production of biodiesel via land plants. On the other hand, studies have been conducted that show useful fuel production for energy purposes to be unfeasible at present (LaMonica, 2014). Many more studies are certainly needed to enable the appropriate use of microalgae. Whether such a use of marine species as an alternative to limnic algae represents an advantage is rather questionable.

7.4.4 Further Research Approaches

Many new ideas deal with the possibility of using marine organisms for the concentration of rare substances in seawater. For example, snails (Chrysomallon squamiferum) from the deep sea are known to coat their feet with iron sulphite, or microorganisms that can accumulate gold in themselves (Kashefi et al., 2001). However, a great deal of basic research is still required before these properties can one day be used biotechnologically.

An essential prerequisite for this will be that the aquaculture or bioreactor systems required for this are marketable. But the more stringent the ecological requirements for the operation of aquacultures in open waters become worldwide, the more attractive land-based systems become. The advantage of these systems is that they are permanently and comprehensively monitored. In addition, other organisms can be kept in the cycle, which produce highly complex biomolecules, for example. These can be used in the pharmaceutical and cosmetics industries. The even greater use of polymerisable molecules or plant fibres for clothing materials or composite materials is also currently being investigated (Redaktion Pflanzenforschung, 2010). In the future, the marine bioeconomy will take place both on land and in open waters. We will use the sea gently and sustainably, similar to what is currently being done in Iceland. But all production processes that can be economically successful on land will also move there. Aquacultures in open waters will only have a future if they can prevent the emission of substances and organisms and avoid exposure to pathogens. In any case, they must fit into the surrounding system.

7.5 Conflicting Objectives

7.5.1 Economic Trade-Offs

As long as there is a market for cheap products that are not produced sustainably – i.e. not according to bioeconomic rules – a circular economy will not prevail in this sector either. In order to achieve this, (a) real alternatives to conventional products must be offered and (b) products must be available at competitive prices. To this end, the necessary framework conditions are still lacking in some cases, such as the development of new production processes or tax relief for such innovatively working companies. The new tax incentives for research, also for small and medium-sized enterprises, are in any case a step in the right direction.

7.5.2 Ecological Trade-Offs

Conservationist nature protection often prevents the economic use of biological resources. Concepts are still lacking that allow areas to be managed in a sustainable manner while still preserving biodiversity. Possibilities for this were discussed in the previous chapters. At present, too many products are still being removed from the ecosystem without appropriate restocking measures. Compensation through sufficient land-based aquaculture facilities is also lacking. Another major challenge is to secure the already possible, gentle marine use in the area of algae harvesting by law and thus to enable this work to become attractive for operators of such facilities. This requires, on the one hand, a broad-based social education process about opportunities and risks, and, on the other hand, the creation of framework conditions that offer the highest possible security – both for the ecosystem and for the managers.

7.5.3 Technical Conflicts of Interest

The development of facilities for both different approaches to the economic production of marine fish on land and zero-emission facilities in open waters is still at a relatively early stage, so that these do not yet represent a real alternative to the conventional production of marine organisms.

The situation is similar with the development of bioreactors for the propagation of animal and plant single cells. The existing approaches have so far been available mainly on a laboratory scale and some of them cannot yet be used profitably. There is still a lack of corresponding economic commitment to operate such facilities on a large scale. The greatest technical challenge will be the handling of saline water in land-based aquaculture facilities. The solution to this lies in technically feasible and cost-effective recovery plants, so that recirculation plants are also the means of choice for this.

7.5.4 Conflicting Scientific Objectives

One of the main obstacles to the greater development of the marine bioeconomy is the still insufficient knowledge we have about the biological processes in the marine habitat. This ranges from ecological relationships to molecular and biochemical processes. This requires broad-based basic research, flanked by parallel investigations into possible applications.

The companies interested in this are still not sufficiently networked with the corresponding research institutions, which could be achieved, for example, through tax relief for the necessary research and development work. An effective innovation and funding framework designed for this purpose is currently still lacking.

7.5.5 Conflicting Objectives on the Consumer Side

On the consumer side, there is widespread scepticism towards biotechnological processes and the products manufactured with them. There is a lack of broad-based education here that explains the basics, possibilities, but also risks of these technologies and thus increases consumer acceptance. A marine bioeconomy can only be successful if it is of economic interest and can operate profitably.

References

BIOCOM AG Berlin. (2018). Bioökonomie.DE – Island. https://biooekonomie.de/island. Accessed 23 January, 2020.

Chomo, V., & De Young, C. (2015). *Towards sustainable fish food and trade in the face of climate change*. Fisheries biores. https://www.ictsd.org/bridges-news/biores/news/towards-sustainable-fish-food-and-trade-in-the-face-of-climate-change. Accessed 15 March, 2018.

Davidson, F., Barrows, F. T., Kenney, P. B., Good, C., Schroyer, K., & Summerfelt, S. T. (2016). Effects of feeding a fishmeal-free versus a fishmeal-based diet onpost-smolt Atlantic salmon Salmo salar performance, water quality and waste production in recirculation aquaculture systems. *Aquacultural Engineering*. https://doi.org/10.1016/j.aquaeng.2016.05.004

Fraunhofer VLS. (Hrsg.). (2017). *Blue biotechnology – Start into a new dimension*. https://www.lifesciences.fraunhofer.de/content/dam/vls/en/documents/Blue_Biotechnology.pdf. Accessed 28 December, 2018.

Gelpke, N. (Hrsg.). (2017). *World Ocean Review – Band 5 Die Küsten – ein wertvoller Lebensraum unter Druck. Kapitel 02 Mit den Küsten leben und Kapitel 04 Küsten besser schützen*. https://worldoceanreview.com. Accessed 15 March, 2018.

Guðfinnsson, E. K., Sigurjónsson, J., Ásgeirsson, Þ., & Bjarnason, P. (2007). *Erklärung über verantwortliche Meeresfischerei in Island*. https://www.responsiblefisheries.is/media/1/statement_on_responsible-fisheries_de.pdf. Accessed 23 January, 2020.

Haas, S., Rößner, Y., Schröder, J., Bronnmann, J., Jooss, F., Loy, J.P., & Schulz, C. (2015). Konzeptionierung einer umweltverträglichen, marinen Aquakultur in Schleswig-Holsteinischen Ostseeküstengewässern. Abschlussbericht. https://www.schleswig-holstein.de/DE/Fachinhalte/F/fischerei/Downloads/KonzeptstudieUmweltvertraeglicheAquakultur.pdf?__blob=publicationFile&v=3. Accessed 14 March, 2018.

Hermann, L. (2013). *Algenzucht liefert Rohstoff für umweltfreundlichen Kunststoff*. https://www.vdi--nachrichten.com/Technik-Wirtschaft/Algenzucht-liefert-Rohstoff-fuer-umweltfreundlichen-Kunststoff. Accessed 28 December, 2018.

Irmer, J. (2015). *Bioenergie. Mit Algensprit ans Ziel*. http://www.spektrum.de/news/energiewende-mit-algen-zu-sauberer-energie/1352317. Accessed 15 March, 2018.

Kashefi, K., Tor, J. M., Nevin, K. P., & Lovley, D. R. (2001). Reductive precipitation of gold by dissimilatory Fe(III)-reducing bacteria and archaea. *Applied and Environmental Microbiology*. https://doi.org/10.1128/AEM.67.7.3275-3279.2001

Kleitou, P., Kletou, D., & David, J. (2018). Is Europe ready for integrated multi-trophic aquaculture? *A survey on the perspectives of European farmers and* *scientists with IMTA experience.* https://doi.org/10.1016/j.aquaculture.2018.02.035

LaMonica, M. (2014). *Der geplatzte Traum vom Mikrobensprit*. Technology review. https://www.heise.de/tr/artikel/Der-geplatzte-Traum-vom-Mikrobensprit-2109860.html. Accessed 15 March, 2018.

Meyer, S.,Griese, M.,Schlachter, M., Gehlert, G., & Schulz, C. (2016). *Konzeptstudie zur Nutzung der Synergieeffekte zwischen Industrieparks und Ernährungswirtschaft insbesondere der Aquakultur in der Region Unterelbe*. http://www.knaq-sh.de/fileadmin/daten/dateien/KNAQ/DE/Konzeptstudie_Aquakultur_Unterelbe_final_.pdf. Accessed 15 March, 2018.

Nagel, F., Appel, T., Rohde, C., Kroeckel, S., & Schulz, C. (2016). Blue mussel protein concentrate versus prime fish meal protein as a dietary attractant for turbot (Psetta maxima L.) given rapeseed protein-based diets. *Journal of Aquaculture Research and Development*. https://doi.org/10.4172/2155-9546.s2-012

Puri, M. (2017). Algal biotechnology for pursuing omega-3 fatty acid (bioactive) production. *Engineering*. https://doi.org/10.1071/ma17036

Rakers, S., Gebert, M., Uppalapati, S., Meyer, W., Maderson, P., Sell, A. F., Kruse, C., & Paus, R. (2010). Fish matters‘: The relevance of fish skin biology to investigative dermatology. *Experimental Dermatology*. https://doi.org/10.1111/j.1600-0625.2009.01059.x

Rakers, S., Imse, F., & Gebert, M. (2014). Real-time cell analysis: Sensitivity of different vertebrate cell cultures to copper sulfate measured by xCELLigence®. *Ecotoxicology*. https://doi.org/10.1007/s10646-014-1279-6

Rakers, S., Klinger, M., Kruse, C., & Gebert, M. (2011). Pros and cons of fish skin cells in culture: Long-term full skin and short-term scale cell culture from rainbow trout, Oncorhynchus mykiss. *European Journal of Cell Biology*. https://doi.org/10.1016/j.ejcb.2011.08.0032011

Redaktion Pflanzenforschung. (2010). *Rohstoffe aus dem Wasser*. http://www.pflanzenforschung.de/de/journal/journalbeitrage/rohstoffe-aus-dem-wasser-1078. Accessed 15 March, 2018.

Richter, F.J., & Betz, M. (2011). *Fischkonsum und Nachhaltigkeit*. http://www.fischinfo.de/images/broschueren/pdf/ZB_Fische_RZ_web_Final.pdf. Accessed 15 March, 2018.

Stentiford, G. D., Sritunyalucksana, K., Flegel, T. W., Williams, B. A. P., Withyachumnarnkul, B., Itsathitphaisarn, O., & Bass, D. (2017). New paradigms to help solve the global aquaculture disease crisis. *PLoS Pathogens, 13*. https://doi.org/10.1371/journal.ppat.1006160

Stieber, R. (2015). *Marine Biotechnologie: Neues aus dem Meer*. GIT-Labor – Portal für Anwender in Wissenschaft und Industrie. http://www.git-labor.de/forschung/lebensmittel/marine-biotechnologie-neues-aus-dem-meer. Accessed 14 March, 2018.

Vondracek, I. (2012). *Marine Biotechnologie: Ungeahnte Hoffnungsträger aus der blauen Tiefe*. Gesundheitsindustrie BW. https://www.gesundheitsindustrie-bw.de/de/fachbeitrag/dossier/marine-biotechnologie-ungeahnte-hoffnungstraeger-aus-der-blauen-tiefe/. Accessed 15 March, 2018.

Walker, T. (2016). *Prototype land-based IMTA system combines best of two concepts*. Aquaculture North America. https://www.aquaculturenorthamerica.com/research/prototype-land-based-imta-system-combines-best-of-two-concep-1123. Accessed 15 March, 2018.

Walter, T. (o. D.). *Makroalgen – Wirkstoffe und Potenziale*. http://fileserver.futureocean.org/wissenstransfer/thorsten-walter.pdf. Accessed 15 March, 2018.

Wibawa, D. S., Nasution, M. A., Noguchi, R., Ahamed, T., Demura, M., & Watanabe, M. M. (2018). Microalgae oil production: A downstream approach to energy requirements for the minamisoma pilot plant. *Energies*. https://doi.org/10.3390/en11030521

Yakimov, M. M., Timmis, K. N., & Golyshin, P. N. (2007). Obligate oil-degrading marine bacteria. *Current Opinion in Biotechnology*. https://doi.org/10.1016/j.copbio.2007.04.006

Zuber, P. (2009). *Innovationsmanagement in der Biotechnologie. Nachhaltigkeit als Leitbild einer entwicklungsbegleitenden Evaluierung*. Springer Gabler.

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Waste and Residue-Based Bioeconomy

Andrea Schüch and Christiane Hennig

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_8

8.1 Introduction

> The guiding principle of the bioeconomy is the development of a circular economy that enables the best possible recycling and multiple use of raw materials and material flows – including across sectors – in the interests of resource efficiency and sustainability (BMBF, 2014, p. 6).

Biogenic waste and residues do not compete with food or feed production. In addition, the risks to ecosystems and food security associated with their use are much lower than for forest wood residues and agricultural biomass, which is why biogenic residues and waste materials in particular should be used to provide bioenergy (Acatech et al., 2019).The use of biogenic wastes and residues is very important for a sustainable bioeconomy for the reasons mentioned above. The focus of this chapter is on the classification, current status and function of biogenic wastes and residues, as well as conflicting goals in their use.

8.2 System Description

In the waste- and residue-based bioeconomy, various groups of actors are interrelated. These are outlined in simplified form in ◘ Fig. 8.1. In order to better understand the interrelationships, some important terms are defined below, actors and their responsibilities are described, and the legal framework is explained.

According to the legal definition, waste is any substance or object which its owner discards, intends to discard or is required to discard, cf. §3 section 1 of the Circular Economy Act (KrWG, 2012). This also applies to biogenic waste. According to §3 Section 1 of the KrWG, biogenic waste includes

> biodegradable waste, animal or fungal garden and park waste, landscaping waste, food and kitchen waste from households, restaurants and catering, retail and similar waste from food processing plants, and waste from other sources […] insofar as it is comparable to the waste mentioned above.

The Biowaste Ordinance (BioAbfV, 1998) defines biogenic waste even more precisely by means of lists of substances and declarations. According to this, biogenic waste is produced by consumers in households, in municipalities during the maintenance of green spaces, during the processing of biomass in industry, but also on markets. Waste wood is also a biogenic waste insofar as it is subject to §3 Section 1 KrWG. The Waste Wood Ordinance (AltholzV, 2002) distinguishes between industrial waste wood and used wood, whereby the latter must have a wood content of more than 50%.[1] Industrial waste wood accumulates in wood processing companies, used wood is usually collected with the bulky waste collection in the municipalities. Another important biogenic waste is sewage sludge, which is produced in households and food processing and accumulates in sewage treatment plants. According to the legal definition, residues or by-products are not waste. So-called by-products arise alongside the cultivation of biomass, for example straw in the production of grain, residues alongside the main products during production processes, for example sawdust in the production of wood products. If a residual material or by-product is reused, marketed (for example sawdust) or used for the production of other products, it is to be classified as a by-product (§4 KrWG). For example, residual wood that accumulates as a by-product is not

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[1] In terms of mass or weight.

waste wood. This applies, among other things, to uncontaminated residual wood or sawdust from wood processing or forest residual wood that accumulates during thinning. According to the German Biowaste Ordinance (BioAbfV, 1998), plant residues that accumulate on forestry or agricultural land and remain on this land are not biowaste. This applies, for example, to substances such as straw, manure or slurry that are used to maintain the organic soil substance on the fields.

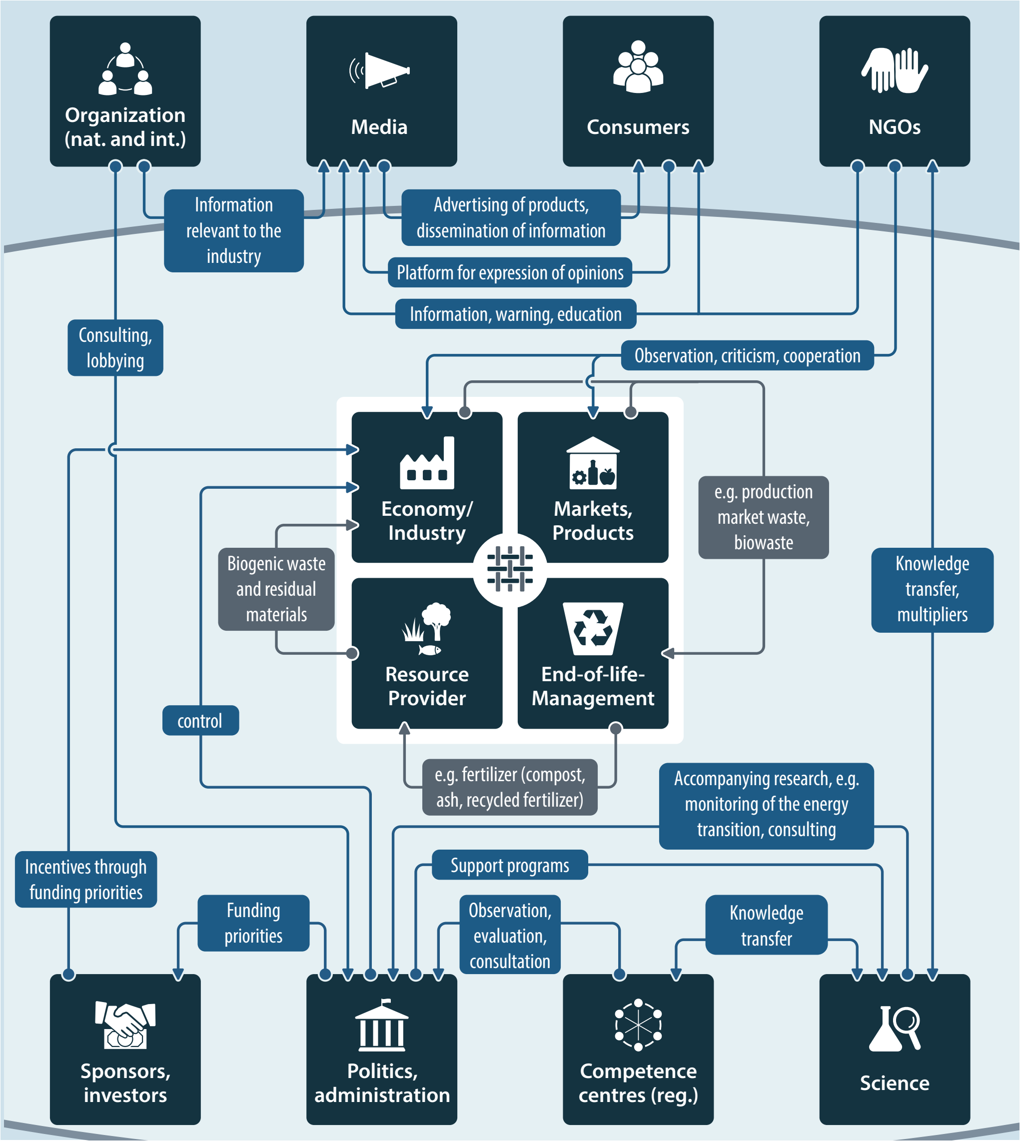

Fig. 8.1 Interaction of the groups of actors in a waste- and residue-based bioeconomy (highly simplified). (Source: Own representation)

Resource provider

- Biomass from agriculture, forestry, fisheries, horticulture, landscape management, etc., e.g. manure and slurry, straw, forest residues, landscape management material

Economy/industry

- Food and wood processing industries, biofuel producers and others,e.g. Unilever, Danone, Kellogg's, Ecomotion, Verbio...

Markets, products

- Food, bio-based non-food products such as furniture, cosmetics, building materials, energy

End-of-life-Management

- Public waste management authorities, commercial waste collectors and recyclers, etc., takes place e.g. in waste fermentation and composting plants, biomass cogeneration plants.

Organizations (nat. and int.)

- e.g. BBE, AEE, DGAW, Gütegemeinschaft Kompost, Bauernverband, Fachverband Biogas ...

Media

- Advertising, news and reports on TV, internet, social media, daily newspapers; articles in trade journals

Consumers

- are at the same time consumers of goods, waste producers and partly recyclers, are strongly influenced by the media

NGOs

- e.g. Deutscher Naturschutzring (DNR) Umbrella organisation of German nature, animal and environmental protection organisations, environmental and consumer protection associations

Sponsors, investors

- Federal programmes e.g. ZIM State funding agencies, banks, project management agencies e.g. FNR, PtJ

Politics, administration

- Federal ministries such as BMUV, BMWK, BMEL, BMBF and state ministries and offices e.g. LUNG, StÄLU

Competence centres (reg.)

- e.g. Biowaste Competence Centre of the Baden Württenberg State Institute for the Environment or 3N Competence Centre e.V.

Science

- Universities, colleges, research institutions, research departments in business and industry

Fig. 8.1 (continued)

A substance is no longer to be classified as waste (end of waste status) as soon as it has been classified as it

> has undergone recovery operations and is of such a nature that it will be used for specified purposes, there is a market for it or demand for it, it meets all technical requirements applicable to its intended use and all legal requirements and applicable standards for products, and its use, taken as a whole, does not give rise to harmful effects on human health or the environment.

This is relevant inasmuch as the bioeconomy is geared in particular to the extension of value chains through cascade use and the combined material and energy use of biogenic resources. ◘ Figure 8.2 provides an overview of the types of biomass used to produce the energy products electricity, heat and fuels. It becomes clear that biogenic residues and waste materials are used in a very wide range of bioenergy technologies and can provide renewable energies in all sectors (waste and residues are mentioned as examples).

Residual and waste materials are subject to differentiated material flows during energy and material use. In a bioeconomically oriented economy, biomass flows that occur in large quantities, are single-variety and/or have value-giving properties and constituents, such as high contents of sugar, fat or lignin, are of particular importance. Currently, 10.3 million t of biowaste are collected separately per year in Germany's households, approximately half of that is collected in the bio bin (Biogut) and collect systems for garden and park waste, so-called green waste (Destatis, 2018, reference year 2017). Since 2015, this biowaste is to be collected nationwide, on the one hand to reduce the organic content in residual waste, and on the other hand to make it usable as a valuable resource. The collected amount of biowaste increased slightly in recent years (Destatis, 2018; BMU, 2018). According to Brosowski et al. (2019), the technical potential of biogenic municipal waste (including, among others, the organic fraction of residual waste, market waste, commercial food waste, sewage sludge) is between 26 and 44 million t dry matter. Due to the continued expansion of collection, the amount of biowaste is expected to continue to increase. Biowaste is treated in composting plants or combined with anaerobic digestion plants and used as compost or digestate mainly in agriculture (Schneider et al., 2018; Ewens, 2018). Sewage sludge, with 1.8 million t dry matter, is produced in smaller quantities compared to biowaste, but contains appreciable amounts of limited available phosphorus, the recycling of which is becoming increasingly important for sustainable agricultural production (Roskosch et al., 2018).

Industrial residues accrue with approx. 15 million t dry matter (technical potential, Brosowski et al., 2019) and are already largely used. However, there is potential for higher-value and/or more efficient use in the sense of the bioeconomy.

As can be seen in ◘ Fig. 8.3, the amount of biogenic residues produced in agriculture, such as straw as a by-product, manure, slurry, etc., is very large at between 16 and almost 35 million t of dry matter per year (technical potential, Brosowski et al., 2019). These biomasses are currently used in animal husbandry (straw) and finally as organic fertilizers, although significant quantities are still available for energy and material related uses (up to 26 million t dry matter per year), taking into account nature conservation and sustainability aspects (Brosowski et al., 2019). Wood and forestry residues also have a large technical potential, with a maximum of 36.6 million t dry matter per year. Although the material and energy use of woody residues is very well developed, there is also significant untapped potential here (up to 10.9 million t dry mass or approx. 200 PJ[2]) (Brosowski et al., 2019).

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[2] PJ = Petajoule; measure for energy.

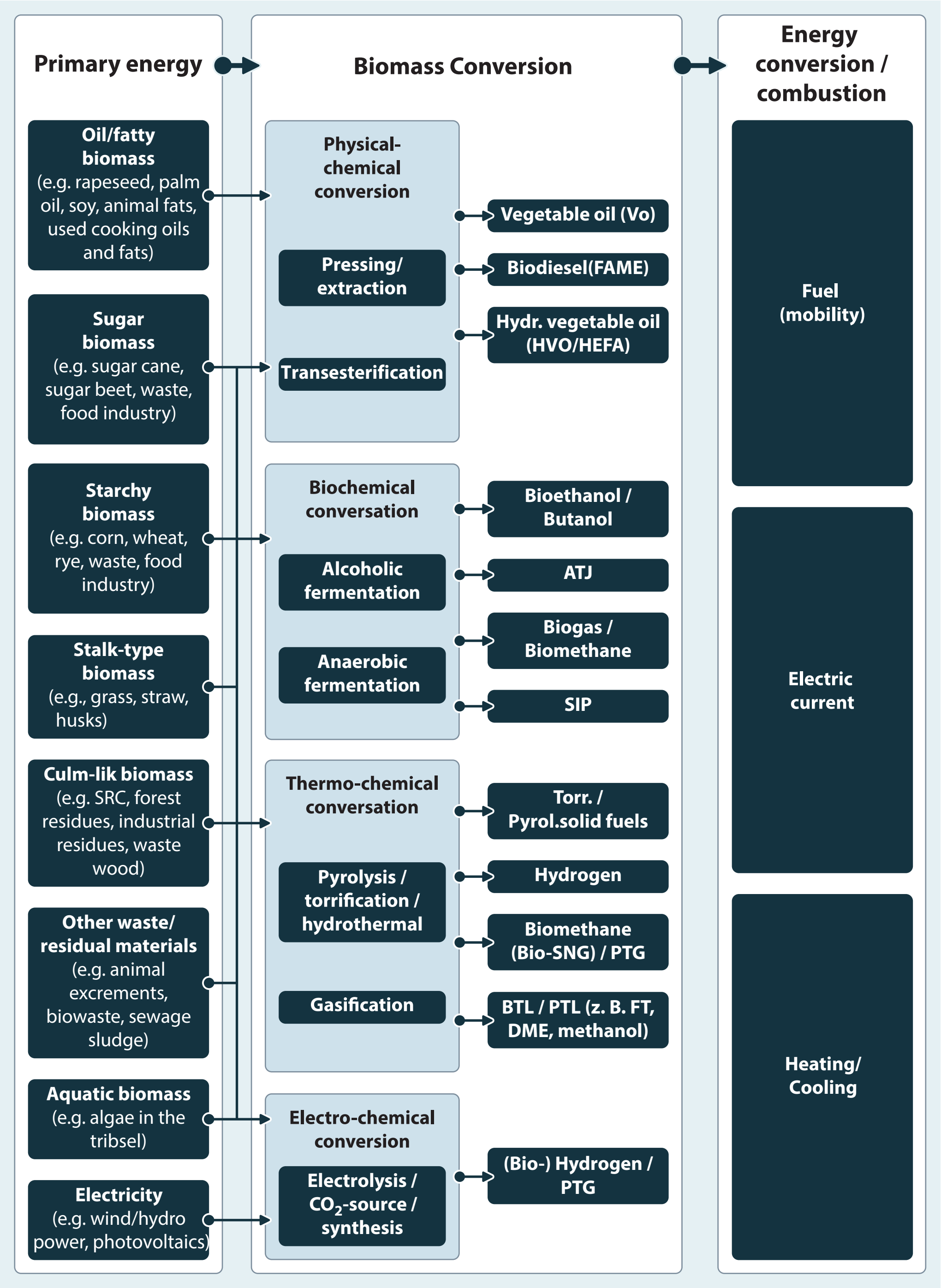
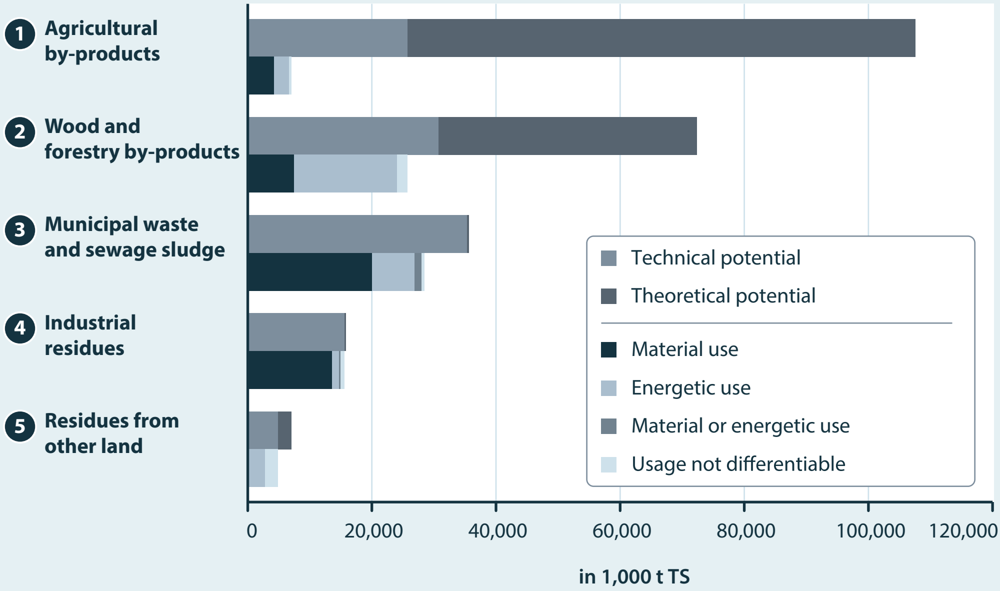


Fig. 8.2 Overview of biomasses and conversion pathways (biomasses highlighted in colour are to be assigned to wastes and residues). (Source: Own representation according to Acatech et al., 2019)

Residual material potentials and current use in Germany (mean values, reference year 2015)



① **22 Individual biomasses:** Digestate, vegetable crops, sugar beet leaves, potato haulm, cereal straw, rape straw, sunflower straw, grain maize straw, grain maize spindles, legume straw, cattle slurry, cattle manure, pig slurry, pig manure, chicken liquid manure, cattle manure, pig manure, chicken dry manure, horse manure, sheep manure, goat manure, other poultry manure.

② **7 Individual biomasses:** Forest residues (coniferous/leaved), bark, sawmill by-products and wood shavings, black liquor, other industrial residues, waste wood

③ **14 Individual biomasses:** Biowaste from private households, green waste, biog. proportion of used textiles, used paper, cooking oils/greases from private households, food waste from retail kitchen/canteen waste, leaves, biog. proportion of street sweepings, biog. proportion of sewerage, sludge from the food industry, sludge from the pulp/leather/textile industry, sewage sludge municipal wastewater treatment plants, biog. proportion of waste water for anaerobic treatment

④ **23 Individual biomasses:** Meat, fish, fruit, vegetable, potato, dairy, grain, tobacco processing, residues from oil mills, starch production, bread/bakery production, breweries, malt houses, distilleries, wineries, sugar, cocoa, ready meals, coffee, feed, yeast, bioethanol production, glycerine from biodiesel production

⑤ **11 Individual biomasses:** Stalks and wood from landscape maintenance areas, roadside greenery/wood, railwayside greenery/wood, stalks/wood from orchards, stalks/wood from vineyards, driftwood/alluvial wood

Fig. 8.3 Biomass residue potentials and their current use. (Source: Own representation according to Brosowski et al., 2019)

In 2015, approximately 3.7% of final energy consumption was provided by waste[3] (UBA, 2019). Statistical data on the current status of the share of biogenic waste and residues in final or primary energy consumption in Germany are not available. If the still untapped potential of biogenic waste and residues is used, 7–9% of the current primary energy consumption in Germany could be covered by waste biomass

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[3] Including non-biogenic waste; corresponds to 320 PJ final energy (gross) (reference year 2015).

(Brosowski et al., 2016). This share roughly corresponds to the current share of bioenergy[4] in final energy consumption (UBA, 2019). If primary energy consumption were halved, it would be[5] possible to cover 13–17% from biogenic waste and residual materials in the future (Klepper & Thrän, 2019).

In Germany, biogenic residues and waste are already being used to generate renewable heat and electricity, but also to produce biofuels (Naumann et al., 2019; Daniel-Gromke et al., 2017). In this context, the electricity is provided by cogeneration. For this purpose, the feed-in tariff guaranteed for 20 years under the Renewable Energy Sources Act (EEG) or the current tender model for electricity from biomass is applied. Animal excrement, biowaste and commercial waste are used for the coupled generation of electricity and heat in biogas plants (Daniel-Gromke et al., 2017). They account for a quarter of the total biogenic feedstock. Larger fermentation plants also feed in upgraded biogas into the natural gas grid in the form of biomethane.

The use of biogenic residues and waste materials in the fuel sector has gained in importance in recent years. Used cooking oils and fats, for example, represented the largest share of raw materials for biodiesel production in 2017. Biomethane used in the transport sector was produced from 100% waste and residual materials (Naumann et al., 2019). The increasing use of residues and waste materials in the biomethane sector since 2015 is particularly justified by the fact that production here is comparatively cheap and the potential greenhouse gas (GHG) savings of up to 90% are very high. It thus represents a favourable option for meeting the greenhouse gas quota applicable in Germany. In contrast, waste and residual materials have so far played a rather marginal role in the production of bioethanol used in Germany, accounting for 0.2% of the raw material base (60 TJ[6]) (Naumann et al., 2019).

Waste and residue-based fuels can be counted among the so-called advanced renewable fuels, such as methane from biowaste (Meisel et al., 2019). With the amendment of the Renewable Energy Directive, advanced biofuels based on waste and residues were given more relevance according to Annex IX, Part A (RED, 2018) with the establishment of a dedicated sub-quota of 3.5% of the EU fuel mix by 2030. However, taking into account double counting, this target is not ambitious enough to achieve a more comprehensive use of residues and wastes in the fuel sector (Naumann et al., 2019). Assuming the current final energy consumption of 2755 PJ (in 2017, BMWi, 2018a, b) in the German transport sector, this 3.5% share corresponds in real terms to only 1.75% or 48 PJ.

In addition to the legal framework conditions, the technological development of digestion processes and the adaptation and optimisation of plant concepts, for example for using lignin-based biomass, represent a challenge. At the moment, the integration of these processes is at the demonstration stage. In addition, the costs of these production processes must be reduced so that they can become established compared to existing processes. A market launch would expand the range of residual materials that can be used, such as straw, and thus enable a more comprehensive energy use of these material flows (acatech et al., 2019).

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[4] 8.8% bioenergy share in 2018 results as follows: 16.5% share of renewable energy in final energy consumption; 53% of the renewable energy provided was bioenergy.

[5] The aim is to halve primary energy consumption by 2050 (Energy Concept 2050, Bundesregierung, 2010).

[6] TJ = terajoule, 1 TJ ≈ 278 MWh, measure of energy.

8.2.1 Legal Framework for Biogenic Waste and Residues

The legal framework for biogenic waste and residues is defined by laws and directives at EU and implemented at federal and state level. For waste, the binding waste hierarchy specifies the order of priority for waste management measures: (1) prevention, (2) preparation for reuse, (3) recycling, (4) other recovery, in particular energy recovery, (5) disposal (KrWG §6). This also applies to biogenic waste. In the long term, disposal is to be largely avoided in the sense of cascading use without waste *(zero waste)*. The waste- and residue-based bioeconomy focuses primarily on the areas of combined material and energy recovery and recycling. ◘ Figure 8.4 provides an overview of the relevant legislation, although this is only a selection and should not be regarded as comprehensive.

In addition to current regulations and laws, federal policies and programmes also influence and thus support the waste- and residue-based bioeconomy:

- According to the Climate Protection Plan 2050

> » "the use of bioenergy from residual and waste materials will make an important contribution to cross-sectoral energy supply[...] In this context, it is important to develop efficient strategies for the material use of biogenic resources, in which energy recovery is only at the end of a cascade (p. 35)". Furthermore, the "[...] development towards advanced biofuels mainly based on residual and waste materials and with high GHG reduction values is expected (p. 51)". "As an example, the resource biowaste must be used even more than before for energy and materials in cascades" (BMU, 2016, p. 58).

Circular Economy Act Management Act (KrWG) Landfill Ordinance (DepV)	Biowaste Ordinance (BioAbfV)	Federal Immission Control Act (BImSchG)	Animal By-products Disposal Act (TierNebG)	Combined Heat and Power Act (KWKG)
Biomass Sustainability Ordinance (BioStrNachV)	Biofuel Sustainability Ordinance (Biokraft-NachV)	Biofuel Quota Act (BioKRaftQuG)	Renewable Energies Act (EEG)	Renewable Energies Heat Act (EEWärmeG)
Biomass Ordinance (BiomasseV)	Federal Soil Protection Act (BBodSchG) Federal Soil Protection Ordinance (BBodSchV)	Fertiliser Act (DüngG) Ordinance on the Application of Fertilisers (DÜMV)	Fertiliser Ordinance (DüV) Farm Manure Ordinance (WDüngV)	Sewage Sludge Ordinance (AbfKlärV) Waste Wood Ordinance (AltholzV)

◘ **Fig. 8.4** Legislation at national level with reference to bioenergy or biogenic waste and residues (selection). (Source: Own representation)

- Among other things, the German sustainability strategy calls for an increase in total raw material productivity of +1.5% per year (2030), which can only be achieved through waste prevention and an extension of useful life, for example through cascade use (Bundesregierung, 2016).
- The German Resource Efficiency Programme II (2016) also formulates an increase in total raw material productivity: by 30% by 2030 compared to 2010 (BMUB, 2016).

Waste prevention, especially of food waste, is formulated as an important goal of all three programmes. Working groups such as the "Fundamental Issues in Waste Management" working group of the German Waste Management Association (Deutsche Gesellschaft für Abfallwirtschaft e. V.) deal intensively with criteria for high-quality recycling. As a position paper, this provides impetus for policy and the design of legal framework conditions.

8.2.2 Responsibilities and Actors

Depending on their origin, there are different responsibilities and actors for biogenic waste and residues. In Germany the state offices are responsible for compliance with waste legislation (e.g. control of evidence, operator reports, data collection) and immission control and are subordinate to the relevant ministries of the federal states. In the area of agricultural and forestry residues, the ministries of agriculture are responsible.

Waste from households and household-like commercial waste must be handed over to the municipalities and districts, which act as public waste management authorities (§17 KrWG). The public waste management authority is responsible for collection, disposal and recycling. The quality and quantity of municipal biowaste are influenced by many factors and actors: the fee structure, collection container size and collection intervals are determined by the local authority. How much is actually collected and how sorted the biowaste or green waste depends not only on the collection system but also to a large extent on consumer behaviour, which in turn depends on the acceptance of separate collection by the population. Information in the media or through targeted public relations work on site about the usefulness of biowaste collection and its positive effect on the environment and climate can motivate citizens and thus positively influence the quantity and quality of the biowaste collected. Improved service, for example through shorter collection intervals in summer to prevent odour development, or the provision of suitable collection bags, help to improve acceptance (Kern et al., 2018). Offering larger collection containers usually leads to higher collection rates of garden waste (Kern et al., 2010).

The treatment and recycling of biowaste takes place in plants that can be operated by municipalities or also by private entrepreneurs. This operator is also responsible for the marketing of the recycled products (energy, if applicable) and the disposal of non-recyclable fractions. If the treatment of the waste is contracted out, the municipality can influence the type of treatment through the design of the tender and, for example, request the integration of an anaerobic digestion stage. Climate protection targets, legal requirements or favourable economic conditions (in the past the Renewable Energy Sources Act [EEG]) can be triggers for this. The recycled products, such as composts or fermentation residues, are mainly used as fertiliser in agriculture or sold to small consumers, where they can be used again to produce food, fodder or plant raw materials. Or they are marketed to soil manufacturers, who then mostly produce products such as quality soils or organic fertilizers for the retail trade.

Biogenic waste from industry and commerce, such as catering, slaughterhouses, food manufacturers, etc., does not have to be handed over to the public waste management authorities, but must be treated by a specialist disposal company. The waste management company is responsible for the collection and treatment or recycling as well as for the marketing of the end products (materials, energy) and the disposal of non-recyclable fractions. In part, there is a market for non-toxic, easily fermentable waste for recycling in fermentation plants. Proper disposal must be proven in all cases.

Sewage sludge is produced at wastewater treatment plants operated by special-purpose associations or municipalities. Treatment (fermentation, stabilisation, drying) can be carried out either there or at other facilities, including those operated by the private sector. Utilisation in agriculture is currently still possible – but varies from place to place. Disposal in incineration plants, which are mostly privately owned, is steadily increasing.

For by-products, the responsibility is in private hands, but authorities have control tasks to ensure that the overall use does not lead to harmful effects on humans and/or the environment. There is a market for by-products such as uncontaminated wood, sawdust or straw. Other commercial players use by-products as a resource for example to produce chipboard, insulation materials, building materials, chemicals etc. These facilities are also usually privately owned. Data on how many of these by-products are generated and recycled is not available. According to research by Mantau et al. (2018), wood is already being used in a cascading manner. This can be deduced, among other things, from the fact that in Germany, approximately 127 million m^3 of wood was put to use annually, but only 62.5 million m^3 were removed from the forest (reference year 2016, data were adjusted for exports and imports, respectively) (Mantau et al., 2018).

Interest groups represent their respective industry, provide information about it and advocate for their own interests. They are also active in policy advice and engage in lobbying to strengthen their position and, for example, to influence political processes in their favour. In addition, they can also take on advisory and/or monitoring functions, such as the Gütegemeinschaft Kompost (Compost Quality Association). This association awards and monitors a seal of quality which guarantees defined qualities of composts and fermentation products. The quality association also issues recommendations for manufacturers, plant operators and users.

8.3 Conflicting Targets

The waste- and residue-based bioeconomy gives rise to various conflicts of objectives, both today and in the future, which need to be resolved. These conflicts are caused by the different interests of the groups of actors, but also result from conflicting or competing overriding goals. As an approximation to a structuring of the conflicting goals, ◘ Fig. 8.5 outlines selected goals of the groups of actors with regard to ecological, economic aspects or other goals or wishes.

It is obvious that the goals of the various groups of actors differ considerably in some cases, which leads to conflicting goals. In the following, those conflicting goals that are particularly relevant for a waste- and residue-based bioeconomy will be addressed and explained in more detail.

	Ecological aspects	Economic aspects	Other goals / wishes
Consumer / Citizen	Intact clean environment	High quality and affordable products / energy; low waste management fees.	Uncontaminated, healthy food, jobs
Private sector/ economy	Low emissions	Optimization of own processes/facilities possibly combined with expansion of capacities; market shares for products / technologies / energy; profit	
Banks / Investors	Future-oriented, clean "green" technologies	Innovations with economic potential; profit prospects	
Politics / administration	Climate protection targets, energy policy, environmental policy targets	Cost recovery for waste treatment; regional added value	Compliance with regulations and legislation (e.g. development towards a circular economy); infrastructure development
Science	Environmental and nature conservation, climate protection	Raise funds for research	Generating new knowledge, free research, accompanying research
Non-profit organisations (int. / nat.) / NGOs, clubs, associations	e.g. intact environment, protection of endangered species, consumer protection	Recruit / retain members	Influence of consumers, politics, economy, if necessary science, discussion/dialogue through information dissemination and campaigns
Media		(for private media also profit intention)	Dissemination of information, educational mission, consumer, political and economic attention

Fig. 8.5 Goals of stakeholder groups. (Source: Own representation)

8.3.1 Conflicting Targets in the Generation, Collection and Processing of Biogenic Waste and Residual Materials

Biogenic waste and residual materials are limited. Although the amount of municipal biowaste collected can be increased by expanding collection, the general priority should be to avoid waste – especially food waste. High-quality recycling is only possible with little decomposed "clean" biowaste at a reasonable cost. The effort for short emptying cycles leading to "fresh" biowaste is opposed to the economic efficiency of collection, especially in sparsely populated areas. In Germany, the separation of waste has been established for a long time, but misdirected waste still poses enormous problems for biowaste management. Although the inclusion of densely populated areas in biowaste collection leads to higher collection volumes of kitchen waste, it also leads to higher proportions of foreign and contaminated materials, which can only be controlled to a limited extent from a technical point of view. Accompanying education can lead to improvements, among other things, in the acceptance of clean waste separation.

Operators of waste treatment plants currently have the goal of safe waste recovery at reasonable costs (resulting in waste fees) or yield optimisation (especially energy and/or high-quality compost) and not to provide a raw material or to produce new products. Currently, there is a problem to sell compost in agriculture in a cost-covering way, which is related to remaining foreign materials (plastic, glass), bureaucratic hurdles, the supply of alternative organic fertilizers and the requirements of the fertilizer ordinance (Kern et al., 2018; Idelmann & Kleyboldt, 2018; Block, 2018). This currently stands in the way of the recycling of biowaste and the demand-oriented use of composts and fermentation products.

Although biodegradable packaging reduces the consumption of fossil raw materials, it is difficult to recycle it in the established recycling systems and it also makes the recycling of conventional plastic more difficult.

There is a very large biomass potential in the area of agricultural residues. However, there are various hurdles in the way of exploiting this potential. For example, straw as a by-product of grain production is already used in agriculture for maintaining the organic soil substance or in animal husbandry. For the farmer, straw has at least the value of the minerals it contains, which he must replace when it is removed. On the one hand, there is the challenge of logistics for a biomass with low energy density, and on the other hand, there is the connection between demand and supply, which affects the price. Business models for new uses in the sense of the bioeconomy are therefore difficult to develop. For the utilisation of liquid manure and dung, the low energy content reduces its transportability.

Other biomasses whose utilisation is associated with various difficulties are the landscape conservation materials. These can be stalk-like or woody, which require different recovery routes. Furthermore, efficient and economic logistics for landscape conservation materials are also difficult to realize, which is also impacted by the large number of actors involved and their responsibilities (for example farmers, local authorities, landscape management associations, soil and water associations, road construction authorities, etc.). The actors usually act in isolation. In addition, legal hurdles to use arise if the material is classified as waste.

8.3.2 Conflicting Targets in the Use of Biogenic Waste and Residues for Energy and Material Purposes

Conflicting targets in the energy use of residues and waste materials arise from the pursuit of *independent* objectives in climate, energy and environmental policy. For example, the goal that bioenergy from residual and waste materials should make an important contribution to cross-sectoral energy supply can pose a challenge. Due to the limited supply of residual and waste materials, these material flows cannot serve all sectors equally in the long term. Their system contribution must therefore be identified and developed. The decisive factor here is the use of biogenic residual and waste materials in places where other renewable energies cannot make a contribution or can only do so at higher cost (acatech et al., 2019).

In addition, policy instruments that incentivise increased use in energy supply can affect the material use of these material flows. A prominent example is the use of waste wood for electricity and heat generation. The ban of landfilling for this materials and the simultaneous introduction of subsidies for the use of waste wood for energy purposes under the Renewable Energy Sources Act (EEG) have indeed resulted in that all waste wood streams are currently being tied up in recycling routes. However, the use of waste wood for energy and material purposes compete with each other, which has led to an increase in prices with, in part, a higher willingness to pay when used for energy provision.

It should also be noted that the cascading of biomass carries the risk that contaminants can accumulate in a circular economy. It should also be noted that biobased materials degrade. In contrast to municipal biowaste, waste fermentation plants compete for industrial organic waste for which high disposal fees can be achieved or which has a high energy content and favourable fermentation properties.

Biogenic waste and residues can often be used in different systems. As described, there is already competition between thermal and material use for waste wood residues. The use path is determined by cost factors, not by sustainability criteria.

Current responsibilities and the legal framework for biogenic waste and residues ensure compliance with environmentally sound treatment and disposal or the protection of agricultural land, but may at the same time hinder novel recovery pathways.

8.4 Innovations

The new aspect of a future bioeconomy is, that biogenic waste and residues should build the basis for it. These biomasses should be raw materials that are utilised in cascades and not primarily be treated and disposed.However, this is only possible with fundamentally changed ways of thinking, new business models and adapted framework conditions. For example, the recycling-oriented design of consumer goods improves their recycling possibilities enormously or even makes recycling possible. In the future, bio-based products must also be recyclable. Processing methods must be adapted in such a way that, in addition to lower raw material and energy consumption, waste streams can also be avoided or made usable. The potential of biogenic waste and residual materials is limited. By optimising existing use and mobilising previously unused potential, a more efficient application can be implemented in the future.

The further development of new recycling methods, products and processes to create and extend value chains is also already part of research and development today. Some examples are briefly described in this chapter. However, the innovations required for a waste- and residue-based bioeconomy must go far beyond this and include not only technical and economic aspects, but also social aspects.

In future, the conversion processes that convert biomass into chemicals, products, heat or energy will be more closely linked. In biorefinery concepts, for example, not only one main product as well as wastes and residues will then be provided, but several main and by-products and/or energy. In this way, the recycling of biogenic wastes and residues can generate not only energy and organic fertilizer, but also high-quality recycled products that serve as feedstock for further processing, such as organic acids, proteins, fibres, etc.

In future, carbon dioxide from biomass plants would no longer be released into the atmosphere as an emission, but would also be kept in circulation or stored and thus withdrawn (BECCS[7]). The technologies required for this are already available today, such as biological or catalytic methanation, the production of methanol, etc. CO_2 is a by-product of biogas upgrading and is rarely used as a material, especially in waste fermentation plants. By means of biological methanisation, the CO_2 contained in the biogas can be used without capture. Together with electrolysis, which uses excess electricity from fluctuating sources, biomass plants can thus make a valuable contribution to the energy transition and climate protection. There is a need for innovation in the development of the BECCS plant technology itself as well as in the design and construction of a transport and storage infrastructure for the carbon dioxide (Thrän, 2019).

▣ Figure 8.6 presents examples of some innovative processes. Most of these are still being developed or tested, but some have already been implemented in practice. The technical innovations can develop into economic ones, for example new business models.

Social innovations can increase the acceptance of new products or processes or, for example, lead to a higher quality and quantity of collected waste fractions. Waste management companies are working to make collection more consumer-friendly and to involve citizens in decision-making processes. New media are particularly suitable for this purpose, in addition to classic measures such as citizen surveys and the like. Positive experience has been gained in pilot projects in which apps were used to obtain citizen feedback on satisfaction with waste collection: Collection site clean, containers overfilled and the like. This feedback has been used to manage the routes of waste collection vehicles, resulting in cost savings (no empty trips) and more satisfied customers (demand is taken into account). Waste management apps and websites have been developed and continuously improved, for example to help with single-sort collection (what goes where, where to find suitable disposers). Disposal calendar apps of the local authorities are already state of the art and remind of collection dates or inform about changes.

A wide variety of approaches to the waste- and residue-based bioeconomy can be found in international research. For example, the path from "classical" biorefineries to a sustainable circular economy is intensively discussed (O'Callaghan, 2016; Venkata Mohan et al., 2016; Maina et al., 2017; Nizami et al., 2017; Bell et al., 2018; Dahiy et al., 2018; Zabaniotou, 2018).

However, innovative processes and value chains can also give rise to new conflicts. For example, new recycling routes can jeopardise the economic viability of existing recycling plants (even if they operate sustainably). In the area of industrial organic waste, there is already competition in which the lowest disposal price rather than the most sustainable recycling is the deciding factor. New products can ultimately only become established if they are accepted by society, i.e. by the consumer. However, the legislator can provide an adapted legal framework for innovative processes and new value chains.

8.5 Images of the Future

What does a waste and residue-based bioeconomy of the future look like? The scenarios range from the "desirable" (ideal from the point of view of individual actors) to the "possible" (derived from a combination of non-contradictory development directions) and the "probable" (for example, based on expert forecasts) to the "sustainable" (evaluation of the development directions from the point of view of sustainability) (Schug et al., 2007, 2008).

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[7] BECCS – Bioenergy with Carbon Capture and Storage.

Product	Explanation
Silicate	Silicate from biomass such as straw, sedges (ashes), etc. for the production of catalysts or for use as an additive in plastics and elastomers, paints and varnishes as well as glues and sealants.
Lignin	Extraction from agricultural or woody residues or digestate.
Sugar	Extraction of lignocellulose-based sugars as an industrially available base chemical for subsequent high-quality bioproducts (biochemicals, biopharmaceuticals, bioplastics, etc.) from agricultural residues such as straw, e.g. using the LC2GreenSugar® process[1].
Biopolymer	In the joint research project SYNPOL[2], research was conducted into the production of biopolymers through synthesis gas fermentation. Organic waste was used as the starting substrate.
Chemicals and auxiliary materials	Example leather industry: collagen-containing shavings and cuttings are used to produce and use "X-Biomer" retanning agents on site (LANXESS[3]). Example biorefinery (IBÖM0^2: CapAcidy[4]): combined production of the fatty acids capric and caprylic acid and biogas from biomass, a project of the Helmholtz Centre for Environmental Research and the German Biomass Research Centre which received the Biogas Innovation Award in 2019. The developed process is based on an anaerobic fermentation process in which complex substrates can be used without cost-intensive pre-treatment. This is followed by a separation and purification cascade to recover the medium-chain fatty acids.
Protein and fat	Utilisation of biowaste and organic residues by the soldier fly[5]: In Austria, the company "ECOFLY GmbH" produces 500 Mg of larvae per week and processes them into fish meal substitute for aquaculture, using the industrial by-product beer pomace as food source. In Saxony, the company "Bio S" has successfully produced larvae on a pilot scale. Oil should be separated from the soldier fly larvae. This can serve as a substitute for palm oil.
Biochar	Thermochemical processes (pyrolytic or hydrothermal processes) can be used to produce biomass carbonisate (biochar) from biomass. These processes have been known for a long time such as for charcoal production. In the area of wet biogenic waste, hydrothermal processes offer a wide range of applications, although practical implementation is associated with challenges. The company TerraNova[6] has successfully developed an HTC plant for the treatment of sewage sludge and put it into practice. Biochar production can be coupled with phosphorus recovery. Processes from other companies are also ready for the market.

1) https://www.oav.de/iap-32017/artikel-417.html
2) http://www.synpol.org/Dissemination/
3) https://lanxess.de/de/corporate/corporate-responsibility/credentials/auszeichnungen/
4) https://biooekonomie.de/foerderprojekt/ibom02-capacidy-bio-basierte-capron-und-caprylsaure-herstellung-aufreinigung-0
5) The flies/grubs are considered livestock and therefore cannot be fed on protein from ruminants, catering waste, meat and bone meal and manure (Regulation (EU) 2017/893).
6) http://terranova-energy.com

Fig. 8.6 Examples of new products, processes or applications using organic waste and residues or agricultural residues. (Source: Own representation)

A complete, environmentally compatible recycling of all municipal waste in the sense of a circular economy, which is intended to make waste disposal in landfills superfluous, will have a major influence on the German waste management industry. For the "economy without waste", i.e. a "circular economy", extensive recycling will be necessary, but also the acceptance of recycled products in the economy and society. In the project "KIDA – Cooperation in Waste Management", future scenarios of waste management were examined and discussed (time horizon 2007 + ten to 15 years).

Various scenarios were developed from the aforementioned project (Schug et al., 2007, 2008):

- Scenario 1: ecologically oriented resource management from an energy point of view where the responsibility lies with the municipalities and at the same time an international orientation and a concentration of players
- Scenario 2: regional orientation of waste flows without integration of environmental aspects at high costs
- Scenario 3: complete recycling of the decreasing quantities of waste in large-scale plants with sufficient availability of energy and raw materials, also due to energy recovery from waste

In order to describe the images of the future in more detail, a selection was made from possible development scenarios during workshops held by various groups of actors (KIDA project). Possible development directions of the key factor "waste as a resource" would be, for example (Schug et al., 2008):

- A worldwide shortage of raw materials causes the activation of all raw material resources in waste and leads to the use of every last gram.
- Scandals involving secondary raw materials have caused a complete collapse in acceptance among users and the general public. Everyone demands "primary goods".
- High primary energy prices make the use of waste as a fuel economical. Even high costs for processing are accepted.
- The hunger for raw materials of the so-called emerging countries such as China or India is sucking the world market dry. The requirements for materials in these regions are significantly below the European standard – the "co-incineration market" in Europe is collapsing.

A look at the future scenarios developed about twelve years ago (KIDA project) allows an assessment of whether the expected development has occurred. Some things have been regulated differently by legal frameworks, some global influencing factors are stronger or weaker – the development of many of the key factors considered is still unclear and there is controversy among the groups of actors as to which should be the right direction.

In an ecologically oriented resource economy (scenario 1), it is assumed that waste will be recycled down to the last gram in future, whereas this is viewed critically in scenario 2. There, it is rather assumed that the acceptance of secondary raw materials will collapse due to quality deficiencies (Schug et al., 2008). This clearly shows that the success of what is "desirable" for resource and climate protection reasons – the complete recycling of waste – is associated with hurdles, especially with regard to acceptance. The cascade use of waste as a resource is a central element in the waste- and residue-based bioeconomy. The extensive utilisation of waste and residual material flows that have not yet been optimally utilised is seen as feasible in the short and medium term in order to contribute to climate protection.

Very idealised images of the future of the bioeconomy were developed in the project "BioKompass – Communication and Participation for the Societal Transformation to the Bioeconomy" (Kimpeler et al., 2018). Biogenic waste and residual materials are largely avoided, unavoidable waste is recycled and regional material cycles are promoted. Depending on the scenario, global material cycles are also considered. What all scenarios have in common, however, is the radical transformation of lifestyles, including nutrition (massive reduction in meat consumption), through to consumer behaviour and waste avoidance – especially of food waste – as well as a high level of environmental awareness among the population.

In contrast to the use of energy crops, the energy recovery of residual and waste materials that are not suitable for material use or recycling is highly accepted. This is due in particular to the fact that the cultivation of primary raw materials for energy use in competition with food, animal feed or bio-based material production is seen as requiring a large amount of land or as an undesirable change to the landscape. A current study on future fields of application of bioenergy shows that the raw material issue is the decisive component for generating social acceptance and thus a successful application of biomass in the energy system. Consequently, the evaluation of the role of bioenergy in the future energy system focuses on an increased use of residual and waste materials for the expansion of the resource base (Klepper & Thrän, 2019).

Key factors for the acceptance of energy infrastructures are

- the acknowledgment of the necessity,
- a perceived personal benefit,
- experienced self-efficacy and
- emotional identification (acatech et al., 2019).

These factors also influence the acceptance of a comprehensive material use of waste and residual materials in a future bioeconomy and especially the change of living habits.

▶ Section 8.2 has already partly explained the developments to which the waste and residual material flows described are subject to. Despite immigration, a slight population decline is still expected in Germany (Destatis, 2019), which, together with increasing waste avoidance, could lead to falling waste volumes in the long term. An economy without waste is an ambitious long-term goal which, in addition to the implementation of technical innovations, can only be achieved with social change and broad acceptance.

However, it is non-controversial among experts that thermal waste treatment will continue to be an important pillar of waste management in the future for reasons of environmental and health protection. The extent to which waste will become an integral part of the energy supply is difficult to estimate. Since many thermal power plants that were also involved in cogeneration will go offline in the next few years, waste-to-energy plants could fill a gap in the heat supply (Flamme et al., 2018). Optimised waste-to-energy use of the future could be characterised by the following keywords: integrated, decentralised and heat-led.

Waste should therefore be recycled where it is produced, which generally also enables effective heat utilisation. The integrated operation of various supply and disposal facilities can leverage synergies, thereby reducing costs and optimising ecological benefits (for example, the system of waste incineration – sewage treatment plant – biowaste treatment) (Flamme et al., 2018).

If one follows the analyses of the Intergovernmental Panel on Climate Change (IPCC), bioenergy will most likely not only be CO_2-neutral from the middle of the century onwards, but will also contribute to removing CO_2 from material cycles and being able to store it permanently through BECCS (Rogelj et al., 2018). Thus, different images exist for the future use for bioenergy. Depending on which developments are socially prioritised, accepted and promoted, different preferred biomass applications emerge. So-called *switch points* are (acatech et al., 2019):

- Heat network infrastructure: available or not?
- Liquid biofuel technologies based on lignocellulose: ready for the market or not?
- CCS technology as a climate protection instrument: accepted or not?

If a heat network infrastructure is maintained and expanded, the heat supply will be based on small and large combined heat and power (biomass) plants, depending on the urban structure. This will be combined with a flexible electricity supply to support fluctuating renewable energies. For this, fermentable biomass as well as straw and wood are used in different technologies. If this pathway is not prioritised, lignocellulosic biomass will be increasingly used for heat in industrial processes and BECCS and possibly on a larger scale for biofuels, so-called lignofuels. If such lignocellulosic fuels become competitive, they could be produced in centralised large-scale biorefineries. Such very complex biorefineries can only work economically if an industrial scale is achieved. The necessary preliminary stages, which focus on the feedstocks, must be produced decentrally in order to increase the transportability of the biogenic input materials. At the same time, a market for the new fuels and the by-products must also develop. The application of CCS technology as a climate protection instrument has a major influence on the bioenergy technologies that will be preferred in the future; for efficiency reasons, large biomass plants and biomass use in industrial processes will be prioritised. In addition to the market maturity of CO_2 capture from flue or exhaust gases, safe transport and storage of the captured carbon dioxide are also necessary for widespread implementation.

Decisions on the above three switching points will lead to clear preferences as to where the limited biomass should be used in the future. Regardless of this, the cascade use of biogenic waste and residual materials helps to save energy and resources and, in addition, to temporarily store CO_2 in products.

References

acatech – Deutsche Akademie der Technikwissenschaften, Nationale Akademie der Wissenschaften Leopoldina, & Union der deutschen Akademien der Wissenschaften. (Hrsg.) (2019). Biomasse im Spannungsfeld zwischen Energie- und Klimapolitik – Strategien für eine nachhaltige Bioenergienutzung (Schriftenreihe Energiesysteme der Zukunft). https://www.acatech.de/Publikation/biomasse-im-spannungsfeld-zwischen-energie-und-klimapolitik-strategien-fuer-eine-nachhaltige-bioenergienutzung/. Accessed: 02.04.2019.

AltholzV. (2002). Verordnung über Anforderungen an die Verwertung und Beseitigung von Altholz (Altholzverordnung – AltholzV, Ausfertigungsdatum: 15.08.2002).

Bell, J., Paula, L., Dodd, T., Németh, S., Nanou, C., Mega, V., & Campos, P. (2018). EU ambition to build the world's leading bioeconomy – Uncertain times demand innovative and sustainable solutions. *New Biotechnology*. https://doi.org/10.1016/j.nbt.2017.06.010

BioAbfV. (1998). Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden (Bioabfallverordnung – BioAbfV). *Ausfertigungsdatum, 21*(09), 1998.

Block, R. (2018). Rechtliche Vorgaben der Düngeverordnung beim Komposteinsatz. In M. Kern & T. Raussen (Eds.), *Neue Perspektiven für die Bioabfallwirtschaft* (pp. 27–34). Witzenhausen Institut für Abfall, Umwelt und Energie.

BMBF (Bundesministerium für Bildung und Forschung). (2014). Wegweiser Bioökonomie, Forschung für biobasiertes und nachhaltiges Wirtschaftswachstum. https://biooekonomie.de/sites/default/files/publications/wegweiser-biooekonomiepropertypdfbereichbiooekosprachederwbtrue.pdf. Accessed: 21.08.2019.

BMU (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit). (2016). Klimaschutzplan 2050, Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung. https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf. Accessed: 02.04.2019.

BMU (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit). (2018). Abfallwirtschaft in Deutschland 2018, Fakten, Daten, Grafiken. https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/abfallwirtschaft_2018_de.pdf. Accessed: 02.04.2019.

BMUB (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit). (2016). Deutsches Ressourceneffizienzprogramm II Programm zur nachhaltigen Nutzung und zum Schutz der natürlichen Ressourcen. https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/progress_ii_broschuere_bf.pdf. Accessed: 02.04.2019.

BMWi (Bundesministerium für Wirtschaft und Energie). (2018a). Energiedaten: Gesamtausgabe. https://www.bmwi.de/Redaktion/DE/Downloads/Energiedaten/energiedaten-gesamt-pdf-grafiken.

pdf?__blob=publicationFile&v=34. Accessed: 21.08.2019.

BMWi (Bundesministerium für Wirtschaft und Energie). (2018b). Erneuerbare Energien in Zahlen. Nationale und internationale Entwicklung im Jahr 2017. https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/erneuerbare-energien-in-zahlen-2017.pdf?__blob=publicationFile&v=27. Accessed: 21.08.2019.

Brosowski, A., Thrän, D., Mantau, U., Mahro, B., Erdmann, G., Adler, P., Stinner, W., Reinhold, G., Hering, T., & Blanke, C. (2016). A review of biomass potential and current utilisation – Status quo for 93 biogenic wastes and residues in Germany. *Biomass and Bioenergy, 95*(2016), 257–272.

Brosowski, A., Krause, T., Mantau, U., Mahro, B., Noke, A., Richter, F., Raussen, T., Bischof, R., Hering, T., Blanke, C., Müller, P., & Thrän, D. (2019). How to measure the impact of biogenic residues, wastes and by-products: Development of a national resource monitoring based on the example of Germany. *Biomass and Bioenergy*. https://doi.org/10.1016/j.biombioe.2019.105275

Bundesregierung. (2010). Bundestag stimmt Energiekonzept 2050 zu.https://www.bundesregierung.de/breg-de/suche/bundestag-stimmt-energiekonzept-2050-zu-409414. Accessed: 21.08.2019.

Bundesregierung. (2016). Deutsche Nachhaltigkeitsstrategie, Neuauflage 2016. https://www.bundesregierung.de/resource/blob/975292/730844/3d30c6c2875a9a08d364620ab7916af6/deutsche-nachhaltigkeitsstrategie-neuauflage-2016-download-bpa-data.pdf?download=1. Accessed: 21.08.2019.

Dahiy, S., Naresh Kumar, A., Shanthi Sravan, J., Chatterjee, S., Sarkar, O., & Venkata Mohan, S. (2018). Food waste biorefinery: Sustainable strategy for circular bioeconomy. *Bioresource Technology*. https://doi.org/10.1016/j.biortech.2017.07.176

Daniel-Gromke, J., Rensberg, N., Denysenko, V., Trommler, M., Reinholz, T., Völler, K., Beil, M., & Beyrich, W. (2017). Anlagenbestand Biogas und Biomethan – Biogaserzeugung und -nutzung in Deutschland, DBFZ Report Nr. 30/2017. https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_30.pdf. Accessed: 21.08.2019.

DESTATIS (Statistisches Bundesamt). (2018). GENESIS Online Datenbank. Aufkommen an Haushaltsabfällen, Erhebung der öffentlich-rechtl. Abfallentsorgung, Deutschland. https://www-genesis.destatis.de/genesis/online/logon?sequenz=tabelleErgebnis&selectionname=32121-0001&zeitscheiben=2. Accessed: 21.08.2019.

DESTATIS (Statistisches Bundesamt). (2019). 14. Koordinierte Bevölkerungsvorausberechnung – Basis 2018. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Bevoelkerungsvorausberechnung/aktualisierung-bevoelkerungsvorausberechnung.html. Accessed: 21.08.2019.

Ewens, H.-P. (2018). Entwicklungen in der Bioabfallwirtschaft in Deutschland. In M. Kern & T. Raussen (Eds.), *Neue Perspektiven für die Bioabfallwirtschaft* (pp. 9–13). Witzenhausen Institut für Abfall, Umwelt und Energie.

Flamme, S., Hanewinkel, J., Quicker, P., & Weber, K. (2018). Energieerzeugung aus Abfällen Stand und Potenziale in Deutschland bis 2030. UBA Texte 51/2018. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2018-06-26_texte_51-2018_energieerzeugung-abfaelle.pdf. Accessed: 21.08.2019.

Idelmann, M., & Kleyboldt, P. (2018). Von der Aufbereitung bis zur Vermarktung – Neue Wege der Kompostvermarktung. In M. Kern & T. Raussen (Eds.), *Neue Perspektiven für die Bioabfallwirtschaft* (pp. 40–51). Witzenhausen Institut für Abfall, Umwelt und Energie.

Kern, M., Raussen, T., Funda, K., Lootsma, A., & Hofmann, H. (2010). Aufwand und Nutzen einer optimierten Bioabfallverwertung hinsichtlich Energieeffizienz, Klima- und Ressourcenschutz. UBA Texte 43/2010. https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4010_0.pdf. Accessed: 25.04.2019.

Kern, M., Siepenkothen, H.-J., & Turk, T. (2018). Erfassung und Qualität von haushaltsstämmigen Bioabfällen. In M. Kern & T. Raussen (Eds.), *Neue Perspektiven für die Bioabfallwirtschaft* (pp. 53–68). Witzenhausen Institut für Abfall, Umwelt und Energie.

Kimpeler, S., Schirrmeister, E., Hüsing, B., & Voglhuber-Slavinsky, A. (2018). Zukunftsbilder aus dem Leben in einer Bioökonomie – Kurzfassung. Fraunhofer-Institut für System- und Innovationsforschung. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccv/2018/Zukunftsbilder_BioKompass_Kurzfassung.pdf. Accessed: 21.08.2019.

Klepper, G., & Thrän, D. (Hrsg.) (2019). Biomasse im Spannungsfeld zwischen Energie- und Klimapolitik. Potenziale – Technologien – Zielkonflikte. Schriftenreihe Energiesysteme der Zukunft. https://www.acatech.de/Publikation/biomasse-im-spannungsfeld-zwischen-energie-und-klimapolitik-potenziale-technologien-zielkonflikte/. Accessed: 21.08.2019.

KrWG. (2012). Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz – KrWG). *Ausfertigungsdatum, 24*(02), 2012.

Maina, S., Kachrimanidou, V., & Koutinas, A. (2017). A roadmap towards a circular and sustainable bioeconomy through waste valorization. *Current Opinion in Green and Sustainable Chemistry, 8*, 18–23.

Mantau, U., Döring, P., Weimar, H., Glasenapp, S., Jochem, D., & Zimmermann, K. (2018). Rohstoffmonitoring Holz – Erwartungen und Möglichkeiten. Fachagentur Nachwachsende Rohstoffe. https://www.fnr.de/fileadmin/allgemein/pdf/broschueren/Broschuere_Rohstoffmonitoring_Holz_Web_neu.pdf. Accessed: 21.08.2019.

Meisel, K., Millinger, M., Naumann, K., Majer, S., Müller-Langer, F., & Thrän, D. (2019). Untersuchungen zur Ausgestaltung der Biokraftstoffgesetzgebung in Deutschland – Arbeitspapier. DBFZ. https://www.dbfz.de/fileadmin/user_upload/Referenzen/Studien/Ausgestaltung_Biokraftstoffgesetzgebung.pdf. Accessed: 22.08.2019.

Naumann, K., Schröder, J., Oehmichen, K., Etzold, H., Müller-Langer, F., Remmele, E., Tuneke, K., Raksha, T., & Schmidt, P. (2019). *Monitoring Biokraftstoffsektor* (4. überarbeitete und erweiterte Aufl.) DBFZ Report Nr. 11. https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_11_4.pdf. Accessed: 21.08.2019.

Nizami, A. S., Rehan, M., Waqas, M., Naqvi, M., Ouda, O. K. M., Shahzad, K., Miandad, R., Khan, M. Z., Syamsiro, M., Ismail, I. M. I., & Pant, D. (2017). Waste biorefineries: Enabling circular economies in developing countries. *Bioresource Technology*. https://doi.org/10.1016/j.biortech.2017.05.097

O'Callaghan, K. (2016). Technologies for the utilisation of biogenic waste in the bioeconomy. *Food Chemistry, 198*, 2–11.

RED II. (2018). European Parliament and Council of the European Union: Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources: RED II 2018. http://www.europarl.europa.eu/doceo/document/TA-8-2018-0444_EN.html. Accessed: 09.09.2019.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Séférian, R., & Vilariño, M. V. (2018). Mitigation pathways compatible with 1.5°C in the context of sustainable development. Global warming of 1.5 °C. An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change (Chapter 2). Intergovernmental Panel on Climate Change.

Roskosch, A., Heidecke, P., Bannick, C.-G., Brandt, S., Bernicke, M., Dienemann, C., Gast, M., Hofmeier, M., Kabbe, C., Schwirn, K., Vogel, I., Völker,D., & Wiechmann, B. (2018). KLÄRSCHLAMMENTSORGUNG in der Bundesrepublik Deutschland. Umweltbundesamt. https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/2018_10_08_uba_fb_klaerschlamm_bf_lol.pdf. Accessed: 26.08.2019.

Schneider, M., Röhlen, S., & Abel, C. (2018). Vermarktungsalternativen für Komposte außerhalb der Landwirtschaft. In M. Kern & T. Raussen (Eds.), *Neue Perspektiven für die Bioabfallwirtschaft* (pp. 35–39). Witzenhausen Institut für Abfall, Umwelt und Energie.

Schug, H., Krück, C., Ploetz, C., & Zweck, A. (Hrsg.) (2007). Nachhaltigkeit, Kooperationen und die Zukünfte der Abfallwirtschaft, Aktuelle Problemstellungen und Lösungsansätze aus Theorie und Praxis. Zukünftige Technologien Consulting. https://www.vditz.de/fileadmin/media/publications/pdf/Band_68_nachhaltigkeit_kooperationen_zukuenfte_abfallwirtschaft.pdf. Accessed: 21.08.2019.

Schug, H., Krück, C., Ploetz, C., Werner, T., & Zweck, A. (2008). Die Zukunfts(t)räume der Abfallwirtschaft. Der Almanach der Recycling-Branche 2008 (S. 12–15). https://www.vditz.de/fileadmin/media/publications/pdf/zukunftstraeume_RecyclingAlmanach.pdf. Accessed: 21.08.2019.

Thrän, D. (Hrsg.) (2019). Interdisziplinäres Bewertungsinstrument für Bioenergie-Entwicklungspfade. Materialien zur Analyse „Biomasse im Spannungsfeld zwischen Energie- und Klimapolitik. Potenziale – Technologien – Zielkonflikte. Schriftenreihe Energiesysteme der Zukunft". https://www.akademienunion.de/fileadmin/redaktion/user_upload/Publikationen/Stellungnahmen/ESYS_Materialien_Bioenergie.pdf. Accessed: 21.08.2019.

UBA (Umweltbundesamt). (2019). Erneuerbare Energien in Zahlen. https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen#statusquo. Accessed: 21.08.2019.

Venkata Mohan, S., Nikhil, G. N., Chiranjeevi, P., Nagendranatha Reddy, C., Rohit, M. V., Naresh Kumar, A., & Sarkar, O. (2016). Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives. *Bioresource Technology, 215*, 2–12.

Zabaniotou, A. (2018). Redesigning a bioenergy sector in EU in the transition to circular waste-based bioeconomy – A multidisciplinary review. *Journal of Cleaner Production, 177*, 197–206.

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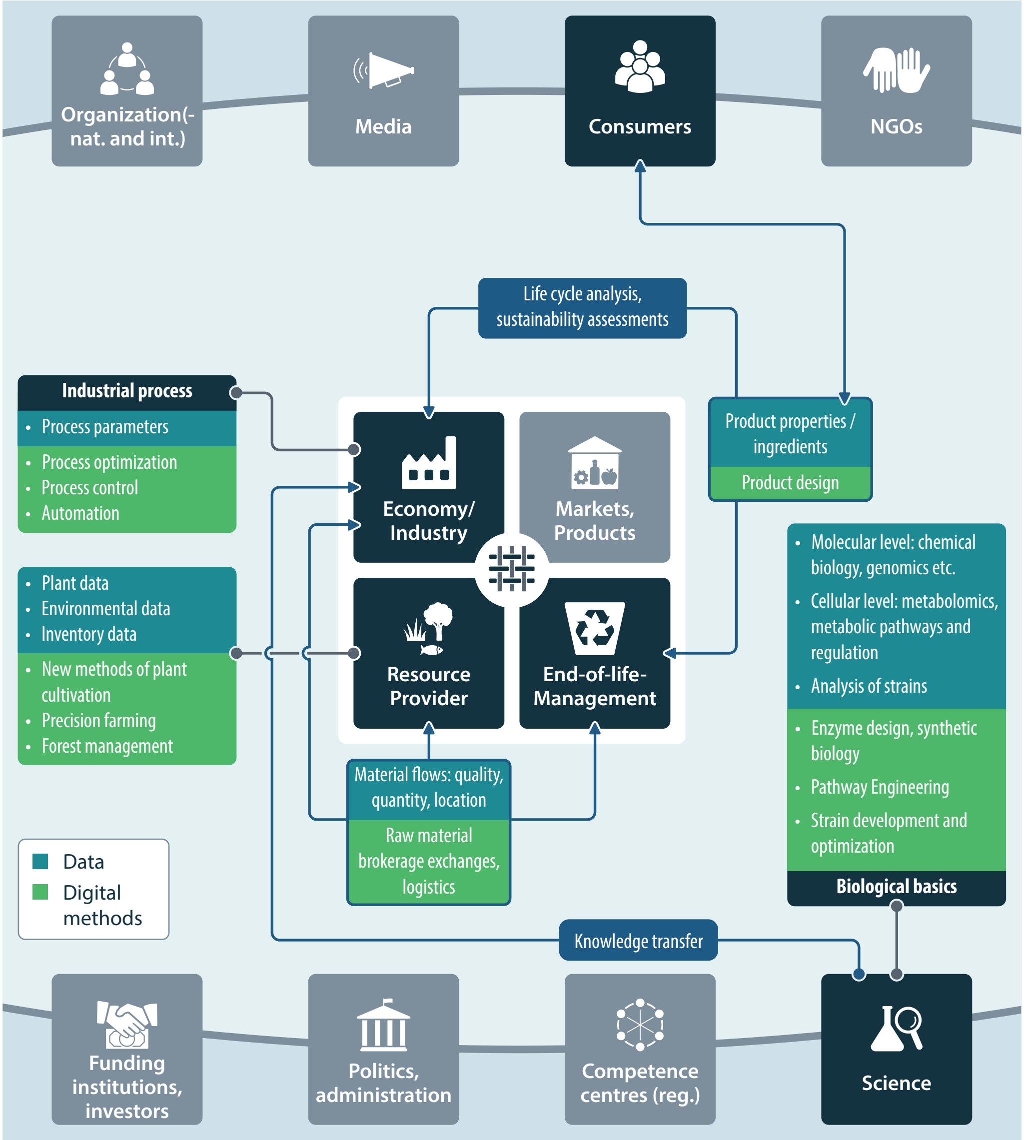
Digital Bioeconomy

Kathrin Rübberdt

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_9



9.1 System Description

Everyone is talking about "digitalisation" – but those who talk about it do not always mean the same thing. Interpretations range from the expansion of the information superhighway, which is more a question of infrastructure, to artificial intelligence as a vision for a medium to distant future in which machines take over a large part of the work. The scope and time horizon of what is understood by digitalisation sometimes differ quite considerably.

In the context of the bioeconomy, too, "digitalisation" describes a whole range of different aspects. What they all have in common is that it is essentially about the collection, electronic processing and exchange of data. For biotechnological research and development, the following definition can apply:

> In this context, we understand the term 'digitalisation' to mean the comprehensive virtualisation, i.e. the creation of digital images, of resources, workflows and processes in the context of the development of products and production methods, right through to the operation of biotechnological production processes (DECHEMA, 2018, p. 4).

New analytical methods ("Big Data") and the linking of data from different sources allow new insights to be gained. Digitalisation also includes feedback: processes can be automatically controlled and optimised at a wide variety of levels. As a rule, the goal can be considered to be to increase resource and product efficiency – at all stages of value creation from research and development to closing material cycles on a large scale (Klitkou et al., 2017). In the bioeconomy, this does not only concern the individual laboratory or company and its internal data flows, but encompasses different sectors such as agriculture, logistics, processing industry up to end users and authorities. At the same time, rules must be created for the exchange of data, for example by setting standards that make data flows possible in the first place, or through governance that ensures data protection.

9.1.1 Data Sources

In view of the diversity of data generated in the context of the bioeconomy, this sector seems predestined for digitalisation. In the bioeconomy, digitalisation activities have been underway for some time at various points in the bioeconomy circle. They range from the molecular level to the systemic consideration of the bioeconomy in all its dimensions, but have so far usually only covered a sub-area such as high-throughput technologies in research and development or the availability and plannability of resources from agriculture and forestry. The challenge lies in linking and interpreting these data, which describe a wide range of dimensions and are therefore available in a variety of formats, in a meaningful way.

Data is generated, for example, in **plant breeding,** from screening the ingredients of different plants for breeding selection to molecular biological methods that can be used to determine properties on the basis of the genome. In agriculture itself, data relating to the **environment** – such as soil constituents or moisture levels – play a role, as do weather data. And in both agriculture and forestry, remote sensing can be used to obtain data on the **crop** per area and the condition of the plants (maturity, diseases, pest infestation, etc.).

9.1.1.1 Research and Development

Biotechnological methods play an essential role in the use of renewable resources. Enzymes are able to precisely transform the complex components of biomass. In order to develop and use such methods in a targeted manner, it is important to understand what is happening at the molecular level. Enzymatic processes have long been used in industry. In food production, they are almost as old as the processing of food itself – a frequently cited example of enzymatic fermentation with whole cells is beer brewing, which was already known to the Sumerians around 3000 BC. Via the pharmaceutical industry with its large and complex molecules, often based on natural substances, biotechnology has now also found its way into the chemical industry. Its advantages for many applications are obvious: high selectivity under comparatively mild conditions and a very high efficiency, especially for targeted modifications of complex molecules. Enzymes are characterized by the fact that they function according to a "lock and key" principle: The molecule to be modified fits the enzyme in exactly one specific way. This is made possible by the often very complicated structures of enzymes, which can also change in the course of reactions. It is only thanks to new possibilities in analytics that it has been possible in recent years not only to understand the mechanisms of action, but also to predict them. The considerable amounts of data generated in this process are not only stored in databases, but are also used for the targeted development of new enzymes (Sect. ► 9.2.1.2).

In many biotechnological processes, different production organisms such as bacteria, yeasts or fungi are used. Compared to cell-free systems, such processes are more complex in terms of processing, but can be significantly more robust. In order to better understand and use the systems, the cellular level is comprehensively analysed. In order to increase yields, it is not only necessary to find the appropriate organism, but also to optimise it as far as possible in terms of production rates. In addition, the strains must be tolerant to the desired products and any by-products, and they must be able to tolerate fluctuations in process parameters such as pH or temperature so that the processes run as robustly as possible.

9.1.1.2 Process Development & Process Engineering

A single synthesis step does not constitute an entire process; most methods combine several conversion steps before the raw material has been transformed into the desired molecular structure. In recent years, there has been an increasing trend towards combining biotechnological and chemical reaction steps in order to use the alternative with the highest efficiency. However, this leads to new challenges – starting from the question of solvents (chemical reactions are usually carried out in organic solvents, whereas water is used in biotechnology), to the development of new process windows (temperature, pH, pressure, etc.) that enable a continuous process with few intermediate processing steps, to the very different requirements for the isolation of the products. Each individual reaction step is linked to a set of data that includes the reaction conditions, but also reaction rates, yields and much more.

An essential step in process development is *upscaling,* the transfer from laboratory scale to larger volumes. What works in a test tube cannot simply be reproduced 1:1 in a larger reactor. In the past, this usually required a step-by-step adaptation – from the laboratory scale with a few 100 mL to the pilot plant to the hectoliter range to the large-scale industrial process – which was essentially based on experiments. Today, researchers and developers are working on simulation and modeling methods that make it possible to directly calculate large-volume processes on the basis of existing data and models.

9.1.1.3 Process Control and Optimisation

Industrial processes are continuously monitored and improved even after their introduction. Process control and optimisation are based on the constant observation of processes with regard to process parameters such as temperature, pH or pressure as well as product control. Whereas in the past samples were taken for this purpose and brought to the laboratory, today as much as possible is measured in the running process *(inline)* in order to be able to react to deviations as quickly as possible. In addition, processes are continuously optimised to reduce energy and resource consumption, increase yields and cut costs.

9.1.2 Data Exchange

As a holistic approach, the bioeconomy is dependent on the interaction of a wide range of sectors. Accordingly, the exchange of data between different sectors is important, but so far this has mostly been unidirectional and usually only takes place between two fields.

9.1.2.1 Material Flow Management

A major difference between the previous mainly fossil-based economy and the bioeconomy is the question of raw material supply and availability. While fossil resources generally come from point sources (oil fields, coal mines) and have very similar compositions within a certain range of variation, the raw material sources for the bioeconomy are generally decentralised, vary seasonally, and the composition of biomasses can differ considerably. Therefore, material flow management has a crucial role to play. The question of feedstock availability is already one of the key discussion points of the bioeconomy at the macro level. So far, corresponding studies at the European Union level have focused mainly on biomass availability for bioenergy and on larger areas such as Germany or the European Union as a whole (BMU and BMELV, 2009; Elbersen et al., 2012; Europäische Kommission, 2019). For the individual plant, the regionally available quantities are the crucial issue (Verband Region Rhein-Neckar, 2010). Seasonal fluctuations can lead to low plant utilisation rates or even plant shutdowns and thus have a negative impact on economic efficiency. Therefore, the question of which material flows are available and where they are directed is one of the key challenges for the implementation of the bioeconomy. This requires data on the composition, quantity and location of the biomass as well as the demand and processing options and possible transport routes.

9.1.2.2 Integration of the *Supply Chain*

Until now, the data integration of the *supply chain in* the process industry has played a rather subordinate role. Unlike consumer goods such as cars, clothes or food, mass products such as platform chemicals are far away from the end consumer and can hardly be differentiated. Only with the new trend towards smaller batches and new business models that offer customer-oriented solutions instead of a bulk chemical product (Bjacek, 2014), does the backward integration of data across the value chain play a greater role: it enables companies to align their production more closely with customer needs. To do this, data such as specific customer requirements, delivery quantities by time and place, and additional services must be bundled and fed back into production; from there, orders to suppliers are in turn controlled, in extreme cases all the way to the beginning of the value chain at the raw material producer.

9.1.3 Data Storage

In view of the enormous amounts of data that are already being generated every day on the Internet, in research or in industrial process monitoring, the question of suitable storage methods arises. Conventional storage systems have limited capacities, require space and raw materials and, last but not least, energy – the CO_2 footprint of the digital society is increasingly becoming an issue.

Instead of looking at new electronic storage media, the focus is on biological systems. After all, DNA is nothing other than a very compact data storage medium. Up to 215 petabytes (that is 215 million GB) of information can be stored in one gram of DNA. If properly stored, it can be preserved for centuries and millennia, and the “data format” is dictated by nature and thus readable by future generations regardless of technology (Service, 2017). Not only scientific institutions, but also companies are already researching ways to make the processes for storing data in DNA cheaper and faster (Pharmabiz, 2018). However, the method is still too expensive and too slow for everyday applications.

9.1.4 Cross-Cutting Data Models

The vision of the bioeconomy includes sustainability as a basic requirement. A biomass-based economic system can only be sustainable if all stages from agriculture and forestry to logistics and processing to use and recycling are taken into account. This means that the data from each individual stage is given to the product as a "rucksack". These include models ranging from the "footprint" (usually related to individual environmental parameters such as water consumption or CO_2 emissions), methods for measuring the resource efficiency of processes, through to life cycle assessment or life cycle analysis in its various variants (► Chap. 20). What all these methods have in common is that they require an enormous amount of data to deliver meaningful results (O'Rourke, 2014; Saurat et al., 2015).

9.2 Innovations

The overview shows how much data can be of importance for the bioeconomy. While a wide variety of innovations based on digitialisation are already in use today within the individual sectors or are about to be introduced in practice and significantly increase efficiency within the individual sectors, digital models based on data exchange or describing entire systems are still rather in their infancy. However, it is precisely here that the potential for innovation is likely to be greatest.

9.2.1 Digitalisation of Individual Areas

9.2.1.1 Resources

Digitalisation can make significant contributions to more efficient land use. This starts with the plant: Modern analysis and high-throughput methods make it possible to significantly accelerate the breeding of plants with certain characteristics (Koch, 2014; Spektrum, 2018). This involves, among other things, analysing and selecting the desired breeding traits already in the genome. High-throughput analysis techniques make it possible to simultaneously record the metabolic products of the plants. One example of the use of such methods is the breeding of the Russian dandelion for the production of natural rubber (FNR, 2011). Thanks to the new techniques, suitable plants could be selected and optimised starting from a project in 2011, and seven years later car tyres made from the dandelion rubber are being tested (Continental, 2016) – an enormously short development time for such a process. However, the market launch has so far been hindered by the (still) uncompetitive costs.

But the digitalisation of agriculture does not end with the plant. *Precision farming* is the locally differentiated and targeted cultivation of agricultural land. The differences within a field are taken into account on a small scale. Remote sensing data can provide information on moisture or chlorophyll content, for example, while sensors on agricultural machinery determine parameters such as nitrogen content while driving across the field. This data can then be used to supply small units of land with fertiliser, pesticides or water with pinpoint accuracy (Pößnek, 2011). Digitalisation has also already found its way into forestry: With the help of drones, forest stands can be mapped from the air and checked for damage. Modern forestry machines can use sensors to record timber harvesting volumes and optimise sales assortments (Forstpraxis, 2017).

Comprehensive data on the available resources should be incorporated into material flow management in the future. Efforts are being made to develop integrated models in which the raw materials are analysed and the analytical data on their composition and material contents are fed into material flow exchanges together with information on the quantity of raw materials and the place of origin or storage. In such exchanges, availability and demand could then be brought together and, at the same time, optimal transport routes determined in order to bring the biomass from the supplier to the consumer with as little effort as possible.

For other resources such as sponges or microalgae, systematic recording of potentials is still in its infancy; for example, of an estimated more than 100,000 algal species, fewer than 10,000 have been classified to date (Bippes et al., 2016).

9.2.1.2 Industrial Processes

▪▪ Research and Development

Plausible estimates say that not even 1% of microorganisms can be cultivated in the laboratory. For this reason, new microbial enzymes are usually first discovered *in silico*, i.e. by computer analysis of the genome data of very diverse microbial communities, for example from soils or wastewater. The amount of data and the computational effort required for metagenome analysis are gigantic, because the data sets from the sequencing, which are several gigabases in size, have to be assembled into overlapping genome sequences in the computer and searched for protein-typical sequence patterns. Due to the enormous progress made in bioinformatics and chemical biology, which would not have been possible without appropriate data processing capabilities, the understanding of how biomolecules function has deepened enormously in recent years. As a result, “tailor-made” enzymes can now be developed. For example, the Braunschweig database BrEnDa contains data on more than 84,000 enzymes (BRENDA, 2019). In total, more than 20 million protein sequences, “enzyme blueprints”, are now stored in scientific databases. Much smaller is the number of known three-dimensional protein structures, of which about 140,000 are currently archived in the Protein Data Bank. This information is important for the targeted *in silico* design of new enzymes with precisely predetermined functions (Bornscheuer et al., 2012). To generate them, one uses directed molecular evolution of those regions of an enzyme that are relevant to the functions to be optimised. Modern, data-intensive, high-throughput methods make it possible to apply the mechanisms of evolution in the test tube (*in vitro*) and to “fish out” the desired enzymes from libraries of 10^9 to 10^{10} molecular variants.

However, digitalisation opens up new avenues not only at the molecular level, but also at the cellular level:

> Tomorrow’s bioeconomy relies on emerging technologies such as synthetic biology (the direct engineering of microbes and plants), proteomics (the large-scale study and manipulation of proteins in an organism), and bioinformatics (computational tools for expanding the use of biological and related data), as well as new technologies as yet unimagined (US Government, 2012, S. 1).

All these methods are based on obtaining and processing very large amounts of data: Complete genetic information (genome), the entire protein inventory of a cell (proteome) or all metabolic products (metabolome) are analysed and evaluated, for example, to open up new production possibilities. Through so-called *pathway engineering*, the metabolism of the cell is “modified” in such a way that secondary metabolites are produced in much higher quantities, i.e. by-products of the cellular metabolism. Modern methods of *genome editing* such as CRISPR/Cas enable the targeted exchange of individual genes. Synthetic biology aims to use “bio-bricks”, i.e. biological building blocks, to assemble metabolic pathways or organisms that optimally fulfil certain tasks (Becker et al., 2016). In addition to the development of evaluation methods, the prerequisite for the use of all these processes and their further development is a high-performance IT infrastructure (Deutsche Akademie der Naturforscher Leopoldina e. V., 2014).

Process Development and Process Engineering

An essential prerequisite for the development of biotechnological process steps is strain development, i.e. the targeted selection and cultivation of microorganisms that have proven to be particularly suitable for a specific production task. For this purpose, many test approaches are nowadays carried out in a largely automated way within the framework of high-throughput procedures: Cultures are prepared in tiny reaction vessels, and machines are used to screen and select strains for further development. More than 10,000 strains can be tested per week in this way.

High-throughput methods in miniaturised reactors are also used for process development. Analysis and evaluation are automated. This means that reaction conditions can be optimised within a very short time. With the help of modern simulation and modelling methods, not only individual steps can be calculated in advance, but also entire synthesis paths. Particularly when integrating chemical and biotechnological processes that follow completely different prerequisites, the use of algorithms to determine the "lowest common denominator" is an essential aid in process development.

For biotechnological processes, *upscaling* is generally more complex than for classical chemical processes. Biotechnology is subject to many more factors and interactions, and inhomogeneities in the reactor can lead to populations developing quite differently in some areas than is actually desired. This step, too, is now often carried out with the help of modelling calculations – or it is dispensed with altogether and approaches of *up-numbering* are followed instead: instead of one large reactor, many small reactors are used. At the same time, this allows production quantities to be adjusted extremely flexibly.

Process Control and Optimisation

Even if the process then runs on an industrial scale, the influence of digitalisation does not stop – quite the opposite. Processes are becoming increasingly automated. This is possible thanks to new sensors that record a variety of process data in real time and as non-invasively as possible and report it to the controller, which processes the data immediately. This can go as far as the sensor itself intervening in the process in a controlling manner, thus creating an independent local control loop. In this process, the "intelligence" increasingly migrates from a central control station to the individual sensors themselves. This partially circumvents the problem of the huge volumes of data that need to be transported and reduces response times (DECHEMA, 2017). New optical sensors allow the parallel measurement of multiple parameters. Such devices can perform a complete spectral analysis and thus determine, for example, nitrogen compounds, organic compounds and other measurands simultaneously and in real time – important for environmental monitoring, but also biogas plants or fermentative processes. At the same time, it has become clear that biotechnological processes, with their high complexity and inherent dynamics, cannot be fully modelled from a scientific point of view. Various relevant parameters, such as biomass concentration, are very difficult or impossible to determine directly *in situ,* which leads to high inaccuracies. Therefore, scientists are developing process monitoring systems based on *fuzzy logic* (Birle, 2017). Such systems are intended to represent what a human plant operator incorporates into decisions as experiential knowledge or "gut feeling". They can carry out process optimisations despite inaccuracies or incomplete information and thus control fermentations in the food industry, for example. So far, however, many of these innovations have been hampered by the lack of common data standards and permeability within the production plant.

9.2.1.3 Material Flow Management

A whole series of projects at national and EU level are currently addressing the question of how material flows can not only be recorded, but also how the availability of a wide variety of biomasses can be reconciled with the needs of processors depending on location and time and actively managed. The EU's DataBio project, for example, aims to use big data methods to optimally match the cultivation portfolio to the needs of the processing industries (DataBio, 2018).

9.2.1.4 Supply Chain Integration

The integration of the *supply chain* from the raw material supplier via the processor to the end customer is at the heart of the "Industry 4.0" concept. This does not stop at the bioeconomy. In medicine, in the form of personalised medicines, or in consumer products such as muesli or clothing, the individualised product is already established. Particularly in the case of consumer-oriented products, such as cosmetics or food, such approaches are also easily conceivable in the context of the bioeconomy. They appear somewhat further away in the production of chemicals or plastics, which are then further processed. Turning customer demands into products quickly requires a data stream running along the entire value chain. So far, it is not only technical hurdles such as different data formats that stand in the way, but also concerns regarding the protection of trade secrets.

9.2.2 Systemic Approaches

In order to assess the bioeconomy from a systemic perspective, not only data but also corresponding data models are lacking. With the "Bioeconomy Monitoring" project, the German government has provided an impetus to create the corresponding foundations. Based on three pillars – raw material availability (Thünen-Institute, 2018), economic aspects (Fraunhofer ISI, 2018) and sustainability as well as an integrated modelling tool (UFZ, 2017) – a comprehensive systemic monitoring is to be established that can provide the basis for more far-reaching decisions.

9.2.3 New Business Models

Digitalisation also opens up opportunities for new business models. Who carries out measurements? Or – especially in the case of data integration across several companies – who acts as a neutral "data broker" and ensures that critical data does not fall into unauthorised hands? In *precision farming*, for example, *farming service providers* very often take over the geocoded soil sampling, the planning of fertiliser use and the creation of corresponding maps (Pößnek, 2011). There are already approaches for start-up companies to establish themselves as service providers for data storage and exchange.

9.3 Images of the Future

The greatest potential of digitalisation for the bioeconomy lies in the convergence of the individual innovations mentioned. The combination of the different technologies in interaction with other trends such as miniaturisation can lead to the implementation of completely new approaches for the bioeconomy that would not be conceivable without digitalisation.

9.3.1 Vision: Industrial Development Pipeline

Numerous new methods have already found their way into research and development laboratories. The consistent combination of these methods, which are largely based on miniaturisation, automation and/or digitalisation, has the potential to make industrial development processes completely different in the future than they are today and lead to new business models and markets. The first companies are already largely relying on the generation and evaluation of large biotechnological data volumes for the development of antibody or gene databases that are built and evaluated on behalf of other companies. The working world for scientists will also change fundamentally if work processes are systematically made more flexible and digitally supported.

> The industrial development pipeline of the future will thus resemble an automated production line in the automotive industry more than a classic laboratory operation. The employees of corresponding companies will be able to concentrate on the essentials in the laboratory thanks to assistance systems and will work predominantly at the computer, where they will design biological systems and processes on the drawing board, commission experiments using distributed resources and monitor automated, modular production processes with intelligent sensor networks (DECHEMA, 2018, p. 9).

Such concepts are particularly interesting in the field of process development, where it is a matter of selecting suitable molecular structures or organisms from a large number of possibilities. They have already been implemented to some extent in the development of biopharmaceuticals, for example in antibodies or in personalised medicine. However, the prerequisites for a comprehensive and cross-company implementation also for industrial biotechnology are, among other things, the creation of interfaces and data standards and the targeted combination of different technologies into a stringent overall concept.

9.3.2 Vision: Integrated Flexible Biorefinery

A central concept of the bioeconomy is the integrated biorefinery. Similar to the way in which petrochemical refineries today produce a range of platform chemicals, which are then used to manufacture the entire variety of chemical products, a biorefinery aims to produce a large product portfolio from biomass. Existing plants are based on a single feedstock, usually sugar, starch or vegetable oil. Some visions go a big step further: the flexible biorefinery could process a wide variety of raw materials, from green waste to straw and food processing residues, thus largely solving the problem of local and seasonal raw material availability. Such a highly flexible plant would have to be modular in design so that, depending on the raw material and product range, the individual plant components could be combined and exchanged, from raw material feed through pretreatment and processing to product preparation. Initial approaches to this exist in the field of flexible lignocellulosic biorefineries, which can be adapted to different raw materials such as sawdust or different types of straw. The prerequisite for this are “intelligent” components: Modules that perform a specific function communicate with each other, automatically adapt to each other and control each other. This requires ubiquitous interfaces and data standards that cover almost any combination of modules. The chemical industry is already developing such modular concepts. For a flexible biorefinery, which would have to cover a much wider range of raw materials, the number of possible modules would be much higher again and the variety – from bulk material hoppers to drying facilities and grinding plants, to consider only the step of raw material feeding and processing – much greater.

9.3.3 Vision: Decentralised Bioeconomy

One of the key differences between the fossil-based economy and the bioeconomy is, as mentioned, that the resources occur decentrally. In addition to the approach of optimising logistics, there is another school of thought: why should further processing not take place where the biomass is produced? Models for this range from mobile plants in containers for the extraction of phytoextracts to 3-D printers (BioPro, 2018) in every household that obtain their plastic granulate from the nearest farm. In order to implement this vision, completely new operator models would have to be developed in addition to the appropriate technological requirements, or the plants would have to be so highly automated and operate autonomously that even someone without specific process engineering training could use them. Depending on the amount of raw material, plants could be transported to the respective site on a mobile basis and would process the raw material into a saleable product, for example plastic granulate.

9.3.4 Vision: Maximum Sustainability and Value Creation from Field to Recycling

One of the key questions on the way to a sustainable bioeconomy is which raw material should be used to manufacture which product. In forestry, models already exist in which the parameters of a tree (circumference, rounding, etc.) are used to determine the recovery with the maximum added value. In the process industry, such models are still in their infancy. The vision: Available raw materials and desired products are fed into an algorithm that determines which raw material is converted into which product using which processes in order to achieve maximum value creation while at the same time maximising sustainability across the entire portfolio.

A large number of different synthesis routes based on different raw materials often exist for the manufacture of specific products. The increasing integration of biotechnological and chemical processes, in which one process step is carried out enzymatically and another "classically-chemically", increases the number of possibilities even further. However, this means that for each possible synthesis route or each individual synthesis step and each raw material, all the data on energy requirements, efficiency, by-products and their recycling, data on the ecological footprint and much more must be available. In addition, decisions often include parameters that cannot be represented in the form of "objective" data. One of the best known examples is vanilla, which can be produced both naturally and biotechnologically as well as synthetically. Beyond the available "bare figures", value standards for production (for example, livelihood security for farmers versus land consumption or "natural" versus "chemical-synthetic") are individual and can be in conflict with objectives.

9.3.5 Vision: Biological Transformation of Value Creation

The concept of the "biological transformation of value creation", which is currently being discussed, goes one step further. It is no longer limited to considering the bioeconomy as an economic system, but also includes the integration of the digital and technological spheres.

> » Last but not least, the comprehensive interaction of technical, informational and biological systems is leading to the creation of completely new, autonomous production technologies and structures,

> so-called biointelligent value creation systems. In essence, the transformation is taking place towards personalised health care, intelligent transport organisations, and decentralised production of consumer goods and food with the help of smart biomanufacturing devices (intelligent decentralised production cells). From the technical renewal of industrial value creation, an advanced form of economy is developing: the technology-based demand economy (Fraunhofer IPA, 2019, p. 9).

9.4 Conflicting Goals and Hurdles

Today, practical hurdles to digitalisation exist primarily in the area of non-uniform data standards. The permeability of data exchange often already fails within one sector due to missing interfaces and different data formats. Although work is currently being done on cross-manufacturer standards in certain fields such as the laboratory, biobanks or the process industry, implementation will still take some time.

In addition, questions of data protection and *ownership* play a role. With regard to companies, it is about business-critical data that should be kept within one's own company. With regard to the individual, this mainly concerns consumer behavior, which is, however, an essential factor for an integration of the value chain and the development of customer-specific products.

Both partial aspects and the bioeconomy as a whole are the subject of critical public debate. Questions relate primarily to the use of modern breeding methods and *genome editing*. The question of the legal classification of *genome editing* is still open; the strong rejection of genetic engineering in Germany and Europe means that some of the theoretically available methods cannot be used. If these restrictions are extended further, there is a danger that research in this area will continue to lose ground in a global comparison.

The second, more fundamental point concerns the bioeconomy as a whole: to what extent are we subjecting the biosphere to a purely economic view and subjecting nature to maximum efficiency thinking? Most of the effects of digitalisation are aimed at increasing efficiency; this is opposed by demands, especially from environmental associations, to fundamentally rethink current consumer behaviour. On the other hand, the digitalisation of the bioeconomy can be used to keep resource consumption – including land use – as low as possible and to open up new space for biodiversity.

Warning voices go even further, seeing digitalisation as a way to "hack the human being". If biology can be completely captured, described and controlled by data, why should this not also apply to the individual? The ethical debate about human dignity in the context of such biologistic approaches is already underway. Examples of an emerging debate about the social and ethical consequences of linking digitalisation and biologisation are the handling of genome data of individual human beings as a "logical" continuation of the collection of health data or the calculation and manipulation not only of purchasing decisions but also of political decision-making processes (Harari, 2018).

The structural consequences of a decentralised bioeconomy in particular have been less discussed to date. The consequences of a complete shift away from fossil-based industry towards a bioeconomy that is decentralised rather than taking place in large interconnected plants would be serious and probably only comparable to the regional consequences of the coal phase-out.

Finally, questions about the impact of digitalisation on the world of work also affect the bioeconomy. This becomes obvious when discussing modern research methods and "smart laboratories", which fundamentally change the role of those working there – in the worst case to an "executive organ" controlled by artificial intelligence, in the best case to a scientist who uses the automated and "intelligent" tools to support him and can contribute his creativity to a much greater extent than today.

References

Becker, A., Luzhetskyy, A., Takors, R., Weber, W., & Wiechert, W. (2016). *Positionspapier: Innovationsmotor Synthetische Biologie*. Vorgelegt von der DECHEMA-Fachgruppe Systembiologie und Synthetische Biologie. https://dechema.de/dechema_media/Downloads/Positionspapiere/PP_SynthBio_2016_A5.pdf. Accessed 17 July, 2018.

BioPro. (o. D.). *Biobasierte Kunststoffe für den 3D-Druck*. https://www.bio-pro.de/de/projekte/cluster-biopolymere/biofabnet/. Accessed 17 July, 2018.

Bippes, M., Brauer, T., Brück, T., Buchholz, R., Cotta, F., Friedl, T., Griehl, C., Griesbeck, C., Heckenberger, U., Kistenmacher, H., Michels, J., Mostertz, M., Muffler, K., Müller-Rees, C., Posten, C., Ripplinger, P., Schmidt, K., Stute, S., Trösch, W., & Verseck, S. (2016). *Mikroalgen-Biotechnologie. Gegenwärtiger Stand, Herausforderungen, Ziele*. DECHEMA. https://dechema.de/dechema_media/Downloads/Positionspapiere/PP_Algenbio_2016_ezl.pdf. Accessed 08 January, 2019.

Birle, S. J. (2017). *Fuzzy logic based solutions for the management of uncertainty-biased process control of fermentative systems*. Dissertation, Technische Universität München. https://mediatum.ub.tum.de/doc/1327234/1327234.pdf. Accessed 08 January, 2019.

Bjacek, P. (2014). *Chemicals in transition: Using technology to conquer megatrend challenges*. Accenture. https://www.accenture.com/us-en/blogs/blogs-using-technology-to-conquer-megatrend-challenges. Accessed 17 July, 2018.

BMU (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit), & BMELV (Bundesministerium für Ernährung Landwirtschaft und Vebraucherschutz). (2009). *Nationaler Biomasseaktionsplan für Deutschland. Beitrag der Biomasse für eine nachhaltige Energieversorgung*. https://www.eti-brandenburg.de/fileadmin/user_upload/downloads2009/nationaler_biomasseaktionsplan_bf.pdf. Accessed 08 January, 2019.

Bornscheuer, U. T., Huisman, G. W., Kazlauskas, S., Lutz, S., Moore, J. C., & Robins, K. (2012). Engerineering the third wave of biocatalysis. *Nature*. https://doi.org/10.1038/nature11117

BRENDA. (o. D.). *The comprehensive enzyme information system*. https://www.brenda-enzymes.org/. Accessed: 08 January, 2019.

Continental. (2016). *Continental brings dandelion rubber to commercial vehicles*. Continental-Pressemitteilung. https://www.continental-tires.com/car/media-services/newsroom/taraxagum/2016-09-15-dandelion-rubber-commercial-vehicles. Accessed 17 July, 2019.

DataBio. (o. D.). *Projektwebseite*. https://www.databio.eu/en/summary/. Accessed 17 July, 2018.

DECHEMA. (2017). *Positionspapier: Smarte Sensoren für die Biotechnologie*. https://dechema.de/dechema_media/Downloads/Positionspapiere/PP_SmartSensors.pdf. Accessed 08 January, 2019.

DECHEMA. (2018). *Positionspapier: Neue Schubkraft für die Biotechnologie*. Miniaturisierung, Automatisierung und Digitalisierung revolutionieren die Entwicklung biotechnologischer Prozesse und Produkte. https://dechema.de/dechema_media/Downloads/Positionspapiere/PP_Schub_Biotechnologie_2018_A5.pdf. Accessed 08 January, 2019.

Deutsche Akademie der Naturforscher Leopoldina e. V. – Nationale Akademie der Wissenschaften. (2014). *Zukunftsreport Wissenschaft*. Lebenswissenschaften im Umbruch – Herausforderungen der Omics-Technologien für Deutschlands Infrastrukturen in Forschung und Lehre. https://www.leopoldina.org/uploads/tx_leopublication/2014_Zukunftsreport_Langfassung_web.pdf. Accessed 08 January, 2019.

Elbersen, B., Startisky, I., Hengeveld, G., Scheelhaas, M.-J., Naeff, H., & Böttcher, H. (2012). *Atlas of EU biomass potentials. Deliverable 3.3: Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources*. Biomass Futures. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biomass_futures_atlas_of_technical_and_economic_biomass_potential_en.pdf. Accessed 17 July, 2019.

Europäische Kommission. (2019). *Biomass availability and sustainability information system (BASIS)*. https://ec.europa.eu/energy/intelligent/projects/en/projects/basis. Accessed 17 July, 2018.

FNR (Fachagentur Nachwachsende Rohstoffe). (2011). *Kaukasischer Löwenzahn – künftige Rohstoffquelle für die Reifenindustrie?*. FNR-Pressemitteilung. https://news.fnr.de/index.php?id=8145&tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Baction%5D=detail&tx_news_pi1%5Bnews%5D=3345&cHash=a4a9dd257a0564352d67e0e188336690. Accessed 17 July, 2018.

Forstpraxis. (2017). *ThüringenForst: Digitalisierung initiiert Branchenwachstum*. https://www.forstpraxis.de/thueringenforst-digitalisierung-initiiert-branchenwachstum/. Accessed 17 July, 2018.

Fraunhofer IPA (Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA). (2019). *Biointelligenz: Eine neue Perspektive für nachhaltige industrielle Wertschöpfung. Ergebnisse der Voruntersuchung zur biologischen Transformation der industriellen Wertschöpfung (BIOTRAIN)*. Fraunhofer.

Fraunhofer ISI (Fraunhofer- Institut für System- und Innovationsforschung ISI). (o. D.). *Ermittlung wirtschaftlicher Kennzahlen und Indikatoren für ein Monitoring des Voranschreitens der Bioökonomie (Bioökonomie-Monitoring)*. Projektwebseite. https://www.isi.fraunhofer.de/de/competence-center/neue-technologien/projekte/biooeko-monitoring.html. Accessed: 17 July, 2018.

Harari, Y. N. (2018). *The new challenges of the twenty-first century*. Rede anlässlich der Eröffnung der Jahrestagung des Deutschen Ethikrats 2018. https://www.ethikrat.org/fileadmin/jahrestagung-2018-simultanmitschrift. Accessed 13 December, 2019.

Klitkou, A., Bozell, J., Panoutsou, C., Kuhndt, M., Kuuslsaarl, J., & Beckmann, J. P. (2017). *Background paper: Bioeconomy and digitalisation*. MISTRA – The Swedish Foundation for Strategic Environmental Research. https://www.mistra.org/wp-content/uploads/2017/12/Bilaga-1-Bakgrundsdokument-Bioeconomy-and-Digitalisation.pdf. Accessed 08 January, 2019.

Koch, M. (2014). *Moderne Labormethoden ergänzen die klassische Pflanzenzüchtung*. Innovation. https://www.magazin-innovation.de/export/sites/magazin-innovation.de/extras/dokumente/Innovation-ab-4-13/1-14-moderne-labormethoden.pdf. Accessed 08 January, 2019.

O'Rourke, D. (2014). The science of sustainable supply chains. *Science*. https://doi.org/10.1126/science.1248526

Pharmabiz. (2018). *Molecular assemblies completes store and receive digital information in DANN*. http://www.pharmabiz.com/NewsDetails.aspx%3Faid%3D110850&sid%3D2. Accessed 28 August, 2018.

Pößnek, J. (2011). *Precision Farming im Pflanzenbau. Landesamt für Umwelt, Landwirtschaft und Geologie, Freistaat Sachsen*. https://www.landwirtschaft.sachsen.de/landwirtschaft/download/Precision_Farming-Endfassung-Internet-v2.pdf. Accessed 17 July, 2018.

Saurat, M., Ritthoff, M., & Smith, L. (2015). *Overview of existing sustainability assessment methods and tools, and of relevant standards: Sustainability assessment tools to support decision-making in the process industries*. https://www.spire2030.eu/sites/default/files/users/user355/SAMT_D.1.1_final_updated-links_Dec2016.pdf. Accessed 03 October, 2019.

Service, R. F. (2017). *DNA could store all of the world's data in one room*. Science. http://www.sciencemag.org/news/2017/03/dna-could-store-all-worlds-data-one-room. Accessed 08 January, 2019.

Spektrum. (o. D.). *Lexikon der Biologie – Pflanzenzüchtung*. https://www.spektrum.de/lexikon/biologie/pflanzenzuechtung/50727. Accessed 17 July, 2018.

Thünen-Insitut. (o. D.). *Bioökonomie-Monitoring*. Projektwebseite. https://www.thuenen.de/de/institutsuebergreifende-projekte/biooekonomie-monitoring/. Accessed 17 July, 2018.

UFZ (Helmholtz-Zentrum für Umweltforschung). (2017). *SYMOBIO – Systemisches Monitoring und Modellierung der Bioökonomie*. Projektwebseite. https://www.ufz.de/index.php%3Fde%3D37150. Accessed 17 July, 2018.

US Government. (2012). *National Bioeconomy Blueprint released. White house president Barack Obama*. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf. Accessed 08 January, 2019.

Verband Region Rhein-Neckar. (2010). *Biomasse-Stoffstrommanagement für die Region Rhein-Neckar*. Metropolregion Rhein-Neckar. https://www.edoweb-rlp.de/resource/edoweb:7007444/data. Accessed 08 January, 2019.

Kathrin Rübberdt

(born 1973) studied chemistry at the Georg-August University of Göttingen and the University of Leipzig and received her doctorate from the Georg-August University of Göttingen. From 2001 to 2008, she worked in strategy at various management consultancies. She also completed additional studies in business administration at the Distance Learning University of Hagen. Since 2008 she has been working in the office of the DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e. V. (Society for Chemical Engineering and Biotechnology). Since July 2021, she is Head of the Division "Science and Industry".

Organisational Forms of the Bioeconomy

Contents

Actors in the Bioeconomy

Urs Moesenfechtel

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D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_10

10.1 Introduction

The bioeconomy is supported, shaped and questioned by actors from industry, research and society. They are involved in numerous fields of action. This chapter presents some of these actors from a wide range of fields. Both individual portraits of "bioeconomy makers", and presentations of networks, clusters or platforms provide an overview of the organisers and organisational forms of the bioeconomy. The focus is on the clusters that are widely spread in Germany, in which several bioeconomy actors come together, primarily regionally and usually mainly oriented towards a specific biomass resource. In addition to all that, the reader is given an outlook on the European forms of organisation of the bioeconomy is given.

Despite clusters, networks and platforms, many actors are not centrally organised and only interact with those actors that fit their individual needs. Nevertheless, the presentation of the clusters active in Germany is particularly suitable for illustrating the bioeconomic specificity of the interaction. This specificity lies in their inter- and transsectoral networking, which takes place due to the competition with existing industries and alliances of conventional economic forms. Their strength lies in the claim to build up sustainable coupling and cascading uses, circular economy and science integration.

This book attempts to narrow down the list of actors and to provide an insight into the actors and their associations. It is proposed to divide the landscape of actors into two or three main groups:

- "Bioeconomy circle actors", defined by the concrete handling of biomass along the bioeconomy-relevant material flows, such as biomass resource producers, biomass resource processors, market distributors, recyclers etc.,
- "bioeconomy framework actors", that have an impact on this system or are influenced by it. These would be, for example, the media, funding agencies, science, NGOs, politics and administration, etc., as well as
- Actors that can be considered as "networkers", such as logistics providers, IT service providers or even cluster organisers.

This rough subdivision structures the following presentations. It was not possible to draw on numerous research studies, and there was no existing overall view. This is due to the complexity of the bioeconomy system and the fact that the bioeconomy can be regarded as an economic and social system that is still being developed. Nevertheless, an initial overview of the landscape of actors is provided below in the form of self-portraits.

10.2 Christian Schiffner – Forest Engineer

Source: Private

My name is Christian Schiffner and I have been a qualified forest engineer since 2008. As a freelance forester and managing director of holzimpuls Service u. G., which emerged from the Holzimpulszentrum Rottleberode in 2017, I deal with almost all aspects of forest management, wood use and associated nature conservation and environmental protection issues. The holzimpulszentrum sees itself as an important component of a wood-based bioeconomy. My activities as a scientific assistant at the Rosenheim University of Applied Sciences underline this self-image. There, I devote myself to scientific questions concerning sustainability or innovation issues in the wood industry. This includes, for example, the development of strategies for the economic use and silvicultural treatment of heavily peeled hardwood stands.

As a forester, I am at the beginning of the wood raw material chain and at the same time bear the responsibility for preserving the forest, wood and nature for future generations. With the knowledge of climatic changes and site conditions, I make, for example, precise decisions about the care and preservation of a particular section of forest. We plant new trees and remove timber, taking into account the protection and recreational needs of the forest.

However, the forest is not only a “resource provider”. It provides a unique habitat for animals and plants. It is also a recreational area for us human. It is important for the climate, it stores and filters water and cleans our air. Although forests are always managed by specific owners, we and society as a whole as a society make use of the “ecosystem services”, provided by the forest, e.g. water filtration. Thus the forest is always a “public good”, and its management is therefore not only subject to private-sector interests. Most certainly, forest management is subject to numerous interests and requirements that must be reconciled. This can only succeed if forests are managed and cared for in such a way that both their protective and public services and their timber products are simultaneously and permanently safeguarded over the entire area. We foresters speak here of sustainable management strategies implemented through compliance with professional quality standards.

Energy recovery should therefore always come at the end of a raw material’s use. In view of the many possible uses of wood, the timber industry is one of the mainstays of the bioeconomy. However, the work of the forestry industry is coming under increasing criticism because many work processes are not sufficiently well known to the general public and therefore lead to misunderstandings. One reason for this is probably the increasing urbanisation and thus alienation of society from nature. Due to the lack of contact with nature – by which I do not mean urban parks, but rather extensive forest areas – nature is romanticized. “Managed nature”, cannot be reconciled with this ideal image.

Thus, protests against necessary forest protection measures are increasing. Even if, for example, paths are kept clear, specific forest habitat types are preserved or restored, or natural regeneration is secured. Of course, a harvesting machine in the forest is a major intervention, but it is also necessary if the raw material wood is to be obtained. In addition, it is often kinder to the forest and also more economical to carry out short, targeted interventions with harvesting machines instead of working in the forest over a longer period of time with smaller machines (e.g. chainsaws).

I am convinced that modern forestry, which provides wood as a raw material in a measured and targeted manner, can be easily combined with nature conservation requirements. After all, compared with conventional forestry, but also with other ecosystems or previous technical solutions, sustainably managed forests in particular effectively make the greatest contribution to long-term CO_2 sequestration – and thus also to climate protection.

My task as a forester is to preserve the forest as an ecosystem and economic factor for future generations. An essential part of this is not only the concrete work in the forest, but also networking in the economy, science and society. Thus, public relations work has also become an important part of a forester's work. The fact that so many different groups claim "the forest", from naturally leads to the fact that all "forest topics", are discussed very controversially. This will not diminish with a developing bioeconomy; after all, the bioeconomy will increase the demand for wood. The existing and future increasing controversies also have the advantage that we as foresters can inform about the forest ecosystem, the timber industry and the wood-based bioeconomy.

I advocate a curious, respectful, appreciative, but also demystified view of the forest and its management. To this end, I offer, for example, interactive forest tours, provide information – not only on the Internet – about wood-based products, advocate for sustainable forestry in committees, and much more. Together with our network partners and competent professional colleagues, I would like to interest a younger generation in particular in the forest, so that they become involved in the preservation of this important cornerstone of our nature and our economy.

For the bioeconomy, I would like to see research into this raw material being driven forward and more products becoming marketable that can be found not only in DIY stores but also, for example, in pharmacies, supermarkets or car dealerships.

Yes, I am on the wood path. And it leads me and the bioeconomy into a sustainable, innovative and renewable future!

10.3 Daniela Pufky-Heinrich – Scientist

Source: Private

My name is Daniela Pufky-Heinrich. I am a qualified chemist in the field of technical chemistry. For 7 years, I have headed the Chemical Processes Group at the Fraunhofer Center for Chemical-Biotechnological Processes CBP.

The Fraunhofer Society focuses on applied research and the creation of innovation in an industrial environment. Together with the state of Saxony-Anhalt and the federal government, the centre was founded in 2009 at the chemical site in Leuna and has since concentrated on sustainable processes for the use of biomass in the chemical and process industries. The mission of the Fraunhofer-Society and the funding agencies was to create a basis for an innovation centre that addresses and promotes the knowledge-based bioeconomy.

As a group leader, I built up the department of chemistry and processing technology. My goal as a scientist was and is to assess future research perspectives and priorities and evaluate its market potential in order to set-up the appropriate infrastructure within the centre. My work as a group leader meant a great challenge, which provided an exciting opportunity to carry out my work with foresight and determination. It required strategically sound decisions as well as a fair amount of enthusiasm and stamina. After completing the set-up phase, I was appointed deputy head of the centre and have since been in charge of the strategic and scientific orientation of the work area as well as the entire centre.

The research and policy strategies of Germany and Europe have a significant influence on our activities. The development of production routes for bio-based fine and platform chemicals, bioactive agents, polymer building blocks or fuels are examples of our research. Sugars, lignocelluloses, oilseeds or even microalgae are pulped, chemically or biotechnologically converted and processed for industrial use. The focus here is on replacing petroleum-based products and thus, process development is mainly product-driven. In recent years, we have developed processes for the production of olefins from wood for use as polyethylene and polypropylene. Fuels such as isooctane or ETBE have been obtained from sugar solution and beta-carotene from the microalgae *Dunaliella salina.*

A very current research topic is the material use of carbon dioxide as an alternative carbon source, which is currently the focus of federal funding measures. Our task is to evaluate and phase technologies within the framework of the idea of sector coupling. Here, we demonstrate the entire process and value chain from carbon dioxide to the use of renewable energy and the production of green gases to the purified chemical. An essential component is the provision of sample quantities for application tests, for example as liquid fuel. This enables us to prepare and accelerate the transfer to industrial implementation.

Biomass utilisation generates large quantities of residual and waste materials. As an additional aspect, this results in recycling strategies for the use of waste or by-products, e.g., from the oilseed industry or wood and pulp production. In this way, novel products such as bio-aromatics or pharmaceutically active substances can be obtained. These recycling pathways offer industries the opportunity to increase the added value from their material flows and are an exempal for cascading use in accordance with a biorefinery concept. However, unlike *drop-in chemicals*, the market potential for the new products has to be developed first, which can delay and additionally challenge their industrial implementation.

A particular fascination for me is the interdisciplinary and cross-sector collaboration. Innovation and development take place at interfaces: In the future, forest farmers will supply adhesive manufacturers, the pulp industry will become a chemical manufacturer and oil mills will produce products for the pharmaceutical industry. It is challenging to unite the different interests, to develop ideas and to bring in new things. Initiating interdisciplinary projects on research topics, together with other scientists, is enormously important for this. In recent years, I have built up and intensified collaborations with colleges, universities and other research institutions. Open discussions and the unbiased exchange of knowledge and know-how across disciplinary boundaries are essential.

Germany has been driving the bioeconomy forward for years and should continue to be a technology pioneer. The development of innovative and novel processes is important in order to evaluate and implement the concepts. This requires a willingness to take risks and staying power on the part of politicians and, above all, industry. The latter still has potential, especially in Germany with regard to the chemical industry. Long depreciation periods for industrial plants and the large amount of energy required for production, coupled with dependence on energy prices, dampen the drive for innovation. Precisely for this reason, the technology transfer from science to industrial implementation should be further accelerated and actively supported.

Within the framework of publicly funded projects, we have the opportunity to push strategic developments for the sustainable utilization of biogenic material flows. The targeted development of research priorities for medium- and long-term industrial implementation is an important aspect. The focus here is not only on technical feasibility, but also on issues relating to the sustainable production of biomass, environmental protection and global food security. Life cycle analyses should therefore be just as much a part of development projects as technology analyses and techno-economic assessments.

The transfer of knowledge and the publication of our research activities is an important part of our work at Fraunhofer CBP. The findings therefore are also integrated into the teaching and training of students. For me, it is an incentive and a matter of the heart to pass on my knowledge and experience on bioeconomy topics. This is a contribution to social acceptance and openness to innovation and further development.

10.4 Holger Zinke – Biotechnologist

Source: Kristian Barthen, Archive BRAIN AG

My name is Holger Zinke, I am 55 years old. I see the “biologization”, of the economy as an opportunity to master the crucial challenges of the future. Whether climate change, resource consumption or the consumption needs of a growing population are concerned – the idea of integrating principles from nature into business and industry could provide crucial solutions.

As a micro- and molecular biologist, I have dedicated my working life to the realization of this vision. To this end, we founded the company “BRAIN”, in 1993 – a technology company specialising in white/industrial biotechnology and the bioeconomy. In the meantime, Brain is a publicly listed company and employs about 230 mainly scientific staff. BRAIN now has six subsidiaries and maintains over 100 collaborations with numerous companies in the chemical and consumer goods industries. From 1993 to 2015, I worked for BRAIN as Managing Director and Chairman of the Executive Board then until 2017 as Deputy Chairman of the Supervisory Board, and since 2011 I have also been running an investment and management company and building an academy and business incubator on the subject.

BRAIN has built up a very extensive collection of microorganisms over many years. On this basis, enzymes, biocatalysts and bioactive natural substances are developed for industrial applications using classical microbiological, molecular biological and molecular genetic methods. In essence, the aim is always to unlock the secrets of microorganisms: How and why do they work in this or that application? How can their properties be identified, improved, isolated and used? How do their active substances interact with other substances? How can products be developed from this knowledge?

Let’s take sweating after physical exertion as an example. We ask ourselves: How does sweating actually occur? How does the unpleasant odor develop? Can we add microorganisms to deodorants that prevent this odour formation? Aluminium salts are used in many deodorants for this purpose. However, these are not only harmful to the body because they clog the sweat pores, but also to the environment. We have therefore "reconstructed", a sweat cell and tested thousands of plant substances and metabolites on it. In the end, we were able to isolate substances that reduce the formation of sweat and others that influence the microbial growth of odour-causing bacteria.

Another example: a bacterium is currently being genetically modified in such a way that it metabolises CO_2 on a relevant scale and uses lactic acid to produce a precursor for bioplastics. If this not only works in the lab but becomes applicable in large-scale plants, it will be an immense contribution to solving the climate change and resource scarcity problem. Our products have implications for major industries and certainly for the sustainability of our existing or future economy. A scientific study conducted about 15 years ago marked a major breakthrough in our efforts to reduce CO_2 emissions. It showed that a "washing enzyme", could be used to wash clothes at 40° just as cleanly as at 60° – and reduce CO_2 emissions at the same time. In 2006, the reduction already amounted to an extrapolated 1.4 million tons of CO_2 in Germany – not as "potential", but as real savings.

When we were founded 25 years ago, such "bioeconomic ideas", mostly caused us to shake our heads. There was no social will for change, let alone a political one. The general optimism for the future at that time was still so strong that sustainability considerations only played a subordinate role. However, the "consequential damage", of this economic system has meanwhile become part of the general consciousness. The pessimism about the future that goes hand in hand with this leads on the one hand to many concerns that are connected with innovations, see "genetic engineering debate",; but it also leads to the fact that we are even thinking about restructuring our economic system on the basis of biobased resources, possibly even rebuilding it.

"We biotechnologists", want to contribute to this transformation, this "biologisation", with our ideas, methods, processes and products – even if our innovations are perhaps not as "obvious", as, for example, the car tyre made of dandelion or a bicycle made of bamboo exhibited at trade fairs.

Despite all the changes that have already taken place: The big "narrative", of the bioeconomy, the contribution of biology to sustainability, is not enough to trigger further changes. Large, established companies in particular do not tend to adopt or advance global policy guidelines. Rather, it is the lateral thinkers and company founders who develop and implement new economic ideas and force old industries to change. They need to be supported – and this is happening in some places. Through government funding programmes, initiatives, clusters. None of this is completely wrong, but it is also very formalized. However, "transformation", cannot be organized "on the drawing board". Above all, young companies need a functioning capital market ecosystem with venture capital investors who believe in their idea and want to earn money with it. However, there are far too few of these supporters in Germany, unlike in the USA, Israel and Canada, for example. In this country, people approach innovations with too much caution, trusting in the state to sort everything out. I miss a pronounced "opportunity culture".

The government measures taken so far are not strong enough to change this. It would be much easier to promote a culture of opportunity: I advocate that tax incentives mobilize at least 1% of investment-seeking, private capital to flow into technology companies. At the moment, however, capital flows are either used to bolster existing industries – or flow abroad. Germany is good at providing initial, structural support for start-ups, but they don't then stay here? That has to change.

A rule of thumb says: We need to create at least 20% additional economy every 10 years, with new products and new business models. This is how an economy renews itself, not only to be fit for the future, but also to be able to meet the major challenges. The bioeconomy can provide this renewal. Here we have the "knowledge explosion", that goes hand in hand with a change in social awareness. Hopefully in 20 years we will have built up these new industries that can replace the fossil economy.

10.5 Steffi Ober – Networker of an NGO

Source: Daniel Flaschar

My name is Steffi Ober, I have a PhD in veterinary medicine and a Master's degree in Public Policy from the Humboldt-Viadrina School of Governance in Berlin. With this background in both the natural sciences and the humanities, I work for the Nature and Biodiversity Conservation Union Germany (NABU) as a team leader in the area of economics and research policy. This also includes the bioeconomy.

When the establishment of a German bioeconomy began with the founding of the first Bioeconomy Council in 2009, NABU participated in the discussions right from the start – and was the first nature conservation organization ever to do so. Prior to this, it was primarily the topics of biodiversity and genetic engineering on which NABU contributed its positions and expertise, which was mainly due to the strong biotechnology orientation of research policy. However, with the Bioeconomy Council in 2009, the topic of the bioeconomy also became an important field of action for NABU under this name. However, a comprehensive understanding of the bioeconomy only developed over time among all those involved – and has not yet been completed.

I was allowed to drive this process forward for NABU in terms of content and strategy. First of all, the topic had to be made known within the association scene and a joint commitment had to be promoted – and then ultimately organised. Initially, the bioeconomy was not a term or a topic on which people would have committed themselves. At the time, many NGO actors were wondering whether the bioeconomy was just a new buzzword, whether the concept was viable, whether it made sense to get involved under this *umbrella term*. The work of environmental associations is usually focused on single issues, be it agriculture, plant breeding, food or oceans (and many others). Complex problem contexts encounter obstacles both internally and externally. Cross-cutting issues have a correspondingly difficult time in environmental associations, as the work in the organisations tends to be sectoral. Nevertheless: it has been possible to establish the topic of the bioeconomy within the association scene, even if the degree of engagement within the associations varies greatly and ranges from mere discussion groups and informal exchange opportunities to concrete political action strategies. Often, existing thematic complexes such as "bioenergy", or "biodiversity", have also been expanded to include bioeconomy topics. However, many of the activities do not take place at the member level, but at the association level. For example, several environmental organisations became involved at European level in connection with the EU's BioEconomy Stakeholders Panel and drew up a BioEconomy Manifesto. In the meantime, with the support of the BMU, a dialogue between associations has been established which supports joint exchange and political visibility.

For many years, it has been a matter of concern to me to bring science policy together with the work of NGOs, so that a strategic orientation of the bioeconomy can be discussed and shaped together. Much has been achieved in this area in recent years. In the early years, environmental associations played virtually no political role. The first calls for proposals on bioeconomy topics reflect this: in the funding programmes, some of which ran until 2016, social issues were only taken up at a very late stage. Today, social discourse is being taken into account and calls for proposals are being launched that explicitly address socio-political issues. My point is that the bioeconomy is not an exclusive topic for business or politics. However, politics could play a much greater role in promoting and supporting the exchange between organised civil society, science and industry and strategic integration.

I see both the term and what has now developed under it as an enormous opportunity. Here, different and often competing claims – whether these are resources, market shares, political spheres of influence or something else – are thought together. The example of "land", is a good illustration of this: For a long time, one could observe how a wide variety of actors, whether in the fields of agriculture, energy, material production, infrastructure or nature conservation, asserted claims to use without mutual agreement and planned and acted as if each had sole rights of access. Each tried to optimise its own system at the expense of the other – and that simply could not and cannot work. The bioeconomy offers the possibility of breaking down the individual user groups, making them transparent and identifying trade-offs. Competing groups can be brought together through the bioeconomy. Spaces can be created in which it is possible to negotiate conflicts together.

This systemic approach is the great advantage of the bioeconomy over other, previous approaches to thinking and acting. Accordingly, I am also strongly committed within the associations' scene to understanding the bioeconomy as an opportunity for systemically acting nature conservation. In this context, the bioeconomy is an additional area that can be used by us. Especially when it comes to discussing how we want to use our land in the future – whether for food, energy, recreation, materials, etc. The bioeconomy offers both solutions and opportunities. The bioeconomy in particular offers both solutions on how to alleviate the enormous pressure on land – and equally, the bioeconomy solves or will trigger further, additional land use pressure. It is therefore both a solution and a problem. For nature conservation associations, this also opens up new opportunities to rethink previously divergent convictions and concepts. The fact is that we cannot maintain the level at which we currently produce and consume. Our world has already reached the limits of what is ecologically feasible. Through the concept of the bioeconomy, these causes and effects can be better and more clearly seen, and solutions can be sought.

In the next few years, I see my main task as driving social discourse "on the street". The energy turnaround is well known to large parts of the population. But the necessity of a "material turnaround", a "defossilisation", is not. Crude oil is in many everyday products, in every mobile phone cover, every subway seat and also in my bicycle. It is not enough just to make our electricity needs new and independent of petroleum. In order for this social discourse to begin and lead to a social transformation as soon as possible, the topic must also – and much more decisively than before – be anchored in the political decision-making structures.

In addition, the transformation process must also be supported economically. Subsidies for environmentally harmful, oil-based production must be redirected. For example, land/resource use and social impacts in production should be taken into account in company balance sheets to a much greater extent than has been the case to date. We need new economic instruments so that externalities can be priced. This applies to both petroleum-based and bio-based products. Only in this way the bioeconomy can become competitive in the market economy without repeating old mistakes and making new ones. The challenge is to develop bioeconomy products that are ecologically and socially sustainable. This is no easy task! We environmental associations can contribute our expertise here via the bioeconomy discourse space.

It is a personal concern of mine to participate in this.

10.6 Viola Bronsema – CEO of a Trade Association

Source: BIO Deutschland e. V.

My name is Viola Bronsema; I have a doctorate in biology and I am the managing director of the Biotechnology Industry Organisation Germany e. V. – BIO Deutschland for short. Eleven entrepreneurs founded BIO Deutschland in 2004. The association has currently more than 350 corporate members and member organizations. It supports the development of the modern life sciences sector as an innovative and financially strong industry within the German economy.

We see biotechnology as a central element of the knowledge-based bioeconomy. Thus, we are committed to opening up a new scope for action in the production of goods, the development of innovative products, the establishment of progressive value chains and, ultimately, the formation of new customer groups and markets for traditional industry sectors on the basis of the life sciences.

As Secretary General and CEO, I am the special envoy of the Association (German Civil Code § 30 BGB) appointed by the Board of Directors. I am responsible for the executive management of the association, in particular for personnel matters and the ongoing business of the administration. My activities include coordinating with the association’s Board (e. g. on budget planning and controlling), creating concepts for the development of the association, networking activities to achieve the association’s goals, member support and recruitment, communication with politics and the media and staff management.

Research and policy strategies for a bio-based economy, a bioeconomy, have been in place in Germany since 2010. Germany is thus one of the industry strategy’s pioneers for this global topic. Accordingly, the coalition agreement of the Federal Government (2018 to 2021) stipulated that the transformation to an economy based on renewable resources will be further advanced with the help of the bioeconomy. This could be supported by an agenda “From Biology to Innovation” across relevant governmental departments, a “Biotech Agenda”, so to speak, which is to be developed jointly by industry, science and civil society. Similar efforts can be found at the European level. A bioeconomy strategy has existed since 2012, which was evaluated as of November 2017 and was updated in 2018. BIO Deutschland accompanies these processes on behalf of the German biotechnology industry. For example, we have been a member of the Federation of German Industries (BDI) since the beginning of 2017.

Biotechnology is becoming increasingly important in areas that go beyond nutrition. Examples can be found in medicine (diabetes, cancer and rheumatism drugs), the environment (sewage treatment plants, detergents and care products), with regard to climate (CO2-neutral production), raw materials ((degradable) bioplastics) and energy (biokerosene). The sustainability of the technology is often based on the biological production processes and the CO2-neutral extraction and conversion of renewable raw materials. The biotechnology industry, the chemical and pharmaceutical industry, but also other sectors are already using bio-based raw materials, processes and products in their business models.

I believe that Germany offers very good conditions for establishing a bioeconomy as another pillar of industry. And it should do so now. The pandemic has shown an unprecedented demand for vaccines and basic biologic materials to make vaccines. Similarly, the demand for medicines, seeds, food, etc. could increase. As early as 2009, the OECD formulated:

> » With appropriate policy and good leadership, the bioeconomy of 2030 should provide a higher quality of life and a more prosperous and environmentally sustainable future for all of the world’s citizens.

These challenges are the incentive for our work as an association and my work for it. The fact that I can work on these exciting future issues together with our full-time and voluntary staff, with entrepreneurial researchers, science-driven entrepreneurs, and with courageous and far-sighted politicians fills me with joy, respect and curiosity about what is to come.

10.7 Anne-Christin Bansleben – Company Founder

Source: Andreas Troitsch

My name is Anne-Christin Bansleben, I originally studied nutritional sciences at the Anhalt University of Applied Sciences in Bernburg and specialized in biochemistry and plant analytics. Looking “inside”, plants and finding out what kind of products can be developed from them fascinated me early on. Therefore, after graduation, I took over the management of a research project at the university as a research assistant.

The group’s projects aimed at a close link between science and industry. Several projects focused on the research of rhubarb, as the university has the possibility to access different species. There are about 40 varieties of rhubarb, and the university has done a lot of research on them. Our group found that there are ingredients in the roots of certain rhubarb species that can preserve leather. We isolated these substances and, in cooperation with a company, developed a rhubarb extract that can be used for tanning.

However, tanneries do not want to build new plants for a new type of tanning process, but use existing systems. The conversion of the tanning process to plant-based should also be economically feasible. No one invests in a new plant if it is not yet certain how a new product will establish itself on the market.

In order to incorporate rhubarb extract into existing tanning systems and processes, much detailed knowledge of the physiological and physical properties of the substance was necessary. The first tanning results looked very promising. We were able to show that the replacement of chromium salts or other heavy metals previously used for tanning is possible with our plant extract. Approximately 80% of all leather produced worldwide is tanned with chemicals that pose high environmental risks. For about 6 m^2 of hide we only need the extract of a 3–4 year old rhubarb root. This extract is safe for humans and the environment. The next challenge was an *upscale*: both the extract production and the leather tanning itself had to be successful on an industrial scale.

We were successful here too, so in 2010 we founded the company "rhubarb technology", and the leather fashion label deepmello, based in Leipzig. We had already immersed ourselves so much in the rhubarb theme that we wanted to continue on the path we had taken. We were able to win over numerous supporters who, like us, recognised the potential of vegetable tanning. However, the transition from a pure research activity to the founding of a company was anything but easy. A lot of time and energy went into building the company. Traditional financiers could not do anything with our innovative idea and we also did not have access to research funds. So we financed the company almost exclusively with private capital. All funds flowed into the development of the product, there was no thought of employees.

Our product "rhubarb leather", is now mature. Since we cultivate several fields on which the plants are in different stages of growth, we can harvest permanently and all year round using the cycle method. Large quantities of the raw material can be produced on a relatively small area. We sell the stalks of the edible rhubarb varieties we use to the food trade. From the stalks and leaves of the non-edible varieties, we develop ingredients for our cosmetics line, as they have antioxidant activity. All non-edible components remain in the soil and serve as fertilizer.

At present, we are mainly concerned with sales and market establishment. In addition, we continue to research alternative leather tanning processes and develop new products in the background. There is a clear need for further, sustainable tanning technologies, and the possibilities for innovation in this area are far from exhausted. We use our "outside view", when developing new products. We do not come from the traditional, centuries-old tanning trade, we do not continue established processes as others do. This is the only way we can develop new ideas that were previously irrelevant in this industry.

The cooperations with "bioeconomy players", already existing at the university were and are a decisive key to success for our company on the market. Above all, we receive tips on how to improve our product and company ideas. However, when it comes to specific business management issues or questions about the fashion market, which is new to us, we have specifically called in external consultants.

The "leather market", in the areas of production, trade and distribution, is a long-established market. Most tanners do not see the use of chrome – despite all the known environmental dangers – as problematic and stick to it. They are sceptical about new processes. In order to be able to score with new ideas, it is therefore necessary to have a great deal of knowledge about existing processes and their possibilities for change. It also requires a high degree of persuasiveness, which is only possible through exceptional product quality.

Our products – from handbags to car seat covers – are now produced on a large scale. But not only our rhubarb extract, but also our skins are produced ecologically sustainable and regionally in Germany. Furthermore, we are the sole distributor of our products. These aspects are a significant purchase argument for our customers. However, the establishment of an innovative product requires additional and direct customer communication. Only in this way can we present ourselves as reliable, long-term business partners. Almost all companies (more than 100) dealing with sustainable products in the leather sector know us, are interested in our products or already work together with us. Our business activities are aimed at getting even more large, visible brands in the commercial sector interested in our product. This can be all companies that use leather, not only in the fashion sector.

10.8 Kai Hempel – Company Founder

Source: Christoph Bockisch

My name is Kai Hempel and I live in Leipzig. During my business studies, the plan to start my own company matured. Then, about 4 years ago, I heard that more licenses for fish farming would be issued in Leipzig. Up to that point, I had no idea whatsoever about fish farming. But curiosity prevailed – and so my first business plan was born.

However, this could not be achieved with conventional farmed fish. The financial investment for the required infrastructure, feed and medicines was too high. Sustainability also fell by the wayside. So I needed a less demanding farmed fish that could cope better with the limited space of an aquaculture. During my research, I finally came across the African predatory catfish, which fulfilled this requirement. It also requires much less antibiotics than other farmed fish. The problem with the high feed costs remained.

Fishmeal is still partly used for fish farming of predatory fish. In the meantime, soy, algae or peas are often used instead of fish meal – but vegetable proteins do not cover the entire protein spectrum required by fish. The predatory catfish is basically an omnivore, but it also needs animal proteins for its growth. However, these are very expensive, so that my business plan no longer worked. Therefore, I looked for alternative sources of protein to use as feed. One solution is the production of insects as an alternative animal protein source.

So we founded madebymade GmbH, of which I have been managing director together with Dr. Jonas Finck since 2017. Our founding team consists of two business economists and a biologist. My tasks include public relations, the sale of our products and communication with donors. The core idea of madebymade is: “110%”, circular economy. A system in which no residual materials are left over that cannot be recycled. To this end, we have so far only collected plant-based residues from the food industry or the retail trade. We could also use animal products as feed, e.g. meat and milk, but we do not do this yet due to the high legal hurdles.

These residual materials are shredded and fed to our insect larvae. Possible false substances in the feed, such as glass or plastic, are sorted out beforehand. Theoretically, foreign matter could also remain in the feed. Our larvae feed exclusively on the organic matter and practically eat around it. The excrements of the larvae, the larval substrate, are sieved, thus separated from false matter and finally processed into organic fertilizer. The larvae are first dried and then pressed. In this way, apart from the press cake, we still obtain animal fats and oils. The press cake itself is processed into flour. This "protein meal" can be used, for example, as an ingredient in animal feed. A large part of the production runs automatically. Nothing has to be sorted by hand. Likewise, nothing is left over in the form of residual materials. We are a zero-waste company.

The idea of producing proteins from insects is not entirely new. There is another large company in Germany as well as various international market players, for example in Canada or the Netherlands. However, I do not see a big problem for us due to the competitors, because the demand for alternative protein sources is far from being covered worldwide. So far, Germany imports about 200,000 t of fishmeal for industrial animal breeding per year. Currently, we have already completed the first industrial plant near Leipzig. At present, we are mainly concerned with the first expansion stage of our production plant near Leipzig. Our medium-term goal is to process up to 205 t of residual materials from the food industry or retail trade per day. In future, we will be supplied, for example, by a Leipzig company that processes fruit and vegetables. They produce up to 10 t of residual materials per day – taking into account that they are not even a particulary large company. The potential of possible residual materials is therefore enormous. We can produce about 1 kg of insects from 2 kg of residual material. Our current plant can produce up to 3 tonnes of live larvae per day with 20 tonnes of input. The plant is designed for about 400 tonnes of protein meal per year. The initial plan is to produce up to 250 t of protein meal per year and, of course, to sell it. We only need a fraction of the area of a soy farm for the same amount of protein. And: We only use raw materials which are no longer suitable for human or other animal consumption.

Our production facility has a modular structure and functions like a system construction kit. Our goal is not only to sell the end products by mid-2020, but also to be able to offer system solutions for other possible producers worldwide. We only need the existing residual input quantity in order to be able to design and supply a custom-fit system solution, e.g. as a medium technology or downgrade model. We currently have interested parties from Poland, Spain and the Dominican Republic, among others.

We started with not much more than an idea and the resulting business plan, which was supported by the start-up initiative Smile from Leipzig. Through them and a great deal of personal effort, we established contacts with potential investors. Finally, we received "early bird financing", from a Saxon investor from Golzern Holding and were able to start building our first plant.

The biggest challenge for our company is scaling. We have to increase production as quickly as possible. This is the only way to achieve marketability. If we don't manage that, we won't survive in the future. But we know: Our end products are well received and our modular system in particular sets us apart from other companies. As far as we know, they operate immobile large-scale plants. Our modular system, on the other hand, is planned in such a way that it can be quickly deployed all over the world. This allows us to produce sustainably in larger quantities, on site.

Another challenge is the administration. Whether it is animal feed, food or similar – until recently there were no legal regulations for "insects". Accordingly, we often had to struggle with difficulties of understanding and comprehension on the part of those responsible. We see ourselves as feed producers – but do we also have to meet the same or even more requirements as others? Diseases, emissions, killing … as far as insects are concerned, this is all new territory. Are insects, for example, subject to slaughter regulations? According to the definition, blood must be shed during slaughter. But insects don't have blood. And an animal feed production plant must, by definition, be insect-free. Of course, this is not so easy to implement in our country. Many such issues have been resolved in recent months, including at European level, but the future certainly remains exciting.

But one thing is certain: We at madebymade like to get to the bottom of things and are persistent. It takes this urge to keep at it. Otherwise you can't start a company.

10.9 Andrea Noske – Head of Division at the BMBF

Source: BMBF/Hans-Joachim Rickel

My name is Andrea Noske and I am a graduate engineer in materials science in metallurgy. In my first 3 years of work, I was involved in the research funding of projects for the bacterial leaching of ore tailings. A process that was then discontinued in the early 1990s because the raw material prices did not justify the expense. Today, these processes are experiencing a renaissance under the heading of "biomining", and are considered to be part of the bioeconomy. Since 1988, I have not only been active in federal project funding – I also spent 4 years as science attaché at the German Embassy in Washington, DC, USA. I have been a federal civil servant at the BMBF since 1993 and am currently head of the "Sustainable Management; Bioeconomy", unit.

In this responsibility, my department funds research and development projects (R&D) in the field of the bioeconomy with more than €130 million annually – from the acquisition of biological knowledge to methods and technologies to application orientation on a laboratory scale. Through our funding measures, we seek to fill the "innovation pipeline", on the way to more bio-based products, processes and services. In addition, we are in active dialogue with all stakeholders from science, industry and society and are driving forward the development of a bioeconomy monitoring system.

For me as a "trained", engineer, it is fascinating to experience how life sciences are combined with technical sciences in the bioeconomy. Here, doors can be opened into completely new dimensions. For this to happen, however, science must have the freedom to take unfamiliar paths and take risks. This is the only way to find the best solutions for a biobased future. It is not only a matter of continuously developing technologies, but also of working on holistic solutions. These can originate from a single technology as well as from cross-technology approaches or social innovations. In particular, however, we need research that is open to new technologies, without blinkers or prohibitions.

In addition, questions about the value of ecosystem services and nature, about access to resources, about distributive justice and about sufficiency are also important. In the end, there are transformation processes of a magnitude that reach far beyond individual technologies, disciplines and topics. They will have an impact on the way we produce, work and live. We must therefore intensify citizen-oriented technical communication and participation so that the special features of the biobased economy become tangible for people.

The dual finding that there is an urgent need to act and that the bioeconomy opens up new opportunities to do so will shape the new National Bioeconomy Strategy. Building on previous experience and success, the strategy sets new priorities in order to tap the potential of the bioeconomy even better and more quickly. Above all, sustainable solutions are needed that offer real alternatives to traditional forms of production by taking into account the systemic interrelationships between biological systems and their environment, rather than selectively replacing one problem with another. Different perspectives must be linked and interactions at all levels must be taken into account. It is precisely the combination of biological knowledge with economic thinking – the art of managing under conditions of scarcity – that can lead to new breakthroughs.

The topic of the bioeconomy has also gained considerable global importance in recent years. There are now around 50 countries worldwide that have developed bioeconomy strategies. These programmes depend on the biogenic resources available in each case and on the political, social and technological framework conditions, thus illustrating the wide range of the bioeconomy. The trend shows that more and more countries are placing great hopes in the potential of bioeconomic solutions. However, it also shows that the development of the bioeconomy is dependent on international cooperation in order to achieve the ambitious overarching goals. This opens up a wide range of opportunities for exchange.

Cooperation with European partners, in particular, is an important key element with the tried and tested instruments of research, development and innovation cooperation. Overall, we will actively accompany the development of the bioeconomy at EU level in constructive dialogue with partners, because this is also the instrument where innovative regions can establish themselves across borders. The exchange of knowledge across national borders releases synergy effects, both for the cooperation partners involved and for the bioeconomy as a whole. The action plan presented in October by the EU Commissioners for Research, Agriculture and Environment on the road to a strong European bioeconomy is a major step.

10.10 Hans-Jürgen Froese – Head of Division at the BMEL

Source: Private

My name is Dr. Hans-Jürgen Froese. I am Head of Division 525 “Bioeconomy, Material Biomass Use”, at the Federal Ministry of Food and Agriculture (BMEL).

From 1983 to 1988 I studied geography with the subsidiary subjects agricultural economics and economics at the Justus Liebig University in Gießen and subsequently worked on a research project on agricultural trade policy issues of the EC southern enlargement.

I have been employed at the BMEL since January 1992. In addition to various officer functions, I worked as agricultural attaché at the German embassies in Madrid (1997–2000) and Buenos Aires (2003–2008). Subsequently, I moved to the Department for Bioenergy at the BMEL, where I was particularly involved with international issues and the development of sustainability regulations for biofuels. Since November 2010 – with an interruption for work abroad from August 2013 to December 2014 – I have been head of Unit 525, where I am responsible for issues relating to the National Policy Strategy for the Bioeconomy and for the BMEL's funding programme for renewable raw materials.

My day-to-day business is very much determined by organisational issues relating to project funding, technical supervision of the project management agency Fachagentur Nachwachsende Rohstoffe e. V. (FNR), and various enquiries on topics relevant to the bioeconomy. (FNR), and by various inquiries on bioeconomy-relevant topics. Longer-term activities include considerations on new concepts for the funding programme for renewable raw materials, the bioeconomy strategies, the further design of bioeconomy monitoring and the bioeconomy dialogue with society.

For me, bioeconomy means – in short – using our biogenic resources responsibly. In particular, the principles of sustainability and efficiency must be observed at all stages of the value chain and in all areas of value creation, whether in the *food* or *non-food sector*. The use of biological resources behind the term "bioeconomy", will play an increasingly important role in view of the coming challenges in the areas of food security, the supply of energy and raw materials to a world population that continues to grow, and with regard to climate protection and nature conservation. Whether the bioeconomy in the form of strategic approaches or as an economic concept "runs with", this trend will depend in particular on whether political bioeconomy strategies become established and convincing in terms of their implementation and visibility, or whether greater emphasis is placed on sector-specific individual strategies, such as biotechnology, digitisation, biodiversity, arable farming, grassland, animal welfare, forests, etc.

What fascinates me most about the bioeconomy is its breadth. It is a comprehensive subject area that encompasses many sectors and activities. Under the umbrella of the bioeconomy, one can deal with forward-looking innovative biotechnological processes as well as with questions of land use competition and forms of sustainable raw material provision. For me, it is particularly important that we follow a sustainable bioeconomy path that always keeps in mind the conservation of our natural resources for future generations.

I see the greatest advantage and thus also a certain success of the bioeconomy policy strategy as such in the holistic approach, which encompasses all biogenic raw material uses for all areas of application and with which future questions – such as the future availability of usable biomass – can tend to be answered better than would be possible via partial, sectoral considerations (example of bioenergy). I see future challenges for strategy implementation in particular in the concretisation and evaluation of policy measures to the greatest possible extent. This is because national measures will not only have to be evaluated on a national scale, but also with regard to their effects in other countries/regions.

With the Bioeconomy 2030 Research Strategy and the National Bioeconomy Policy Strategy, policymakers have created the initial framework conditions for sustainable bioeconomy development. However, various sector-specific individual strategies and action plans of the Federal Government also contribute to this. They must be reviewed in the light of further developments and adapted if necessary.

The United Nations Global Development Goals (SDGs) and the National Sustainability Strategy represent the highest frame of reference for the bioeconomy strategy. In this respect, the bioeconomy strategy is oriented in particular towards the sustainability and efficiency targets specified in this framework.

The first step towards establishing such a Community policy for the bioeconomy is to discuss whether such an EU bioeconomy policy is at all desirable and necessary as a complement to existing Community policies (e.g. whether it contains policy measures that cannot or cannot adequately be addressed in existing Community policies) and whether it is supported by the EU Member States. Furthermore, the question of departmental responsibilities is unlikely to be easy to resolve either at the level of the European Commission or in the Member States, since bioeconomy policy affects at least the sectoral policies of the agricultural, economic, scientific and environmental ministries.

In view of the limited availability of biological resources and dwindling fossil raw materials, research activities to increase the efficiency of resource use, including the broad field of breeding research, but also innovations in biomass digestion processes, in recycling processes and in the more efficient use of residual and waste materials, are particularly important. Research efforts to reduce greenhouse gas emissions must also be stepped up – across all stages of the value chain. Agricultural raw materials from agriculture have to play a special role here, as they can be used both for food and for numerous other uses in the *non-food sector*, whether in the material or energy sector.

The federal ministries have set up an Interministerial Working Group (IMAG) to deal with all issues relating to the implementation of the bioeconomy policy strategy. The IMAG meets as required, but usually at least twice a year. Among other things, it provides information on the various bioeconomy activities of the ministries and – where possible – coordinates individual measures.

The term "bioeconomy", has a very broad definition and is therefore not easy to communicate to citizens. In my opinion, problems of understanding and acceptance can only be overcome by means of long-term, target-group-specific information and dialogue measures. Sustainable bioeconomy development can only succeed if, in addition to politics and science, economic actors also support this process with appropriate investment decisions and consumers with targeted purchasing decisions. Without their willingness to produce new bio-based products in a sustainable manner or to consume sustainably produced products, it will not work.

10.11 Isabella Plimon – Active for the Bioeconomy in Austria

Source: BMNT/Paul Gruber

My name is Isabella Plimon and I am Head of Department for Innovative Climate- and Energy-Technologies and Bioeconomy at the Austrian Federal Ministry for Climate Action. I also represent Austria in the Strategic Energy Technology Plan (SET-Plan) and the EU-Innovationfons. Before joining the Ministry, I was an advisor on international energy policy and environmental policy for a former Minister of Science, Research and Economy in Austria. Before that, I represented the interests of Austrian companies at national, EU and international level in energy and climate policy for almost ten years. My degrees from the Vienna University of Economics and Business Administration and the Technical University of Berlin also help me to view the topic of the bioeconomy in a cross-cutting way with a view to the associated value chains. This experience in the field of energy and climate policy as well as in representing companies helps me to focus on the contribution to long-term decarbonisation of innovative, bio-based ideas and the opportunities for the business location. Together with my team, developing and now implementing the first cross-sectoral, holistic bioeconomy strategy for Austria was and is a very exciting task. At this point I would also like to thank Gottfried Lamers and Bernhard Zenz, the bioeconomy experts in my team! With their knowledge, heart and soul and enthusiasm, they have played a major role in ensuring that the Austrian bioeconomy strategy was adopted by the federal government in March 2019 and is now implemented.

Bioeconomy stands for an economic concept that aims to replace fossil resources (raw materials and energy sources) with renewable raw materials in as many areas and applications as possible. It encompasses all industrial and economic sectors that produce, process or use biological resources. The bioeconomy thus offers a great opportunity to meet global challenges such as climate change, food and water shortages or environmental pollution, while at the same time strengthening economic development. In order to take the step towards implementing the hitherto knowledge-based bioeconomy – involving the relevant stakeholders and making use of all political instruments – the federal government set out in its government programme and in Austria’s climate and energy strategy, to draw up a strategy for the bioeconomy in Austria. This Austrian bioeconomy strategy was adopted on 13 March 2019. It represents an essential cornerstone of the climate and energy strategy and supports the decarbonisation of the economic system. However, the focus on climate action naturally builds on the sectoral strengths in agriculture, forestry and waste management as well as the manufacturing companies and research in Austria. Building on this, a bioeconomy action plan with concrete implementation measures will be drawn up by the end of the year 2021.

We have also drawn up guidelines for the Austrian bioeconomy strategy in line with the Sustainable Development Goals (SDGs), which on the one hand have a positive impact on the bioeconomy in terms of their objectives, but also highlight the limiting factors. The bioeconomy can be a viable and sustainable form of economy – but it must move along the lines outlined above. Simply increasing efficiency, for example, carries the risk that any gains made will be wiped out by rebound effects. Therefore, changes in behaviour and values are also needed, both among producers and consumers, in order to achieve the goals of the bioeconomy strategy. For this reason, we believe that, in addition to efficiency measures, sufficiency measures, circularity concepts and the inclusion of individual consumption behaviour are essential pillars of a sustainable bioeconomy.

Due to the complex characteristics of biogenic feedstocks, the industrial processing of biogenic raw materials into high-quality products requires sophisticated technologies and processes. Integrated concepts for the material and energetic use of these raw materials therefore also represent a central topic of the bioeconomy.

The German bioeconomy strategy, like other strategies, was a source of inspiration for the Austrian strategy. The latter has highlighted some aspects in particular, e.g. the reference to the SDGs and addressing the aspects of efficiency, sufficiency and individual consumption. Based on the ongoing discussions, I assume that these aspects will also be included in the revision of the German strategy. In our analysis of different bioeconomy strategies, we perceived Germany to be very user and industry oriented, whereas the Finnish strategy is more commodity-centric. Austria's approach of working across sectors to focus on climate actions is somewhat different. The Austrian bioeconomy strategy therefore covers research, resources, technologies and products in equal measure. The political fields of action of the strategy address all sectors.

What both strategies certainly have in common is that they see the bioeconomy as an opportunity for the business location. I hope that this will also lead to joint activities in the future. Unlike Germany, Austria does not have access to the sea, so the potential of a "blue bioeconomy", is naturally more important in Germany. Just as Austria has a number of areas of strength on which the bioeconomy is based, such as the pulp and paper industry or the timber industry, Germany also has globally relevant areas of strength. Germany's technological leadership in the chemical sector, for example, is therefore certainly an exciting opportunity for the bioeconomy.

Urs Moesenfechtel

(born 1978) studied German language and literature, adult education and political science at the universities of Cologne and Leipzig from 1998 to 2005 and since then he has been working at the interfaces of press and public relations, event organisation and education management. The communication of environmental and nature conservation topics is a focus of his work. He has been working at the Helmholtz Centre for Environmental Research (UFZ) since 2013, where he has already served as press and public relations officer for the projects "Natural Capital Germany (TEEB DE)", "Soil as a Sustainable Resource for the Bioeconomy (BONARES)", and "Network Forum on Biodiversity Research Germany (NeFo)". Likewise, since 2013, he has been working at the UFZ Department of Bioenergy as a science communication officer with his main focus on bioeconomy. There, he was in charge of the communication activities within the framework of the accompanying research of the Bioeconomy Cluster of Excellence as well as the Bioeconomy Information Office.

Cluster, Network, Platform: Organisational Forms of the Bioeconomy

Manfred Kirchgeorg

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_11

11.1 Introduction

Almost all economic sectors are affected by this transformation process. For this reason, the adoption of a "National Bioeconomy Policy Strategy" in Germany in 2013 called on all actors in business, politics and society to take up these challenges (BMEL, 2014). Accordingly, the bioeconomy can be seen as a prime example of the use of network-based organisational principles, because it

1. transforms traditional value chains by involving new actors and raw materials at all stages.
2. forms new value chains with new as well as established company players in order to develop bio-based innovations and bring them to market maturity.
3. follows the principles of cascade and linkage use and circular economy through smart linkages within bio-based value chains to increase resource efficiency in the use of biomass (BMEL, 2014; Leal Filho, 2018).

The transformation to a bioeconomy requires "close cooperation between political, economic, scientific, ecological and social actors" (BMEL, 2014, p. 21). In this context, it is necessary to organise decentralised and regionally anchored material and energy cycles of bio-based products and also to link these with national and global markets. In view of this requirement, the transformation process towards a bioeconomy represents a field of application in which network-based forms of organisation are used.

11.2 Forms of Organisation of the Bioeconomy

In view of the emerging ecological challenges (e.g. climate change, CO_2 emissions, plastic waste in oceans), the necessary learning, innovation, implementation and acceptance processes must be accelerated on the transformation path. Thus, the question of efficient forms of organisation for such complex and cross-stakeholder transformation processes is of particular importance.

Against this backdrop, cluster concepts have gained particular attention in both politics and business since the early 1990s (e.g. Porter, 1990, 2008a; Delgado et al., 2012). This approach has also been professionalised, for example, in the "Bioeconomy Cluster Central Germany" through a systematic cluster management process (▶ Sect. 11.3).

With the advance of digitalisation, so-called platform strategies for the coordination of interactions and market transactions have gained in importance worldwide. A variety of examples ranging from search engine providers to BtoB and BtoC marketing platforms underline this development. In business research, more and more papers address the special features and forms of the platform economy, which are spread increasingly and therefore can cause a fundamental change in almost all industries. This raises the question of what similarities and differences exist between cluster and platform concepts (Cooke, 2012), also with regard to the transformation process to the bioeconomy.

11.2.1 Conceptual Understanding: Clusters and Networks

The discussion of clusters and cluster processes requires an understanding of the concept of cluster used. According to the conceptual definition of clusters by Michael Porter (2008a, 2008b), clusters are a geographical concentration of companies (specialised suppliers, companies in complementary, related industries and associated institutions such as universities, research institutes, trade associations) that cooperate with each other in certain fields of their value chain or on the basis of common interests, even if they act as competitors in the market.

A cluster can only be said to exist if there is a sufficient number of companies (critical mass) in spatial proximity whose activities complement or are related to each other along a value chain. As a result, cross-company synergies and local externalities can be created or exploited (Brenner & Fornahl, 2003). Joint problems and projects can ultimately result in competitive advantages for all actors involved through an intensified exchange of experience, a more efficient division of labour and improved access to critical resources. In detail, efficiency advantages (money, time, human resources), image advantages, innovation advantages as well as higher start-up and relocation rates can be achieved through cluster processes.

No general benchmarks can be given for determining critical mass. The following indicators are frequently used to determine critical masses (Brenner & Fornahl, 2003; EC, 2016): the number and size of companies within a region, environmental conditions specified by research institutions, educational institutions, infrastructures, human capital, availability of natural resources. Ultimately, the emergence and development dynamics of a cluster depend on many influencing factors, which must be recorded and evaluated as part of an initial analysis using the so-called diamond model (► Sect. 11.2.4).

Confusion often exists regarding the similarities and differences between the network and cluster concepts. Basically, the following statement applies:

- Each cluster is a network,
- but not every network is a cluster.

Networks can be understood as an overarching concept. They are characterised as a network of interactions between individuals or organisations. Compared to networks, clusters differ in that the actors

- must have a link to the value chain, i.e. there are actors performing different or the same functions within the value chain, as well as actors performing related value chain functions or supporting functions,
- have a physical proximity and
- exceed a critical mass.

The discussion about the effect and success of cluster processes is controversial in practice as well as in science. In many cases, a negative attitude towards the cluster concept has emerged because numerous efforts in the past did not show the desired success. However, this was often due more to poor implementation than to the basic idea of the cluster approach (e.g. Fromhold-Eisebith & Eisebith, 2008; Porter, 2008b; Thomi & Sternberg, 2008; Azúa Mendia, 2009; Sövell, 2009; Sövell et al., 2009). Due to the large number of actors and influencing factors to be considered, there is undivided agreement that systematic cluster management (see also ◘ Fig. 11.2) is a key prerequisite for success in developing and profiling a cluster (Porter, 1990, 2008a, 2008b).

Clusters should have an flexibility to change, and it depends on the design of the cluster management as well as the cluster actors involved how adaptation processes are taken up in value chains. Especially in change processes, an advantage can lie in the use of the “collective intelligence” of all cluster actors compared to isolated strategy concepts. In particular, the exchange of experience between different clusters – e.g. between the automotive cluster and the chemical cluster for the development of bio-based insulation and plastics – can lead to new fields of innovation such as the bioeconomy, which can be quickly addressed through existing cluster processes.

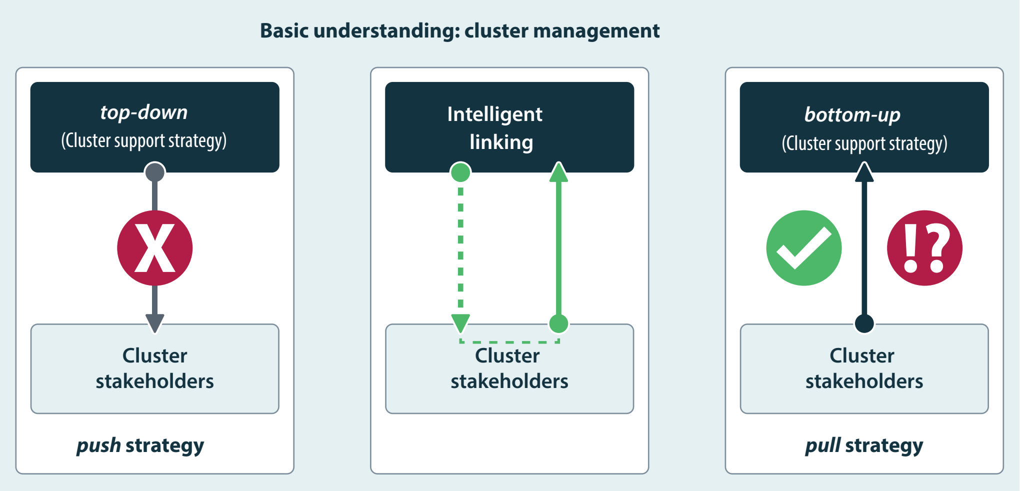
11.2.2 Cluster Definition and Cluster Identification

A controversial question also relates to the issue of whether clusters can be defined ***top-down*** or whether clusters can be identified quasi-empirically from the ***bottom-up perspective*** on the basis of existing agglomerations (▫ Fig. 11.1) (Porter, 1990; Mueller & Jungwirth, 2014). The latter approach assumes that the nucleus for the cluster process already lies in an existing agglomeration. Empirically, clusters can be identified by the existence of a spatial agglomeration of companies that are located horizontally (at the same stage of the value chain) or vertically (linked by supplier and customer relationships) in a value chain and can be identified by certain agglomeration effects. Furthermore, a cluster is characterised by a certain degree of interconnectedness of the companies. The latter can be measured by the intensity of information exchange, the existence of joint projects or economic relationships, such as supplier or customer relationships.

The *top-down approach* is based on the expectation that agglomerations and thus agglomeration effects can be planned and realised within the value chain, even without a sufficient critical mass of actors in the initial phase. Targeted settlement policy is understood here as an instrument for achieving the critical mass of actors over time for a cluster process. The *top-down approach* thus focuses more on the design of cluster processes and cluster-specific framework conditions.

Basically, neither a pure *top-down approach* nor a *bottom-up approach* proves to be effective. While the top-down approach may not sufficiently take into account the perspective and potential of the cluster stakeholders and require considerable resources and time for the development of a cluster, the *bottom-up approach* may not sufficiently exploit opportunities for shaping framework conditions that promote clusters because only existing agglomerations form the starting point for a cluster process. If, for example, funding and cluster organisations are provided without ensuring sufficient participation of the actors of the value creation stages, a cluster development will not continue if funding is no longer available.

A combination of *top-down* and *bottom-up approach* proves to be the best. Particularly in the intense competition between regions

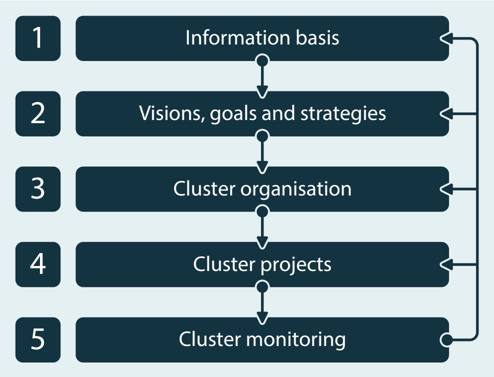


▫ **Fig. 11.1** Intelligent combination of *top-down* and *bottom-up approach* to initiate cluster processes. (Source: Own representation according to Porter, 1990; Mueller & Jungwirth, 2014) and business locations, targeted reflections must be made how to combine both approaches and therefore identify the strengths and existing infrastructure for cluster processes, to improve cluster-specific framework conditions and to delegate cluster actors a leading role in the cluster process.

11.2.3 Cluster Management as a Success Factor for Cluster Development

In modern approaches to cluster development, the function of cluster management is classified as an essential success factor. Following a management process, the tasks and planning stages shown in ▣ Fig. 11.2 can also be highlighted for **cluster management**.

1. **Situation analysis**: The cluster management can only obtain a picture of the location factors and the cluster actors on the basis of a careful and regular situation analysis in order to be able to derive goals and visions for the cluster process.
2. Based on the situation analysis, a **cluster vision** can be defined under which the cluster stakeholders want to advance the cluster process. The vision, e.g. "to establish a leading biotechnology location in Europe", should then be backed by concrete **goals** for the cluster process, which should be specified and updated in terms of content, scope and time reference. To achieve the goals, **strategies** or long-term behavioural plans and fields of action should be defined with the participation of the cluster stakeholders, which are to be adjusted depending on the respective cluster situation (strengths, weaknesses, opportunities, risks).
3. Certain basic **organisational structures** and responsibilities must be defined for the implementation of the strategies. The form of institutionalisation (e.g. association, limited liability company) also plays a decisive role here.
4. **Cluster projects** then represent those concrete activities that are realised through cooperation of cluster actors. Both for the definition of the strategic focus and for the successful implementation of the projects, human resources have to be allocated. The more complex and heterogeneous the clusters are, the more difficult it is to define common fields of action and projects.
5. In the final step, **cluster monitoring** must be used to ensure that the degree to which the activities have achieved their objectives is continuously monitored and that adjustments are made if necessary.



▣ **Fig. 11.2** Planning steps and tasks of cluster management. (Source: Own representation)

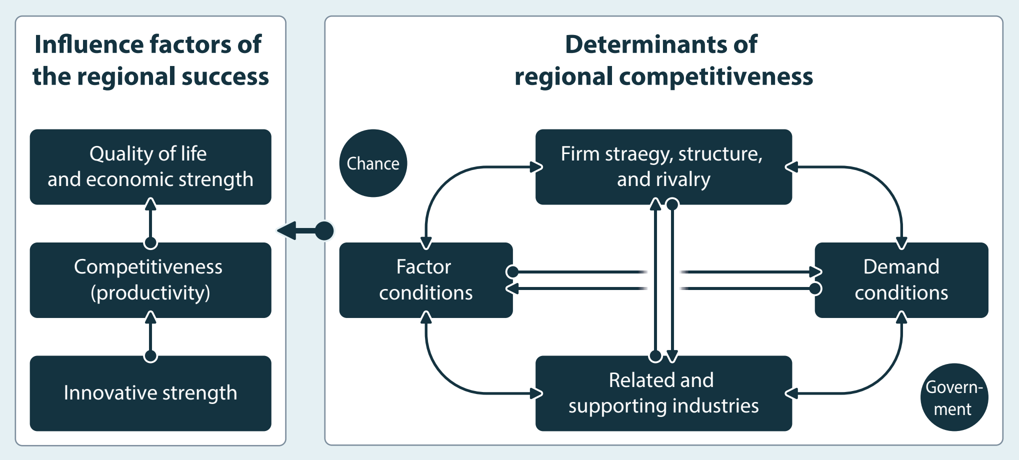
Worldwide analyses of cluster processes prove that without certain organisational structures, professionalisation and acceleration of a cluster development cannot be achieved (see, for example, the documented cluster projects on the internet platform of the MOC network, MOC, 2019).

11.2.4 Influencing Factors and Development Dynamics of Clusters

Whether cluster processes are successful and whether the actors involved and the region can increase their competitiveness as a result depends on many influencing factors. Competitive factors such as access to raw materials, labor costs or economies of scale, which were often considered decisive in the past, are becoming less important in today's economic environment. The reasons for this can be seen in the disruptive changes triggered by digitalisation, which increasingly requires the bundling of innovation competencies even across industry boundaries. In this context, cooperative approaches such as alliances, strategic partnerships and networks are gaining in importance.

According to Porter, regional and national competitive advantages are based on four decisive determinants, which he depicts in a strategic diamond as shown in ◘ Fig. 11.3 (Porter, 1990). Accordingly, it is important to shape the regional economic environment as positively as possible in order to create the conditions for local companies to develop competitive advantages. Ultimately, the factors of regional competitiveness influence the innovative strength and thus the competitiveness of the companies belonging to a cluster. Finally, competitiveness also promotes the quality of life within a region. The decisive factors according to the diamond model are:

- **Factor endowment:** Although the classic factors of production such as labour, land, natural resources and capital are also meant here, this approach is not complete. In modern economies, the decisive factors of production – e.g. skilled labour, knowledge or infrastructure – are not inherited, but deliberately generated and developed.
- **Demand situation:** Here it is not the size of the home market that matters, but rather the composition and nature of demand. On the one hand, competitive advantages arise when the demanders of a region provide entrepreneurs with an earlier or clearer picture of future needs. On the other hand, particularly demanding demanders lead to companies being forced to innovate more quickly than competitors.
- **Related and supporting industries:** Internationally competitive local suppliers deliver inputs quickly and cost-effectively. Even more important than the availability of parts, system components and machines, however, is the role of suppliers in innovations and product improvements that result from the close working relationships between the various partners in the value chain.



◘ **Fig. 11.3** Determinants of regional competitiveness according to Porter. (Source: Own representation according to Porter, 1990)

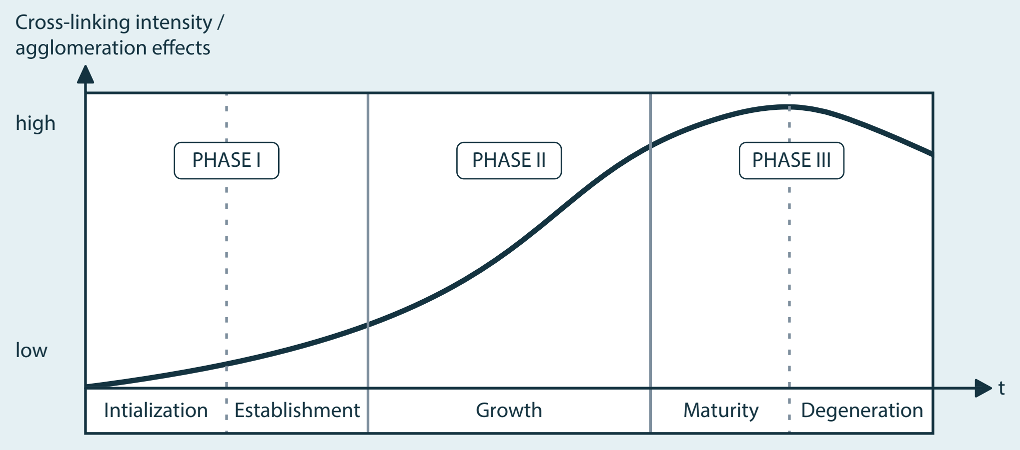
- **Corporate strategy, structure and competition:** In principle, according to Porter, there is no specific successful strategy or structure. Instead, it is crucial that corporate goals, strategy and structure are aligned with each other and with the corporate environment.

In addition, other issues also play a role in cluster development. There are different opinions on whether the public administration (federal government, states, cities and municipalities) should play an active part in promoting cluster processes or whether as little public and state intervention as possible leads to better results. In this context, it becomes apparent that an intelligent interaction of public and private actors creates the best conditions for success. In addition to the determinants of regional competitive advantage already mentioned, Porter also mentions **chance** as an influencing factor. These are events that are related to the situation of a region, but which neither the companies involved nor the public sector can influence.

Depending on the constellation of influencing factors as well as the professionalism of the cluster management and the cluster organisation, a more or less dynamic development of the cluster process may result. Cluster life cycle considerations can be used to illustrate cluster dynamics (e.g. Kirchgeorg & Fiedler, 2004). ▣ Figure 11.4 shows typical life cycle phases of a cluster development process. In certain regions, historically grown interdependencies between regional actors may already exist that were not initiated and established by a targeted cluster development process.

The deliberate development of a cluster organisation is often initiated by *clusterpreneurs,* which may include leading company representatives, scientists as well as representatives of business development or regional marketing initiatives. If the idea of cluster development finds sufficient acceptance, especially among the central actors of an industry, an initiative group is often formed which examines essential infrastructure requirements and organisational structures for the cluster development process and initiates first steps for the establishment of a targeted cluster formation process.

In the *establishment phase,* the initiative group then integrates further actors from the fields of business, science, administration and politics in order to force the degree of networking to generate agglomeration effects. In case of a successful cluster devel-



▣ **Fig. 11.4** Life cycle phases of a cluster development process. (Source: Own representation according to Kirchgeorg & Fiedler, 2004) opment, further vertical, horizontal and lateral cooperations between the actors are formed, so that the endogenous development process continues with disproportionate growth rates (phase II). After the growth phase, clusters can also be characterised by *maturity and degeneration phases* (phase III). These can be caused by industry cycles as well as industry changes or by the fact that more attractive and competitive cluster structures have emerged in global competition. This leads to companies relocating, which results in a degeneration of agglomeration effects.

11.2.5 Basic Approaches and Tools for Cluster Analysis

In the context of the analysis of cluster processes and their effects, two basic approaches can be distinguished: On the one hand, there is the collection and analysis of **objectively ascertainable data** to describe and analyse the effects of the cluster process. On the other hand, it is possible to analyse the cluster process on the basis of the **subjective assessments of the cluster actors involved**.

Especially in the first phase of cluster development, suitable cluster monitoring proves to be particularly important in order to be able to successfully set up the steps of cluster formation. Since the effects of cluster processes only become apparent in the medium and long term in the form of objectively measurable agglomeration effects, the satisfaction of the cluster actors with the process plays an important role as a success indicator in the short term. In the long term, high satisfaction rates can only be achieved with quantifiable effects for the cluster actors, but especially in the initial phase of cluster development, subjective assessments are an important point of orientation.

11.3 Challenges of the Bioeconomy Cluster in Central Germany

The implementation of a bioeconomy and the innovative integration, processing and marketing of renewable raw materials require an interdisciplinary linkage of different economic and research areas along different material flow and value chains. This creates both a considerable need for cooperation and a coordination effort between the various partners in the newly forming material flow and value chains (European Association for Bioindustries, 2005; Kircher, 2012), so that particular importance must be attached to the cluster approach in the bioeconomy. Due to the interdisciplinary links, however, a sufficiently large number and variety of suitable partners are required for regional agglomeration and cluster processes within the bioeconomy (Bioökonomierat, 2010).

Experience shows that such an internationally competitive cluster – a geographical agglomeration of connected and related enterprises and accompanying institutions – must develop over a longer period of time and can only emerge from nowhere under special funding conditions (or coincidences).

The region of the federal states of Saxony, Saxony-Anhalt and Thuringia, known as “Central Germany”, has cluster potential in the distinctive forestry and agricultural industries, the equally traditional mechanical and plant engineering sector and the modern energy industry with a focus on renewable energies (including Solar Valley Central Germany). It has several modern biotechnology locations (including in Dresden, Jena, Leipzig and Halle/Saale) and also has a broad-based manufacturing sector (Kirchgeorg & Wurpts, 2011).

As ▣ Fig. 11.5 illustrates, a novel linkage between these previously only partially

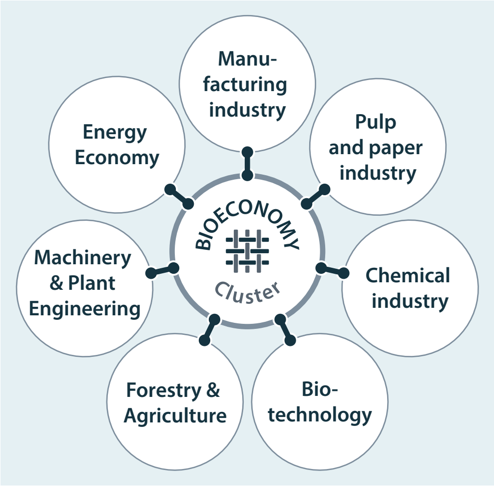


Fig. 11.5 *"Smart specialization" of* the Bioeconomy Cluster Central Germany. (Source: Own presentation based on information from the Bioeconomy Cluster homepage, ► www.bioeconomy.de)

connected sectors and clusters has been established in the bioeconomy cluster in the sense of a "*smart specialization*" (EC, 2016; David et al., 2009).

In view of the special features of the bioeconomy transformation process highlighted in the introduction, bioeconomy clusters also have special features in comparison to "conventional" clusters, such as those that have so far been promoted and scientifically investigated predominantly in the fields of information technology, the automotive industry or biotechnology and other "classic" and "modern" industries. The intended link between the companies and research institutions does not consist of one or a few value chains with one or a few export-oriented end products. It rather consists of several new material flow chains that are subordinate to the sustainability principle, from which a large number of very different and new, in part completely foreign value chains – and thus end products – can be derived.

The new value chains of the bioeconomy which are aimed in the course of the cluster process are to be developed on the one hand in the materials sector and on the other hand in the biochemical sector through innovative conversion processes. Depending on the optimum degree of utilisation, the by-products produced in the process are to be reused either for energy or, if necessary, as nutrients, in order to comply with the principles of cascade and coupled utilisation (BMEL, 2014).

Considerable professionalisation potential can be tapped in specific phases and situations with the help of the management methods transferred to clusters. ▪ Figure 11.6 provides an overview of the instruments that the "Bioeconomy Cluster Central Germany" has developed and used. They form an important information basis for the professionalisation of cluster management.

Through the use of various instruments within the cluster management, the following results were achieved:

1. **National and international benchmarking** provided a central information basis for the profiling of bioeconomy clusters in international competition. This also made it possible to identify clusters with which collaborations were established to form a metacluster as part of the internationalisation of the Bioeconomy Cluster Central Germany.
2. **Agglomeration analyses** provided information on the extent to which companies from cluster-affine industries are represented in a region and the extent to which above-average agglomeration effects can be achieved in a federal state comparison.
3. **Satisfaction analyses** among the cluster stakeholders provided the cluster management, as a central control instrument, with information on the extent to which the expectations of the stakeholders were fulfilled in the early phase of cluster development or where gaps in expectations had to be closed.
4. Based on satisfaction and expectation analysis of the cluster stakeholders, a comprehensive **service portfolio** was devel-

Cluster profile	Contains all relevant status quo and development data of an analysed cluster at a glance.
Cluster mapping	Visual representation of all cluster actors or institutions (companies, university, administration, etc.) and their exchange relationships.
Cluster actor analysis	List of cluster actors combined with secondary and survey data on cluster importance and level of participation and satisfaction with cluster activities.
Cluster development analysis	Life cycle representations of a cluster based on change data relevant to success.
Cluster portfolios	Integrated representation of different clusters based on critical success (output) and influencing factors (input). Also serves to identify cluster overlaps.
Cluster influence factor analysis	Collection of promoting and inhibiting factors influencing the development of clusters.
Cluster benchmarking	Comparative analysis of industry clusters based on selected success criteria.

Fig. 11.6 Overview of the analysis instruments used by the cluster management

oped by the cluster management to offer specific support services to stakeholders.

5. Particularly in the growth phase of the Bioeconomy Cluster Central Germany, a professional **business development process** – initiated by the cluster management – was of particular relevance in order to be able to efficiently allocate resources on the basis of project priorities. For this purpose, the *scoring models* developed for the Bioeconomy Cluster Central Germany could be used for project evaluation and the creation of a project portfolio.
6. The product innovations developed in the bioeconomy cluster were systematically recorded and, based on an **added value catalogue**, the advantages and disadvantages (compared to classic product variants that were not bio-based) were compared with each other in order to identify market potentials and indications for the positioning of bio-based product innovations.
7. The internationalisation of the Bioeconomy Cluster Central represents a logical development step within the growth phase. On the way to designing a metacluster, findings on **internationalisation strategies of networks and companies** can be transferred to cluster contexts.

11.4 Outlook: Linking Cluster and Platform Strategies

Digital platform strategies have gained importance over the last decade as a result of digitalisation. In view of the special features that distinguish digital platforms, the term "platform economy" is also increasingly being used.

The principle of the platform economy is characterised by the fact that a large number of suppliers with their product and service offerings are brought together with demanders on a platform. The German Federal Ministry for Economic Affairs and Energy defines digital platforms as "internet-based forums for digital interaction and transaction" (BMWi, 2017, p. 21). Such platforms include search engines, comparison and rating portals, marketplaces, trading platforms and social networks.

The platform economy consists of at least three groups of actors: The platform operator, a large number of suppliers and a large number of consumers (two-sided markets). As a rule, two effects can be achieved with the help of digital platforms (Tiwana, 2014; BMWi, 2017):

1. Network effects: They describe the benefits (network externalities) that suppliers and/or customers receive on platforms as a result of more and more players being active on a platform. More providers lead to a larger offer, which in turn attracts more demanders. Network effects can exist between both the supply and demand sides or on only one side of the market. For example, xustomers/buyers can also interact with each other and thereby obtain greater benefits. This can, for example, lie in a higher number of customer ratings, which reduce the perceived purchase risk of an individual buyer.
2. Scaling effects: Digital platforms are also used to justify zero marginal cost economics, i.e. additional transactions between suppliers and buyers generate hardly any additional costs for the platform operator (marginal costs). Thus, while platform operators often have high fixed costs due to the hardware/software infrastructures, this may be accompanied by low marginal costs. This leads to platforms following scaling strategies, because no or low marginal costs are associated with additional transactions.

■ Figure 11.7 compares selected characteristics of cluster and platform concepts. Both concepts can be classified as network-oriented forms of coordination or organisation

Criteria	**Cluster**	**Platforms**
Definition	Regionally limited networks of companies, research institutions, service providers and other related institutions that are created through joint exchange relationships along a value chain and through which local externalities can be used to achieve competitive advantages.	Digital platforms are internet-based forums for digital interaction and transaction. Platforms include search engines, comparison and rating portals, marketplaces, trading platforms, social networks, among others.
Provider	Regionally limited	Regionally unlimited
Demander	Regionally limited	Regionally unlimited
Coordinator	Cluster management	Platform operator
Access	Through local presence / location and membership in cluster initiatives	Open platforms: free access Closed platforms: Operator defines access authorization
Communication	Offline / personal and online / digital	Online / digital
Infrastructure	Physical infrastructures, if necessary also use of digital forms of communication	Digital platform (hardware and software)
Effects	Local network effects	Local and global network effects, scaling effects (due to low marginal costs or zero marginal cost economics)

■ **Fig. 11.7** Overview of characteristics of different cluster and platform concepts. (Source: Own representation) that ultimately generate network effects through the mutual exchange of actors (Asheim et al., 2011). It is striking that via the cluster definition the regional delimitation of actors takes place and local externalities or network effects play a role. Digital platforms, on the other hand, have no local limitation, i.e. they can, if necessary, drive the networking of actors globally. Specifically via the phenomenon of zero marginal cost economics, certain digital platform concepts can even scale globally, i.e., connect additional suppliers and demanders without additional marginal costs. While in a regional cluster actors can already participate in network effects through local presence, actors have to actively choose to be present on digital platforms. In this context, access can be regulated by the platform operator (open vs. closed platforms). While open platforms use the creativity of the masses, e.g. in the context of innovation processes, closed platforms can offer a security advantage and greater control of the transaction processes.

Compared to open, globally accessible platforms, the networking radius and network effects of classic clusters are regionally limited because special importance is attached to physical exchange relationships and offline communication. In turn, the emergence of metaclusters – i.e. clusters network with other clusters across regional or national borders – also offers the possibility of exploiting supra-regional networking effects.

If we dare to look ahead, a combination of cluster and platform strategies (Cooke, 2012) seems to be an interesting approach to combine the advantages of both forms of organisation.

References

Asheim, B., Boschma, R., & Cooke, P. (2011). Constructing regional advantage. Platform policies based on related variety and differentiated knowledge bases. *Regional Studies, 45*(6), 1–12.

Azúa Mendia, J. I. (2009). *Clusterizing and glokalizing the economy: The magic of the process: Successful development of clusterization and glokalization processes to improve competitiveness, thus creating intelligent territories*. Enovatinglab.

Bioökonomierat. (2010). Arbeitsgruppe Biotechnologie: Empfehlungen zum Aufbau einer wettbewerbsfähigen und nachhaltigen Bioökonomie–Beitrag der Industriellen Biotechnologie zum wirtschaftlichen Wandel in Deutschland. Positionspapier, Berlin. https://www.iwbio.de/fileadmin/templates/publikationen/berichte/Berichte04-Biotechnologie.pdf. Accessed: 10.01.2020.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2014). Nationale Politikstrategie Bioökonomie – Nachwachsende Ressourcen und biotechnologische Verfahren als Basis für Ernährung, Industrie und Energie. https://www.bmbf.de/files/BioOekonomiestrategie.pdf. Accessed: 27.08.2019.

BMWi (Bundesministerium für Wirtschaft und Energie). (2017). Weissbuch Digitale Plattformen – Digitale Ordnungspolitik für Wachstum, Innovation, Wettbewerb und Teilhabe. https://www.bmwi.de/Redaktion/DE/Publikationen/Digitale-Welt/weissbuch-digitale-plattformen.pdf?__blob=publicationFile&v=24. Accessed: 27.08.2019.

Brenner, T., & Fornahl, D. (2003). Politische Möglichkeiten und Maßnahmen zur Erzeugung lokaler branchenspezifischer Cluster. Max-Planck-Institut zur Erforschung von Wirtschaftssystemen. https://www.unternehmen-region.de/_media/InnoRegio_Regionalspezifische_Cluster.pdf. Accessed: 27.08.2019.

Cooke, P. (2012). From clusters to platform policies in regional development. *European Planning Studies, 20*(8), 1414–1415.

David, P. A., Foray, D., & Hall, B. (2009). Smart specialization: The concept. Knowledge Economists Policy Brief No. 9. https://ec.europa.eu/invest-in-research/pdf/download_en/kfg_policy_brief_no9.pdf. Accessed: 27.08.2019.

Delgado, M., Porter, M. E., & Stern, S. (2012). Clusters, convergence, and economic performance. NBER Working Paper 18250. https://doi.org/10.3386/w18250.

European Association for Bioindustries. (2005). Industrial or White Biotechnology – A driver of sustainable growth in Europe. Working document. https://www.europabio.org/sites/default/files/industrial_or_white_biotechnology_-_a_driver_of_sustainable_growth_in_europe.pdf. Accessed: 27.08.2019.

European Commission. (2016). Smart guide to cluster policy. Guidebook series: How to support SME policy from structural funds. https://s3platform.

jrc.ec.europa.eu/documents/20182/84453/Smart+Guide+to+Cluster+Policy/fd0f16b9-0759-43ca-b950-ec0192e220c8. Accessed: 27.08.2019.

Fromhold-Eisebith, M., & Eisebith, G. (2008). Clusterförderung auf dem Prüfstand. *Zeitschrift für Wirtschaftsgeographie, 52*(2–3), 79–94.

Kircher, M. (2012). Ho to turn industrial biotechnology into reality. *New Biotechnology, 29*(2), 243–247.

Kirchgeorg, M., & Fiedler, L. (2004). Clustermonitoring als Kontroll- und Steuerungsinstrument für Clusterentwicklungsprozesse – empirische Analysen von Industrieclustern in Ostdeutschland. HHL-Arbeitspapier Nr. 66, Leipzig.

Kirchgeorg, M., & Wurpts, K. (2011). Die Wettbewerbsfähigkeit Mitteldeutschlands – Statusbericht und Handlungsansätze. https://digital.zlb.de/viewer/rest/image/15628309/HHL_Mitteldeutschland_online_2_01.pdf/full/max/0/HHL_MitteldeutschlaMi_online_2_01.pdf. Accessed: 27.08.2019.

Leal Filho, W. (2018). Bioeconomy meets the circular economy. In W. Leal Filho, D.-M. Pociovalisteanu, P. Borges de Brito, & I. Borges de Lima (Eds.), *Towards a sustainable bioeconomy: Principles, challenges and perspectives* (pp. 567–575). Springer.

MOC (Microeconomics of Competitiveness). (2019). MOC student projects on country & cluster competitiveness. https://www.isc.hbs.edu/resources/courses/moc-course-at-harvard/Pages/sample-student-projects.aspx. Accessed: 27.08.2019.

Mueller, E., & Jungwirth, C. (2014). Comparing top-down and bottom-up cluster initiatives from a principal-agent perspective: What we can learn for designing governance regimes. *Schmalenbach Business Review, 66*, 357–381.

Porter, M. E. (1990). *The competitive advantage of nations*. Free Press.

Porter, M. E. (2008a). Competitive advantage of nations. In M. E. Porter (Ed.), *On competition* (pp. 171–211). Harvard Business School.

Porter, M. E. (2008b). Clusters and competition: New agendas for companies, governments, and institutions. In M. E. Porter (Ed.), *On competition* (pp. 213–303). Harvard Business School.

Sövell, Ö. (2009). *Clusters – Balancing evolutionary and constructive forces* (2nd ed.). Ivory Tower.

Sövell, Ö., Ketels, C., & Lindqvist, G. (2009). The European cluster observatory – EU cluster mapping and strengthening clusters in Europe. European Communities. https://doi.org/10.2769/10419.

Thomi, W., & Sternberg, H. (2008). Cluster – zur Dynamik von Begrifflichkeiten und Konzeptionen. *Zeitschrift für Wirtschaftsgeographie, 52*(2–3), 72–78.

Tiwana, A. (2014). *Platform ecosystems: Aligning architecture, governance, and strategy*. Morgan Kaufmann.

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12

Bioeconomy in North Rhine-Westphalia

Ulrich Schurr and Heike Slusarczyk

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_12

12.1 Cluster Partners and Contributions

The Bioeconomy Science Center (BioSC) is a research network for sustainable bioeconomy in North Rhine-Westphalia, which was founded in 2010 by the Forschungszentrum Jülich, the RWTH Aachen University, the Heinrich Heine University Düsseldorf and the Friedrich Wilhelms University Bonn. The current 68 member institutes with around 1900 employees from the four BioSC partner institutions form the scientific core of the research cluster (BioSC, 2020a). They conduct research in four main research areas: “Sustainable plant production and resource stewardship”, “Microbial and moleculartransformation”, “Chemical engineering of renewable resources”, and “Economy and societal implications of the bioeconomy” (ibid.). The mission and essential feature of the BioSC (■ Fig. 12.4) is to conduct research across disciplinary boundaries in holistic, integrated projects and to provide contributions to the development of a sustainable bioeconomy at regional, national, European and global level. These range from the sustainable production of plants as food and feed as well as renewable raw materials in integrated biorefinery concepts, in which (bio)chemical, biotechnological and process engineering processes are used to produce biobased valuable materials (platform and fine chemicals, pharmaceuticals, functionalised materials) and energy sources. The focus is on the most holistic possible use of the biobased raw material and its side streams in stages (cascade use) and the closing of (regional) nutrient cycles (*circular economy*) in innovative, sustainable processes. Thematically, research at the BioSC focuses on three focus topic areas(BioSC, 2020b):

- smart management for plant performance,
- integrated biorefineries for sustainableprocesses and products,
- modular biotransformations for high-value compounds and
- Technological and institutional innovations as drivers of bio-based social transformations.

The focus topic areas have so far been implemented e.g. through multi-disciplinary, cross-location collaborative projects, the so-called FocusLabs,[1] with funding of €2.4 million for three years per project.

In addition to the broad disciplinary scientific expertise of the partners, state-of-the-art, unique scientific infrastructures at the BioSC partner institutions are essential pillars for the joint research of the BioSC:

- the pilot biorefinery NGP^2 at RWTH Aachen University (2018),
- the agricultural experimental site Campus Klein-Altendorf of the University of Bonn (2010),
- the Jülich Plant Phenotyping Centre – JPPC at the FZJ (n.d.-b),
- the Jülich Microbial Phenotyping Centre at the FZJ (n.d.-a),
- technology platforms for molecular analytics at the University of Düsseldorf, as well as
- the German Crop BioGreenFormatics Network (GCBN) performance centre (de.NBI, 2018).

The scientific infrastructures are developed and shared by the partners. In addition, they form an important basis for technology transfer in cooperation with industrial partners (chemical, pharmaceutical, food and feed industries, plant breeders, energy industry). The development of sustainable biobased products and processes for various value creation networks and cross-industry cooperation with small and large commercial

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[1] For further information see: ► https://www.biosc.de/researching

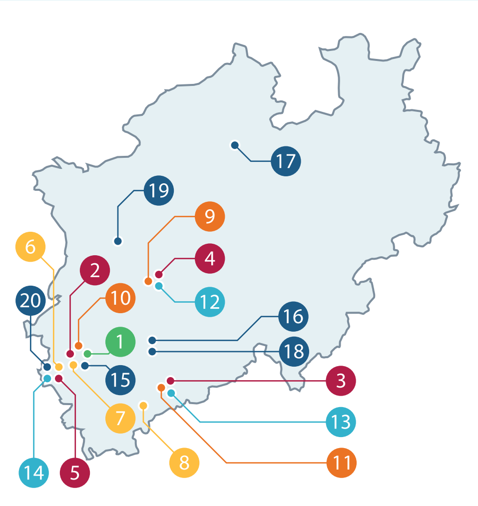
Coordination Office	
BioSC Office (Jülich)	1

BioSC partner institutions	
Forschungszentrum Jülich GmbH	2
University of Bonn	3
University of Düsseldorf	4
RWTH Aachen University	5

Research infrastructures	
Center for Next Generation Processes and Products (NGP²) (Aachen)	6
German Plant Phenotyping Network (DPPN) (Jülich)	7
Agricultural field lab Campus Klein-Altendorf University of Bonn	8

Cooperation networks and alliances	
Cluster industrial biotechnology - CLIB (Düsseldorf)	9
Geoverbund Aachen-Bonn-Cologne-Jülich	10
Forschungsnetzwerk NRW Agrar (Bonn)	11

Cluster of Excellence	
CEPLAS - Cluster of Excellence on Plant Sciences (Düsseldorf)	12
PHENOROB - Robotics and Phenotyping for Sustainable Crop Production (Bonn)	13
FSC - Fuel Science Center (Aachen)	14



Universities, universities of applied sciences, non-university research institutions	
University of applied sciences Aachen, Campus Jülich	15
University of Cologne	16
University of Muenster	17
Max Planck Institute for Plant Breeding Research (Cologne)	18
Fraunhofer Institute UMSICHT (Oberhausen)	19
Fraunhofer Institute for Molecular Biology and Applied Ecology (Aachen)	20

Fig. 12.1 Illustration of the regional networking of the Bioeconomy Science Center (BioSC) in North Rhine-Westphalia and throughout Germany. (Source: Own representation)

enterprises and associations in the region are special features and important drivers of the BioSC. The inclusion of existing infrastructures operated by companies or public institutions also plays a significant role here, in order to bundle and exploit existing technology potential in the region. BioSC member institutes *(Core Groups)* are active in various Clusters of Excellence in North Rhine-Westphalia in the bioeconomy environment (e.g. Cluster for Industrial Biotechnology – CLIB2021, the Geoverbund ABCJ and the DFG Clusters of Excellence CEPLAS,[2] PHENOROB,[3] Fuel Science Center[4]) and are closely networked (see also Figs. 12.1 and 12.2). In many cases, the scientific directors of the BioSC member institutes also hold leading positions in the clusters. At national

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2 For more information, see: ▶ https://www.ceplas.eu/de/home/

3 For more information, see: ▶ http://www.phenorob.de/

4 For more information, see: ▶ https://www.fuelcenter.rwth-aachen.de/cms/~siul/Fuelcenter/?lidx=1

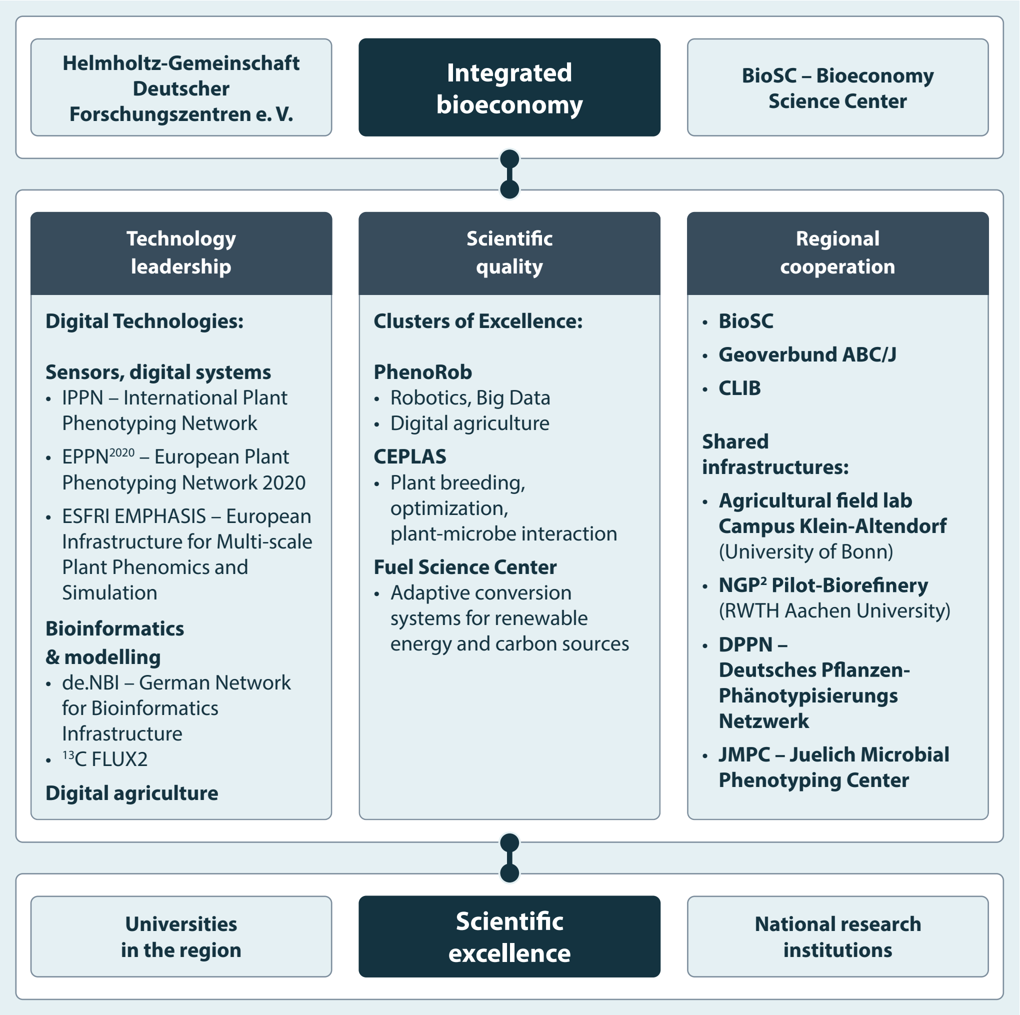


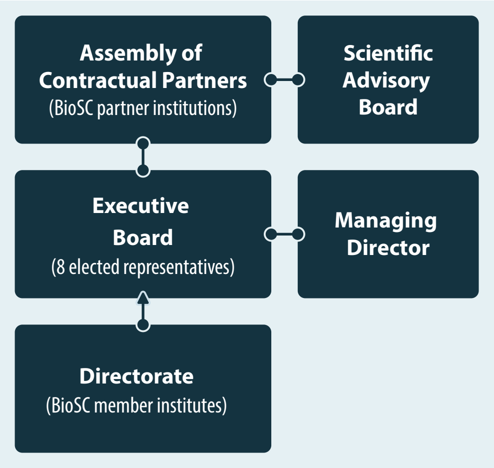
Fig. 12.2 Between scientific excellence and integrated bioeconomy – illustration of the embedding of the Bioeconomy Science Center (BioSC) in the regional, national and international research landscape on the bioeconomy (examples). (Source: Own representation)

level, the BioSC is integrated via the Forschungszentrum Jülich as a member of the Helmholtz Association into the Helmholtz Cross-Sectional Network for Sustainable Bioeconomy, which is coordinated by the FZJ (Fig. 12.2). As a scientific competence centre for bioeconomy research, the BioSC plays an essential role in the network of actors for the development of a model region BioökonomieRevier in the Rhineland (Modellregion BioökonomieRevier, 2019).

In addition to innovation in all sectors involved and the development and establishment of state-of-the-art infrastructures and demonstration plants, the transformation from an economy based on fossil raw materials to one based on renewable raw materials requires well-trained specialists who have a holistic understanding of the requirements of the bioeconomy and can work on these across disciplines with various stakeholders. To this end, the BioSC offers inter- and transdisciplinary training modules in the various topics of the bioeconomy for all educational and career levels (pupils, students, graduates[5,6] life-long learning). Dialogue with society is also an important field of activity for the association.

12.2 Management of the Cluster

The BioSC is a research network that was founded in 2010 on the basis of a long-term cooperation agreement between the four institutions mentioned in ► Sect. 12.1. The core is formed by the member institutes from the four partner institutions, whose heads form the directorate. The Directorate elects the Executive Board from its born members: four scientific directors, for each of whom a deputy is also elected. The Executive Board coordinates and implements the concrete measures for the substantive and strategic development of the BioSC with the support of the Managing Director, who heads the BioSC Office and coordinates and manages the day-to-day business (BioSC, 2020d). Among other things, the BioSC Office handles the scientific-administrative implementation and the public relations work of the BioSC. The Executive Board and the Managing Director coordinate and meet at regular intervals. The heads of the four partner institutions, the chairman and deputy chairman of the FZJ, and the rectors and chancellors of the universities form the Assembly of Contractual Partners, which decides on matters of fundamental importance to the BioSC. The overarching strategic development of the BioSC is supported by a Scientific Advisory Board, in which national and international personalities from science, industry and other areas of society are appointed to advise the Executive Board and the contract partners (ibid.) (▣ Fig. 12.3). The Assembly of Contracting Parties and the Advisory Board meet in plenary session at least once a year. In addition, working meetings with advisory board members on various topics (e.g. training, cooperation with industry) are held several times a year. The scientific heads of the core institutes of the BioSC (Directorate) and their staff meet regularly once a year in the BioSC Forum for an internal retreat. In addition, numerous topic-oriented BioSC events are held in various formats (integration forums, thematic workshops, BioSC spotlights, trade fair presentations) for internal and external networking and interdisciplinary scientific cooperation, most of which are also open to external participants. Since 2016, the BioSC has hosted the International BioSC Symposium "Towards an integrated bioeconomy" once a year in late autumn, where international experts from science and industry present and discuss current



▣ **Fig. 12.3** Organisational structure of the Bioeconomy Science Center (BioSC). (Source: Own representation)

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[5] E.g. Summer Schools, NRW-PhD Day "Future Bioeconomy".

[6] E.g. establishment of the certificate course "Bioeconomy" at the FH Aachen, Campus Jülich in cooperation with Springer Verlag.

research results for inventions and applications in the bio-based economy.

The BioSC represents a cooperation platform for various stakeholders in the bioeconomy at national and international level. Networking with other clusters, networks and different stakeholders in the bioeconomy is a core element of the BioSC concept. External cooperation partners from science, industry and society can be integrated into the BioSC as associated members. These are partly involved in BioSC research projects as cooperation partners or in an advisory role and actively contribute to BioSC events (e.g. International BioSC Symposium, topic-specific workshops, BioSC Spotlights). *Vice versa,* the member institutes of the BioSC act as cooperation partners so that synergies between the different research landscapes in Germany and internationally can be strengthened.

The BioSC sees itself as a cluster for research, innovation and education for a sustainable bioeconomy that pursues integrated approaches in all four fields of action, networks and implements them regionally and acts internationally. This understanding is also reflected in the external communication of the BioSC concept.

12.3 Vision and Mission

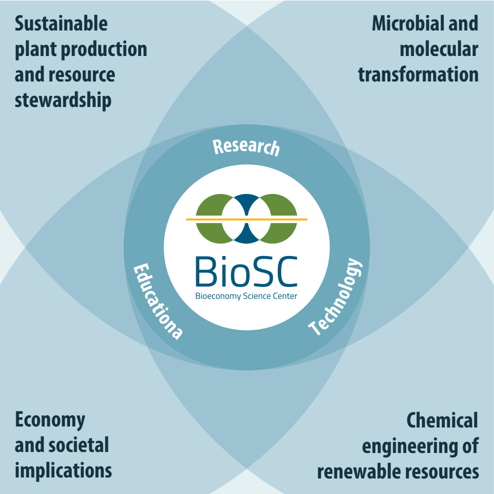
The aim of founding the BioSC was to bring together the complementary competences and infrastructures in research and teaching available at the four institutions in a joint scientific research cluster in order to develop integrated approaches in line with the vision of a knowledge-based, sustainable bioeconomy. The spatial proximity of the four institutions, the long-standing bi- and trilateral cooperation between the four partners, a joint strategy geared towards long-term cooperation, and the fact that the BioSC is embedded in an environment characterised by primary agricultural and forestry production on the one hand and one of the largest energy and chemical locations in Germany on the other formed a profound basis for the establishment of the BioSC. In addition to the development of integrated and holistic approaches between natural sciences, engineering, economics and social sciences in research, inter- and transdisciplinary education in the sense of the bioeconomy should also be implemented in the medium term. With the BioSC, the partners, in cooperation with industry, politics and society, aim to make significant contributions to the knowledge base, to the training of a qualified workforce and to the development and implementation of bioeconomic production processes and concepts in North Rhine-Westphalia and beyond. These are in line with the National Bioeconomy Strategy (BMBF, BMEL, 2020) as well as the policy strategies on the “Sustainable Bioeconomy in Europe” (EC, 2018) and the “European Green Deal” (EC, 2019) of the European Union. The importance of the major global challenges, but also the potentials of a sustainable bioeconomy and its implementation at regional levels have also been incorporated into the recommendations for action of the Global Bioeconomy Summit 2018 (GBS, 2018).

North Rhine-Westphalia also recognised the potential of the bioeconomy at an early stage and in 2010 drew up a potential study on the knowledge-based bioeconomy in NRW, on the basis of which various measures and initiatives for the further development of the bioeconomy were subsequently developed and supported. One example is the funding of the development of the BioSC as a strategic research infrastructure in NRW within the framework of the NRW BioSC Strategy Project (hereinafter referred to as the BioSC Strategy Project) as part of long-term project funding of at least ten years, which is divided into three funding phases. The first phase of the project was launched in 2013, the second at the beginning of 2017. In 2014, North Rhine-Westphalia then implemented the “NRW Regional Innovation Strategy” (MWIDE, 2014), which provides funding for science and industry. This defines lead markets that address a wide range of bioeconomy topics and technologies relevant to them.

12.4 Benchmark and Success Criteria

The objective of the research cluster is to develop biobased products, processes and bioeconomy concepts in integrated, interdisciplinary research projects and cooperations by networking the four research areas of the BioSC and to bring them into application.

In the first funding phase of the BioSC strategy project funded by the state of NRW, the focus was on networking and integrating the approximately 50 member institutes at that time into the BioSC concept and initiating cross-disciplinary research projects of varying degrees of exploration. One measure of the progressive integration of the four different BioSC research areas (◘ Fig. 12.4) and scientific disciplines is the participation of scientists from at least two research areas in the project consortia. In the more than 60 projects that have been carried out or are underway since 2013, there has been an increase in the number of BioSC projects that include all four of the BioSC’s research areas – from plant production, biotechnology and process engineering for renewable raw materials to (socio-)economic implications. The successful integration of BioSC members can also be demonstrated by joint publications and patents that have resulted from the projects (BioSC, 2020c). Likewise, the demand from science and industry for cooperation opportunities in the multidisciplinary BioSC research collaborations and an increasing involvement of companies from different sectors (e.g. chemical companies, enzyme manufacturers, fertiliser manufacturers for horticulture and agriculture) show the success of the concept pursued. In addition, the number of continuing interdisciplinary and multidisciplinary projects (BMBF Maßgeschneiderte Inhaltsstoffe or Bioeconomy International) funded by other funding bodies is increasing. At the end of the first funding phase, a strategy process took place with the aim of focusing the thematic breadth in the initiation phase in order to strengthen the scientific profile and potential of the BioSC. The results of this process are the four focus topic areas, to which research in the subsequent funding phases has been directed.



◘ **Fig. 12.4** Overview and interaction of the four research areas of the Bioeconomy Science Center (BioSC). (Source: Own representation)

The objective for the coming years and the third funding phase of the BioSC strategy project will be to further develop products, processes and concepts developed in the BioSC for their application (Science-2-Business) and to generate new ones. A particular focus will be on implementation in the region.

12.5 Experience

With the establishment of the BioSC, an internationally recognised cluster and a partner for research, innovation and education for a sustainable bioeconomy has developed in the Rhineland. Bringing together the various disciplines and research cultures from more than 65 institutes and achieving a common understanding of the respective challenges for the bioeconomy in the different research fields has taken time. In addition to the time factor, long-term financial support is an essential prerequisite for achieving this objective. The state of North Rhine-Westphalia has recognised this necessity and, with its long-term funding strategy, has provided significant support for the establishment and content-related profiling of the BioSC. The first results for medium-term implementation are emerging. To this end, it is necessary to network the various stakeholders and actors, knowledge and innovations, technological competencies and infrastructures in science and industry even more closely in the future, to support spin-offs, to strengthen the dialogue between industry, science and society and to address global challenges by expanding international cooperation. The BioSC's goal is to continue the developments that have been initiated in this direction.

References

BioSC (Bioeconomy Science Center). (2020a). Expertise and research groups. https://www.biosc.de/expertise_research_groups. Accessed: 31.08.2021.

BioSC (Bioeconomy Science Center). (2020b). Research programme. https://www.biosc.de/research_programme. Accessed: 31.08.2021.

BioSC (Bioeconomy Science Center). (2020c). Publications. https://www.biosc.de/publications. Accessed: 31.08.2021.

BioSC (Bioeconomy Science Center). (2020d). About us: The Bioeconomy Science Center. https://www.biosc.de/bioeconomy_science_center_en. Accessed: 31.08.2021.

BMBF (Bundesministerium für Bildung und Forschung) u. BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2020). Nationale Bioökonomiestrategie. https://www.bmbf.de/SharedDocs/Publikationen/de/bmbf/pdf/nationale-biooekonomiestrategie_3341.html. Accessed: 31.08.2021.

de.NBI (German Network for Bioinformatics Infrastructure). (2018). German Crop BioGreenformatics Network. https://www.denbi.de/network/german-crop-biogreenformatics-network-gcbn. Accessed: 31.08.2021.

EC (European Commission). (2018). A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment. COM/2018/673 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0673. Accessed: 31.08.2021.

EC (European Commission). (2019). The European Green Deal. COM/2019/640 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN. Accessed: 31.08.2021.

FZ Jülich (Forschungszentrum Jülich). (n.d.-a). Jülich Microbial Phenotyping Center. http://www.fz-juelich.de/ibg/ibg-1/DE/JuelichMicrobialPhenotypingCenter/_node.html. Accessed: 31.08.2021.

FZ Jülich (Forschungszentrum Jülich). (n.d.-b). Jülich Plant Phenotyping Centre. https://www.fz-juelich.de/ibg/ibg-2/DE/Organisation/JPPC/JPPC_node.html. Accessed: 31.08.2021.

GBS (Global Bioeconomy Summit). (2018). Communiqué Global Bioeconomy Summit. Innovation in the global bioeconomy for sustainable and inclusive transformation and wellbeing. https://biooekonomierat.de/fileadmin/Publikationen/empfehlungen/GBS_2018_Communique.pdf. Accessed: 31.08.2021.

Modellregion BioökonomieRevier. (2019). Bioökonomierevier. https://www.biooekonomierevier.de/. Accessed: 31.08.2021.

MWIDE (Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen). (2014). Regionale Innovationsstrategie des Landes Nordrhein-Westfalen im Rahmen der EU-Strukturfonds 2014–2020. https://www.efre.nrw.de/efre-programm/programmtexte/innovationsstrategie/. Accessed: 31.08.2021.

RWTH Aachen. (2018). NGP^2 -Center for Next Generation Processes and Products. http://www.avt.rwth-aachen.de/cms/AVT/Die-AVT/~kmbz/NGP2/. Accessed: 31.08.2021.

Universität Bonn. (2010). Campus Klein-Altendorf. https://www.cka.uni-bonn.de/. Accessed: 31.08.2021.

Prof. Dr. Ulrich Schurr

(born 1963) studied biology at the University of Bayreuth and received his PhD in 1992. He develops and uses non-invasive methods for phenotyping – i.e. to measure plants – and optimise them through breeding and management. He has been head of the Institute of Plant Sciences at Forschungszentrum Jülich since 2001. He is spokesman of the Bioecomomy Science Center and was chairman of the European Technology Platform Plants for the Future. He also coordinates the EMPHASIS project of the European Strategy Forum for Research Infrastructures. The aim is to establish a pan-European research infrastructure for plant phenotyping with science and industry. Furthermore, he coordinates the project BioökonomieRevier for the implementation of a model region for a sustainable bioeconomy in the Rhenish coal mining region in structural change.

Dr. Heike Slusarczyk

(born 1967) studied biology at the Rheinisch-Westfälische Technische Hochschule Aachen and received her doctorate in molecular enzyme technology from Heinrich Heine University Düsseldorf in 1997. After her postdoctoral period and a stay at the California Institute of Technology (Caltech) in the USA, she moved to the science management of Forschungszentrum Jülich in 2002. Here, in a staff position, she supported the research areas of Health, Earth and Environment as well as strategic initiatives of Forschungszentrum Jülich and coordinated the office of the Knowledge-Based Bio-Economy initiative. She helped shape the collaborations of Forschungszentrum Jülich, particularly in the bioeconomy. Since 2010, she has been managing director of the Bioeconomy Science Center and heads the office at the Institute of Plant Sciences of Forschungszentrum Jülich. She is active in regional, national and international networks and initiatives on research and education on sustainable bioeconomy.

Bioeconomy in Central Germany

Joachim Schulze and Anne-Karen Beck

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_13

13.1 Vision and Mission

The BioEconomy Cluster came together in 2011 as a regional network (BioEconomy e. V.) with 23 members in Saxony-Anhalt. The original idea was to form a cross-industry cluster ("wood meets chemistry") from the existing regional strengths such as the chemical potential in the chemical triangle Leuna – Schkopau – Bitterfeld-Wolfen, but also Zeitz and the resource availability of wood – especially beech wood within a radius of 150 km around the location.

Founded in 2012, the BioEconomy Cluster was one of the winners of the third round of the Leading-Edge Cluster Competition of the Federal Ministry of Economics and Education (BMBF). From 2012 to 2017 alone, €80 million (of which 50% was contributed by industry) was invested in researching and implementing the bioeconomy. The BioEconomy Cluster supports the national research strategy BioEconomy 2030 of the federal government and aims at thematic and spatial networking with overlapping value creation stages (Hüsing et al., 2017).

The state of Saxony-Anhalt is funding the BioEconomy e. V. as an innovation cluster until 2026. Saxony-Anhalt has designed the Regional Innovation Strategy Saxony-Anhalt (RIS) 2014–2020, which is intended to concentrate on the existing economic strengths and research focuses in the state and further expand their potential. The special profile of Saxony-Anhalt, with its specialisation in e.g. agrochemicals, fine chemicals and specialty chemicals, but also with new fields of application such as automotive lightweight construction with composites, will also be further promoted by the BioEconomy Cluster. The bioeconomy combines research-intensive economic activities in agriculture, forestry and the food industry with the material and energetic use of renewable raw materials. The transformation of the petroleum-based chemical industry into a more sustainable, resource- and energy-efficient, and more bio-based economy is considered to be of great importance worldwide. This lead market "Chemistry and Bioeconomy" is also significantly shaped by the BioEconomy Cluster (MW Sachsen-Anhalt, 2014).

13.2 Mission (Cluster Strategy)

Through the implementation of the coordinated project portfolio in the BioEconomy Cluster, the vision of a globally unique realisation of the bioeconomy is to be achieved by linking the areas of wood, agriculture, chemicals and energy and in an entire region. The following goals are derived from this: maximisation of value creation through coupling and cascade use for the production of chemicals, materials, new materials and energy as well as the acceleration of innovation processes through integrated and spatially coordinated scaling of processes and plants from laboratory to demonstration scale. Ideally, material flows are linked to form new types of value chains and networks, and new processes and product prototypes are developed. The technical prerequisites required for this (results of the original *technology-push-oriented* process developments) enabled the construction and commissioning of new laboratory, pilot and demonstration plants (strategy of the BioEconomy Cluster).

With the production of the first biobased products, this mission shifted to a *market-pull* strategy. This led to a realignment of the overarching strategic goals at the end of 2016. These include the market introduction of biobased products in as many sectors as possible and the promotion of social acceptance of the bioeconomy. The creation of Europe's densest network of pilot, demonstration and production plants along the value chains of the primarily wood-based bioeconomy is being pursued in the BioEconomy Cluster. The overriding long-term goal is to create and secure jobs in the bioeconomy and the chemical industry. An important goal adjustment is the strategic focus on high-value products in the automotive (e.g. composite materials, lubricants, fuels and additives), building materials industry ("green" building materials and finishing products), packaging (films), fine and specialty chemicals (e.g. adhesives, fragrances, flavours and additives), consumer and lifestyle products (e.g. sports equipment, toys, food supplements) or paints and coatings (e.g. surface coatings) markets. The BioEconomy Cluster succeeded in involving its members through regular strategy workshops and adapting the project portfolio accordingly (BioEconomy Cluster Management GmbH, 2018).

The further direction and vision of the BioEconomy Cluster is:

- The use of the infrastructure in Central Germany, which is unique in Germany, by the chemical industry (chemical triangle the forestry and timber industry, the agricultural industry (e.g. sugar) and the energy sector. In addition, there is a high level of acceptance of chemical/technological plants in the Leuna-Schkopau-Bitterfeld region. This must be used and expanded (IHK Halle-Dessau, 2017).
- Better integration of local and supra-regional partners (companies/institutes) from different and hitherto largely separate economic spheres (interdisciplinarity in the bioeconomy – across sectors). These need to be brought together in the network – the aim is to accelerate the development of the bioeconomy.
- The creation and safeguarding of jobs in Central Germany.
- Establishing long-term leadership in the bioeconomy.

13.3 Cluster Partners and Their Contributions to the Cluster

The cluster work of BioEconomy e. V. focuses on the use of renewable raw materials for applications in innovative timber construction, lightweight automotive construction, as bio-based composites, packaging, biopolymers and fine and specialty chemical components, wood materials, but also in biotechnology, e.g. as food and feed additives, fertilisers or cosmetics. At the end of 2017, 80 members were active in the BioEconomy Cluster. The network extends from the core area of Saxony-Anhalt and Saxony to Thuringia, Brandenburg and Lower Saxony. The cluster is now active throughout Germany (▣ Fig. 13.1).

The networking of different economic sectors (e.g. forestry and timber industry, chemistry, mechanical and plant engineering, plastics and packaging industry, pulp and paper industry, etc.) as well as the central approach to process scaling ensure an accelerated development of processes and products from laboratory/pilot to demonstration/industrial scale. Through its members, the BioEconomy Cluster bundles a large portfolio of infrastructure for research and development (R&D) from the first laboratory test to pilot plants and demonstrators. In addition, there are numerous services as a service for the cluster partners from the initiation of projects to the grant notification as well as access to expert know-how and funding opportunities.

One example of such a successful transfer in the BioEconomy Cluster is Global Bioenergies GmbH. Isobutene is one of the key molecules in the chemical industry and an important starting material for various intermediate and end products (e.g. fuel additives, polymers, vitamins or fragrances). Up to now, isobutene has been commercially extracted exclusively from fossil sources such as crude oil. Initiated in the Leading-

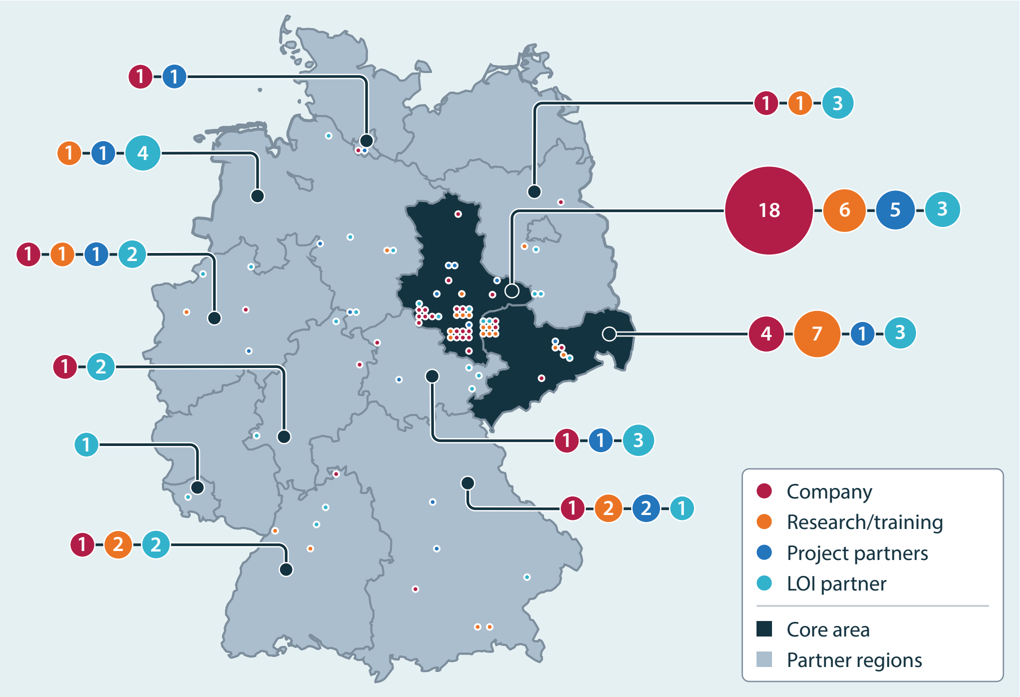


Fig. 13.1 Overview of regional networking of the BioEconomy Cluster throughout Germany. (Source: Own representation)

Edge Cluster, Global Bioenergies GmbH, the Fraunhofer Center for Chemical-Biotechnological Processes (CBP) and Audi AG set out together in a joint project and developed a process to produce gaseous isobutene from sugars directly by fermentation, i.e. with the aid of genetically modified microorganisms. This bio-isobutene development process, which was successful in the laboratory, was transferred to a pre-industrial scale in Leuna. For this purpose, a demonstration plant with a capacity of 100 tonnes per year was built and inaugurated in May 2017 (BioEconomy Cluster, n.d.-b).

In addition to such exciting technological innovations and *upscalings,* a new international master's degree program was introduced in the BioEconomy Leading-Edge Cluster at Martin Luther University Halle-Wittenberg in the winter semester of 2017 to secure a skilled workforce. The Pharmaceutical and Industrial Biotechnology course was established at the chair of Professor Dr. Markus Pietzsch. In terms of training and further education, a new biotechnology laboratory was successfully inaugurated at the Bildungsakademie Leuna GmbH (BAL) at the beginning of 2018, which promotes better practice-oriented training of chemical technicians and thus also process engineering understanding in the bioeconomy environment (BioEconomy Cluster, n.d.-c).

13.4 Management of the Cluster

The BioEconomy Cluster was founded in 2011 as an association by 23 initiators. The cluster is managed by an association board and, as a subcontractor, by the cluster management (◘ Fig. 13.2).

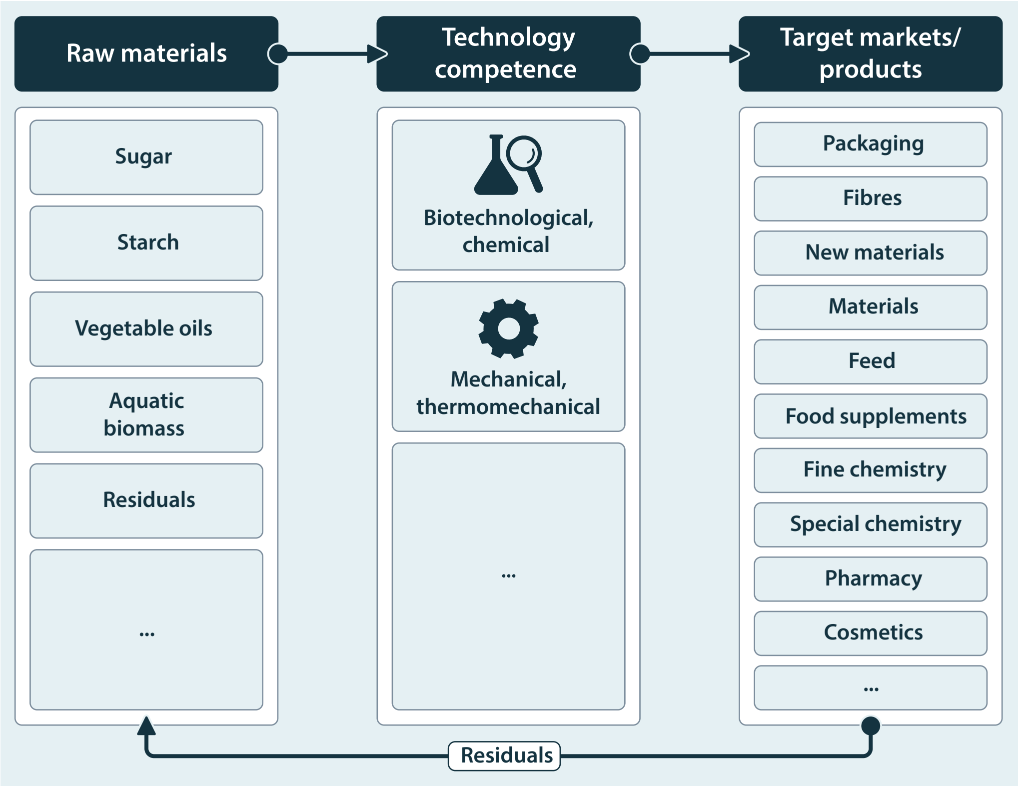


Fig. 13.2 Organisational structure of the BioEconomy Cluster Central Germany. (Source: Own representation)

Since then, the board of the e. V. has included and continues to include representatives of the members who perform this activity on a voluntary basis. Thus, the minimum seven maximum nine board members include representatives from science and industry. For successful project coordination, a subsidiary was founded to act as the executing project company, since the association itself can hardly be represented in project consortia. In addition to the board of directors, which meets regularly and makes decisions, there is also an association advisory board, which advises and supports the cluster.[1]

The members themselves meet regularly at least twice a year at the general meetings. In addition, there are numerous networking opportunities, such as business meetings, *matchmakings,* joint trade fair appearances or conferences, which provide topic-specific but also interdisciplinary networking. In addition to members and partners, interested parties can also participate in the official cluster events, such as the BioEconomy BusinessTreffs. Furthermore, the cluster organises the International Bioeconomy Conference in Halle together with the WissenschaftsCampus Halle (WCH). This conference takes place every year in spring and is dedicated to networking between science and industry. Current research results, applications, markets and companies in the bio-based economy are presented. Each

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[1] For the structure of the association, see also: ► http://www.bioeconomy.de/bioeconomy-e-v/.

year, the main focus and the conference partner region vary. In addition to the success models and experiences of the respective partner region, the region of Central Germany/Germany presents itself in parallel with its innovations.

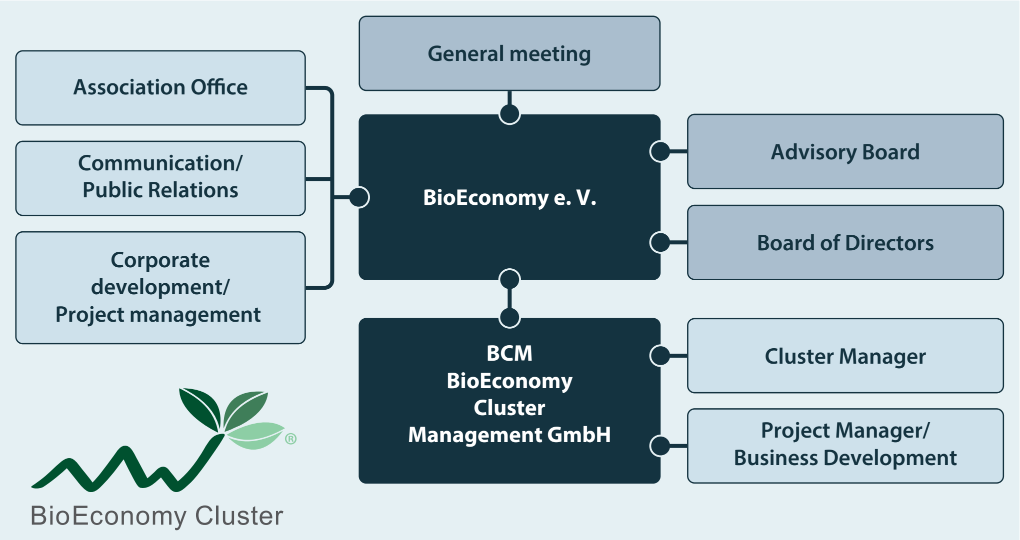
Another important participation opportunity is the ongoing, planned and announced projects. The BioEconomy Cluster acts as an interface, brings together the right project partners (regional, national and international), sets up project consortia, is itself involved in some of the coordination and also makes suggestions for project developments and topics. This networking work is a great added value for all participants.

13.5 Benchmark and Success Criteria

The focus on beech wood alone was good and right for the beginnings of the BioEconomy Leading-Edge Cluster. In the meantime, the resource base has been expanded from beech wood to include all lignocellulosic raw materials. In addition, the raw material side has also been opened up to agricultural raw materials and residues, e.g. from sugar beet processing, but also algae, waste wood or vegetable oils are included in the input side (◘ Fig. 13.3).

In addition to the biomass expansion, another success criterion and thus also a unique selling point of the BioEconomy Cluster is the network of pilot and demonstration plants, with which well over €120 million have been implemented through cluster activities alone since 2012. The targeted combination of actors, technologies, knowledge and material flows from the economically important sectors of forestry, wood, chemicals, construction, automotive, energy and packaging has led to the development and demonstration of innovative value chains, processes and products in 146 individual projects organised in 44 networks (BioEconomy Cluster Management GmbH, 2018).

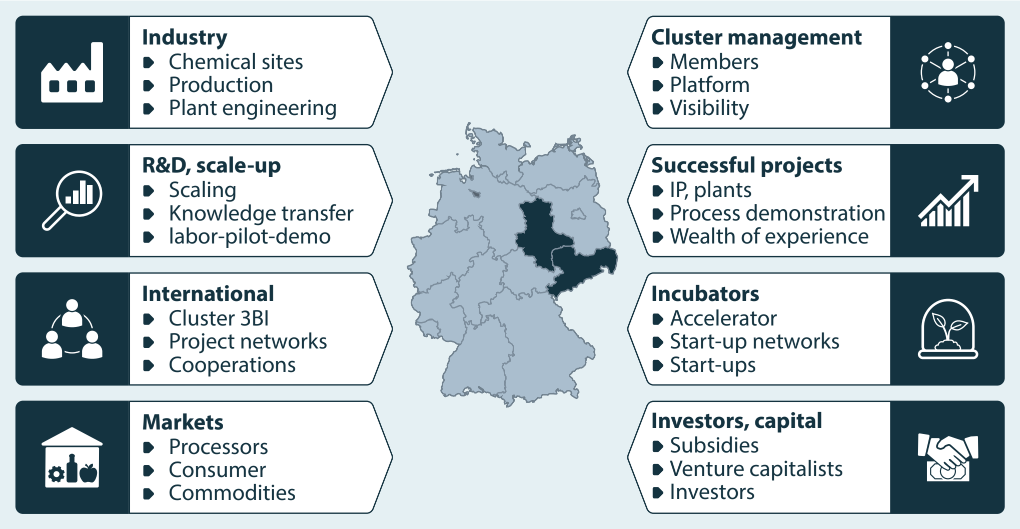
As the most important asset in the research competition, the Leading-Edge Cluster bundles a unique portfolio of R&D infrastructures from laboratory, pilot and demonstration plant scale. The network



◘ **Fig. 13.3** Process for the application of bio-based raw materials for specific target markets. (Source: Own representation) includes facilities operated by research institutions (specific Fraunhofer societies, BMEL departmental research, Helmholtz Association, universities of applied sciences, universities) and structures operated or financed by industry (EW Biotech, formerly thyssenkrupp Industrial Solutions, Linde, Institut für Holztechnologie Dresden IHD, Global Bioenergies GBE, etc.): Pressure-guided biomass digestion processes (Organosolv, Fraunhofer CBP), fully integrated fermentation plants e.g. for isobutene (Global Bioenergies at CBP), fermenters for fine chemicals (EW Biotech) and agricultural input materials (German Biomass Research Center Leipzig DBFZ), a variety of plants for biopolymer production and processing (Fraunhofer Pilot Plant Center PAZ, Fraunhofer IMWS), separation technology, fiber and building product production up to harvesting technology or residue processing are linked via the cluster. They enable the establishment and demonstration of cross-industry value chains (◘ Figs. 13.1 and 13.4).

In addition, from the end of 2015 to the end of 2017, the BioEconomy Cluster Management was able to successfully implement the topic "Gründungen In die Spitzencluster BioEconomy Region Transportieren" (GISBERT) and thus establish a start-up culture (BioEconomy Cluster, n.d.-a). The GISBERT project supported the establishment of start-up promotion activities by dovetailing the start-up and innovation structures in the BioEconomy Cluster region, as well as identifying and raising awareness among potential founders in the bioeconomy sector and supporting them in developing suitable business models and start-ups. The project was funded by the BMBF and coordinated by the HHL Leipzig Graduate School of Management and BioEconomy Cluster Management GmbH. In the project, start-up and spin-off projects with bio-based business models were supported by a wide range of services and an extensive partner network.

This topic must now be continued – and, in addition, the network that has been created must also be used for established small and medium-sized enterprises (SMEs) and their innovation processes. In order to further expand the existing structures and to establish a separate and, above all, more agile space for innovation, start-up and



◘ **Fig. 13.4** Strong basis from the BioEconomy Leading-Edge Cluster. (Source: Own representation) growth in the bioeconomy, there are various approaches and considerations in the BioEconomy cluster.

The networks BIOPRO from Baden-Württemberg or CLIB from North Rhine-Westphalia are both role models and partners, with each cluster having its own focus.

13.6 Experiences

The BMBF's BioEconomy cluster of excellence has developed into a powerful and internationally recognised innovation system for the primarily lignocellulose-based bioeconomy in Europe. The cluster links public and industry-operated R&D infrastructures to form a technology competence that is unique in Europe and enables accelerated research, development and scaling of bioeconomic processes. Here in particular, the network has decisively improved interdisciplinary cooperation between the participants as well as beyond their own horizons. The Leading-Edge Cluster, which was initially strongly dominated by institutes and universities (*technology-push focus*) with few ideas directly from industry, has now been broken up and transformed into a healthy mix of innovative market-driven ideas and target-oriented research results.

In 2015, the steadily advanced internationalisation of cluster activities led to the founding of the European "Intercluster 3BI" with Biobased Delta (NL), IAR (F), BioVale (UK) as well as CLIC (FIN) and to the development of further internationalisation concepts, such as the BMBF-funded project for the internationalisation of leading-edge clusters "Beechwood International".

As a subsidiary of the cluster, BioEconomy Management GmbH (BCM) represents the SME members of BioEconomy e. V. in the BioBased Industries Consortium (BIC) and the private part of the PPP "Bio-based Industries Joint Undertaking" (BBI JU). This is a great added value, especially for small companies that could not afford membership and thus still participate.

With the implementation of the cluster strategy, the aim was to establish a cross-sector bioeconomy region based on the regionally available raw material beech wood, which has since been extended to available biomass in general (raw material openness). The integration of important chemical-industrial production sites led to the development of an integrated coupling and cascade production of timber construction systems, chemical base and intermediate materials, biopolymers, new materials and composites, components for the automotive industry and energy sources.

Existing innovation structures in the start-up sector have been successfully integrated and an initial start-up and innovation culture has been established, which has led to a number of spin-offs and start-ups as well as the establishment of R&D-driven companies. This will become even more of a focus in the future.

By establishing an international master's degree course at Martin Luther University Halle-Wittenberg, the BioEconomy Cluster is helping to secure a skilled workforce. The network was also able to support the Bildungsakademie Leuna (BAL) with various equipment and technology donations to set up a biotechnological and bioeconomic cabinet necessary for the training and further education of technical personnel.

The low oil price leads to a low motivation of the petroleum processing industry, with its infrastructural path dependency and mostly large industry dominated actor world, to invest in the R&D segment of bio-based alternatives. The cluster therefore aims to develop high-value products, such as fine and specialty chemicals. The focus is on agile small and medium-sized companies for which targeted research, development and innovation (R&D&I) projects appear much more attractive. They have the ability and motivation to develop niche markets much faster (adapted from BioEconomy Cluster Management GmbH, 2018).

Since mid-2017, the cluster has succeeded in better integrating the previously too few drivers of the bioeconomy from industry (members who themselves had little or hardly any contact with the topic of the bioeconomy) and also in winning large companies or hidden champions from the sector as committed members (e.g. UPM, Papiertechnische Stiftungen [PTS]) in order to establish more sustainable processes and create jobs in the future. This development must be continued. The already well-functioning network structure, the BioEconomy Cluster, which is now internationally respected and in demand, and the first examples of success are an incentive to bring more biobased innovations to the market with the network and thus save time, costs and resources in the development process, especially for the members.

The construction of large demonstration plants, for example, is very cost-intensive and time-consuming. Alternative concepts are to be applied in the BioEconomy Cluster through suitable infrastructure utilisation concepts. In this way, partners can first use existing infrastructures without expensive new acquisitions and risks and scale up their own R&D developments. The BioEconomy Cluster aims to use the approach of a *sharing economy* (shared use of fully or partially unused resources) and to make its scaling and research capacities quickly and easily accessible worldwide. It aims to initiate and implement R&D&I projects quickly and efficiently.

References

BioEconomy Cluster. (n.d.-a). GISBERT: Ihr Weg zu einem biobasierten Unternehmen. http://www.bioeconomy.de/innovationen/gisbert/. Accessed: 10.12.2018.

BioEconomy Cluster. (n.d.-b). Global Bioenergies: Der Bau der industriellen Demonstrationsanlage in Deutschland beginnt. http://www.bioeconomy.de/global-bioenergies-der-bau-der-industriellen-demonstrationsanlage-deutschland-beginnt/. Accessed: 10.12.2018.

BioEconomy Cluster. (n.d.-c). „Nachbarschaftshilfe“ im Clusterverbund BioEconomy. http://www.bioeconomy.de/nachbarschaftshilfe-im-clusterverbund-bioeconomy/. Accessed: 10.12.2018.

BioEconomy Cluster Management GmbH. (2018). Endbericht Spitzencluster BioEconomy: Zusammenfassung. https://www.tib.eu/de/suchen/id/TIBKAT%3A1025136128/Endbericht-Spitzencluster-Bio-Economy-Zusammenfassung/. Accessed: 10.12.2018.

Hüsing, B., Kulicke, M., Wydra, S., Stahlecker, T., Aichinger, H., & Meyer, N. (2017). Evaluation der Nationalen Forschungsstrategie „BioÖkonomie 2030" – Wirksamkeit der Initiativen des BMBF – Erfolg der geförderten Vorhaben – Empfehlung zur strategischen Weiterentwicklung. Abschlussbericht. Im Auftrag des BMBF. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2017/Evaluation_NFSB_Abschlussbericht.pdf. Accessed: 11.12.2018.

IHK Halle-Dessau (Industrie- und Handelskammer Halle-Dessau). (2017). Mehr Industrie wagen! Eine Studie der Industrie- und Handelskammer Halle-Dessau zur Akzeptanz von Industrieunternehmen. https://www.halle.ihk.de/share/flipping-book/3739486/flippingbook.pdf. Accessed: 10.12.2018.

MW Sachsen-Anhalt (Ministerium für Wirtschaft, Wissenschaft und Digitalisierung des Landes Sachsen-Anhalt). (2014). Regionale Innovationsstrategie Sachsen-Anhalt 2014–2020. https://mw.sachsen-anhalt.de/fileadmin/Bibliothek/Politik_und_Verwaltung/MW/Publikationen/RIS/Regionale_Innovationsstrategie_2014-2020_final.pdf. Accessed: 10.12.2018.

Dr. Joachim Schulze

(born 1960) is a graduate chemist and received his doctorate in inorganic chemistry in 1987. Since the beginning of 2017, he has been managing director of EW Biotech GmbH in Leuna, which specialises in transferring newly developed biotechnology processes to industrial scale. He is the founder of Corvay Bioproduct GmbH and has been an independent management consultant since mid-2019. Prior to that, he worked at ThyssenKrupp Industrial Solutions as a department manager for almost ten years. He has been active in the BioEconomy Cluster since 2016 and has been Chairman of the Board of BioEconomy e. V. since 2017.

Anne-Karen Beck
(born 1980) studied business administration at the Technical University of Dresden. She focused on the topics of environmental economics and marketing, among others. She has been working at the Central German Bioeconomy Cluster (BioEconomy e. V.) since 2016, where she coordinates projects on the topics of business start-ups, business development, technology transfer and internationalisation. She is also responsible for the communication and controlling of the Saxony-Anhalt Innovation Cluster and the external presentation of the network. This includes, for example, the organisation of specialist events – such as the annual International Bioeconomy Conference in Halle, matchmaking events such as the BioEconomy BusinessTreffs or representation at international trade fairs.

Bioeconomy in Baden-Württemberg

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Contents

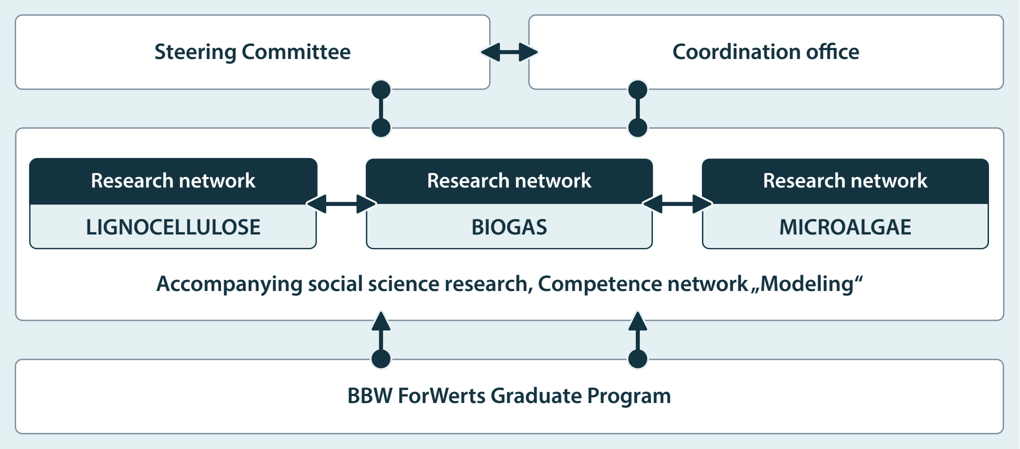
D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_14

14.1 Cluster Partners and Their Contributions

14.1.1 Initiators and Partners of the Bioeconomy Research Program

In 2012, Baden-Württemberg was one of the first federal states in Germany to decide to develop its own bioeconomy strategy. Realizing that research and development are the basis for the desired structural change, the Ministry of Science, Research and the Arts (MWK) initially convened a strategy committee composed of experts from all relevant disciplines to develop a research strategy among the state's universities and research institutes. A detailed analysis of the Baden-Württemberg research landscape with regard to the bioeconomy was published together with a strategy paper "Setting up the bioeconomy in a systemic approach" (MWK, 2013). This strategy was implemented in 2014 and has been financed to date by €14 million funding from the Bioeconomy Research Program. (◘ Fig. 14.1). From the research program arose the initiative to establish the "Baden-Württemberg Bioeconomy Research, Innovation and Training Cluster" which has the aim of continuing and expanding the network already established. This initiative is supported as part of the new state strategy "Sustainable Bioeconomy for Baden-Württemberg" (UM and MLR, 2019). The partners in the Baden-Württemberg research program are primarily those institutions involved in the project funding (◘ Fig. 14.2). These are eight universities, each with its own research focus, and eight non-university research institutions from Baden-Württemberg.

The research program has succeeded in pooling interdisciplinary expertise on the topic of the bioeconomy from within the state of Baden-Württemberg in the fields of agricultural and forestry sciences, environmental sciences, natural sciences and engineering, food technology, nutritional medicine, economics, and social sciences (◘ Fig. 14.3). This results in 46 institutes from 16 institutions working together within the research program. The networking was necessary to implement the research strategy's systemic approach and promote interdisciplinary collaboration on value chains in the various focus areas.

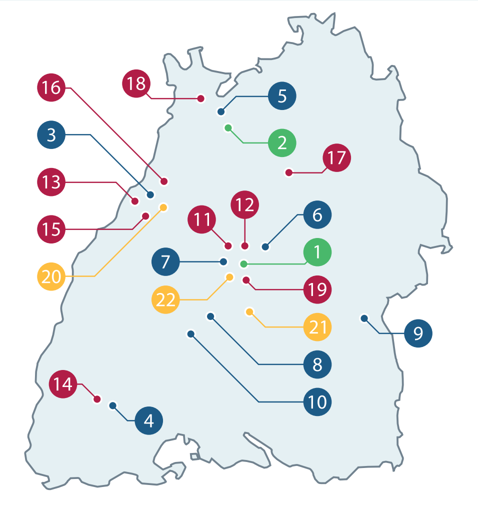


◘ **Fig. 14.1** Structure of the Baden-Württemberg Bioeconomy Research Program. (Source: Authors' own representation)

Coordination offices	
Bioeconomy Research Program Coordination Office	1
BBW ForWerts (Bioeconomy Baden-Württemberg – Research into Innovative Value Chains)	2

Universities and colleges	
Karlsruhe Institute of Technology (KIT)	3
University of Freiburg	4
University of Heidelberg	5
University of Hohenheim	6
University of Stuttgart	7
University of Tübingen	8
University of Ulm	9
University of Applied Forest Sciences Rottenburg	10

Non-university partners and research institutions	
BIOPRO Baden-Württemberg GmbH	11
Dialogik gGmbH	12
DVGW-Research Centre at Engler-Bunte-Institute of KIT	13
Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg	14
Fraunhofer Institute for Chemical Technology ICT	15
Max Rubner Institute (MRI)	16
State Research Centre for Viticulture and Fruit Growing in Weinsberg (LVWO)	17
ZEW – Leibniz Centre for European Economic Research	18
Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB	19

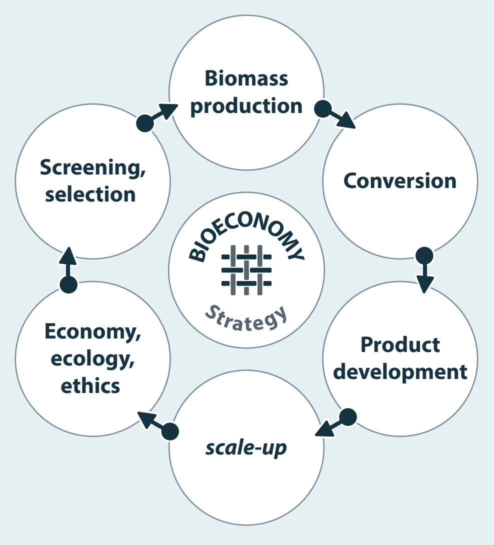


Research facilities	
Bioliq pilot plant at Karlsruhe Institute of Technology (KIT)	20
Unterer Lindenhof – Experimental station for bioenergy, biorefineries, livestock and plant sciences of the University of Hohenheim	21
University of Stuttgart - Institute for Sanitary Engineering, Water Quality and Solid Waste Management, Teaching and research sewage treatment plant (LFKW)	22

Fig. 14.2 Map showing locations of partners in the Baden-Württemberg Bioeconomy Research Program. (Source: Authors' own representation)

14.1.2 Funding Priorities in the First Funding Round of the Bioeconomy Research Program

The MWK's first funding round prioritized research activities that were thematically focused and where a number of sub-projects were brought together to form a research network for collaboration initiation or expansion. The selection of these funding priorities was based on recommendations from the strategy committee. Research fields were selected that had the greatest potential for innovation, unique selling proposition, as well as implementation in Baden-Württemberg. A further requirement was that they cover the areas of energy, materials and nutrition and have different time per-



Disciplines:	
Agricultural science	Process engineering
Forestry	Chemistry
Environmental sciences	Biology
Food technology	Soil science
Nutritional medicine	Ecology
Social sciences	Economy

Fig. 14.3 Interdisciplinary exploration of value chains. (Source: Authors' own representation)

spectives for implementation. The following fields were selected:

- Sustainable and flexible value chains for biogas in Baden-Württemberg (Biogas),
- Lignocellulose – transition to an alternative raw material platform for new materials and products (Lignocellulose),
- Integrated use of microalgae for nutrition (Microalgae),
- Competence network "Modeling the Bioeconomy".

In the research network "Biogas", the focus was placed on optimizing and evaluating technologies in which Baden-Württemberg has taken on a pioneering role, but which due to changes in the Renewable Energy Sources Act (EEG) no longer receive the same support (Bahrs & Angenendt, 2018). The network investigates how biogas production can be further developed through technical innovations (e.g. the integration of power-to-gas concepts) and how residual materials (e.g. biowaste from municipal collections, sewage sludge) can be put to better use. In addition, the scientists are developing business models to integrate biogas as a flexible component in a future energy system based on renewable energies. Baden-Württemberg has a particularly well-developed biogas research infrastructure with the research biogas plant operated by the University of Hohenheim at Unterer Lindenhof (electrical output 355 kW) as well as special laboratories in Hohenheim and at the Karlsruhe Institute of Technology (KIT). Technical expertise and know-how in the evaluation of waste potentials and energy systems is contributed through the Fuel Technology Division of the Engler Bunte Institute at KIT and the University of Stuttgart's Institute of Energy Economics and Rational Energy Use, Institute for Sanitary Engineering, Water Quality and Solid Waste Management, and Institute of Interfacial Process Engineering and Plasma Technology. The University of Hohenheim is responsible for the agro-economic evaluation of the potential of biogas technology. The International Center for Ethics in the Sciences and Humanities (IZEW) at the University of Tübingen contributes to the normative evaluation and development of sustainability indicators, and the company Dialogik is responsible for the establishment of good governance concepts.

The largest of the three research networks, "Lignocellulose", investigates approaches that contribute to the development of sustainable value chains for the use of lignocellulose in new materials. Research into the provision of biomass (cultivation, potential analyses, ecological assessment) is carried out by leading faculties in the field of forestry (University of Freiburg) and agricultural sciences (University of Hohenheim) in their respective research infrastructures and experimental facilities. In addition, the state's Forest Research Institute (Forstliche Versuchs- und Forschungsanstalt) is involved, as is the University of Heidelberg for basic plant science research. The research on biomass supply focuses on forest wood, wood from short rotation coppice and miscanthus. An important partner in this field is KIT, with its bioliq® pilot plant for the processing of straw and other lignocellulose-based biomass into synthesis gas, which is unique in Germany. Important expertise and processing plants for the chemical, biochemical and microbiological conversion of biomass into products such as biobased platform chemicals, surfactants and polymers are located at the participating Fraunhofer Institutes (Fraunhofer Institute for Chemical Technology (ICT), Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB)) as well as the Universities of Freiburg, Karlsruhe, Hohenheim, Stuttgart and Ulm. This collaborative effort has succeeded in integrating research on biomass production with research on different conversion technology approaches in order to link optimal combinations of technologies and develop concepts for co-utilization in which all components of lignocellulose are optimally exploited (Dahmen et al., 2018). These investigations are complemented by research on the economic evaluation of these concepts and sustainability analyses at the University of Hohenheim and the University of Stuttgart.

The third research network, "Microalgae", is investigating the possibilities of using microalgae to produce valuable raw materials for the feed and food industry, such as proteins, lipids and carotenoids. Facilities for the production of microalgae are available in Baden-Württemberg at KIT as well as the University of Stuttgart and Fraunhofer Institute IGB. As part of the research program, cooperations have been established with food technology, nutrition research and animal nutrition institutes at the University of Hohenheim and the Max Rubner Institute. The Universities of Freiburg and Tübingen cover basic research tasks. The cooperation between experts from biotechnology, food technology, nutrition physiology and consumer research has led to the development of promising new product ideas. In addition, concepts have been developed with which microalgae production can be specifically directed towards the production of certain ingredients. Cooperation with nutrition research is important in order to investigate the bioavailability and qualitative assessment of the ingredients depending on the production steps. The Institute for Technology Assessment and Systems Analysis at KIT undertakes sustainability assessment and consumer acceptance studies (Rösch et al., 2018). The results of these are in turn used for process and product development for the selection of sustainable and marketable implementation approaches.

The competence network "Modeling the Bioeconomy" deals with the impacts of increased biomass use on the economy and the environment and investigates competing uses between the four key areas. The competence network spans a range of fields of activity in order to develop a number of bioeconomy scenarios. By combining simulation models already established by the participating institutes, a system is created which can be used for the holistic mapping of the effects of a change in biomass use. To this end, expertise is incorporated from macroeconomic assessment (Centre for European Economic Research), agricultural economics and agricultural policy (University of Hohenheim), energy system modelling (University of Stuttgart and KIT) and sustainability assessment (University of Stuttgart and University of Freiburg).

14.1.3 Funding Priorities in the Second Funding Round of the Bioeconomy Research Program

In the second funding round up to 2020, application-oriented basic research projects continued to be supported in the funding line “**Technological and methodological innovations for new processes in the bioeconomy**”.

The new funding line “**Bioeconomic process and product innovations with a concrete transfer perspective (regional best practice examples)**” aims to advance the transfer of developed ideas and technologies into application. In the consortium project “Lignocellulose biorefinery for the bioeconomy in Baden-Württemberg (B4B)”, for example, results from lignocellulose network subprojects financed in the first funding round are used to establish a lignocellulose biorefinery capable of continuous processing at pilot-plant scale (◘ Figs. 14.4 and 14.5). Another transfer project is concerned with various microalgae applications as food products with health benefits and as plant strengthening agents in viticulture, and builds on the results of the microalgae network.

A. Lignocellulosic Biorefinery for the Bioeconomy in Baden-Württemberg (B4B)

The aim of the consortium project is to set up and operate a complete utilization chain for lignocellulose in the biorefinery pilot plant. The lignocellulose biorefinery implements innovations from various research projects in a modular test facility. In addition, it serves as a platform for process and product development, also in the context of new projects and cooperations.

Its location at the University of Hohenheim’s agricultural experimental station “Unterer Lindenhof” reflects the close coupling of biomass production, processing and conversion for the regional utilization of biomass potentials in integrated process chains.

Partners:

- University of Hohenheim
- Karlsruhe Institute of Technology (KIT)
- BIOPRO Baden-Württemberg GmbH

B. **Microalgae Value Chains for the Bioeconomy in Baden-Württemberg (MIATEST)**

The aim of the consortium project is to optimize the production of microal-

◘ **Fig. 14.4** Lignocellulosic biorefinery at the “Unterer Lindenhof”. (Source: University of Hohenheim)

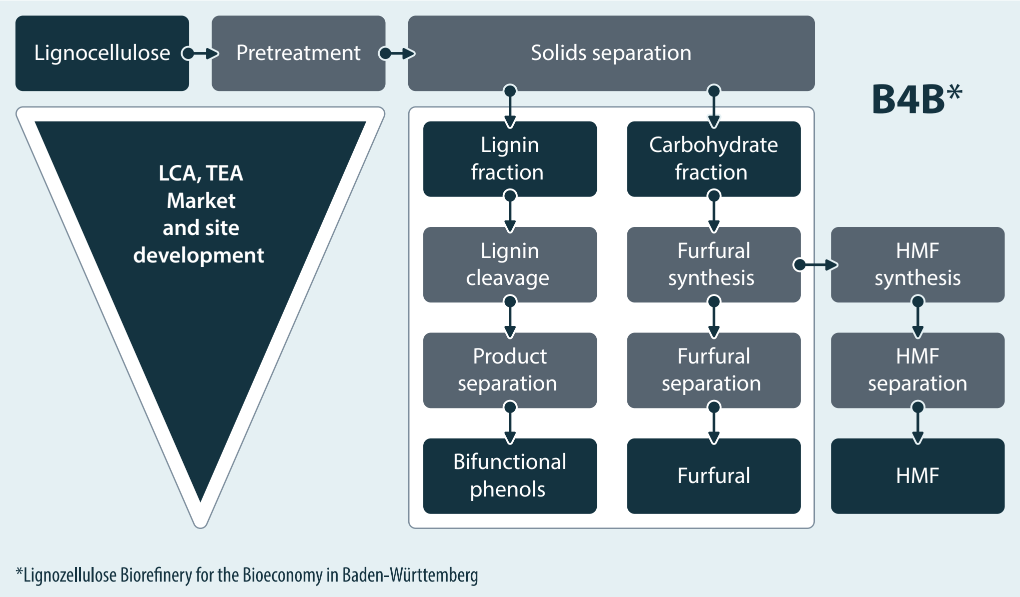


Fig. 14.5 Utilization of biomass potentials in integrated process chains. (Source: Nicolaus Dahmen)

gae biomass with regard to specific applications and to validate two new possible uses. At the University of Stuttgart, the production and processing of microalgae for the production of enriched product samples is being carried out. At the University of Hohenheim, an initial human subject study is investigating whether and to what extent the nutrients from selected microalgae are bioavailable and safe for consumption, and whether they have health-promoting properties. In the consortium's third subproject, the Staatliche Lehr- und Versuchsanstalt für Wein- und Obstbau Weinsberg (English: State Research Center for Viticulture and Fruit Growing Weinsberg) (LVWO) is investigating whether the use of microalgae or laminarin in viticulture induces plant defense mechanisms that protect the plants from fungal infections. This could reduce the use of environmentally harmful fungicides in the cultivation of wine grapes.

Partners:
- University of Stuttgart
- University of Hohenheim
- Staatliche Lehr- und Versuchsanstalt für Wein- und Obstbau Weinsberg (LVWO)
- BIOPRO Baden-Württemberg GmbH

14.1.4 Training Concept in the Bioeconomy Research Program

In order to train university graduates from different disciplines for the changing requirements in research and on the job market, the collaborative graduate program BBW ForWerts (Bioeconomy Baden-Württemberg – Research into Innovative Value Chains) was established between several universities in Baden-Württemberg as an integral part of the research strategy. Here, the young scientists working in the research projects funded by the program gain insights into the diverse fields of work in the bioeconomy beyond their own scientific work. As they are aiming for a doctorate in various disciplines, they benefit from the different disciplinary orientations of the participating universities and the opportunities for interdisciplinary networking.

The young scientists on the program are awarded a doctorate in their subject from their home institution. The graduate program awards a certificate for the additional work performed within the framework of BBW ForWerts, such as participation in methods courses, excursions and interdisciplinary summer schools.

The graduate program supports the overarching goal of networking between the institutions by providing a number of target-group-oriented events for young researchers. The personal contacts established in the program often lead to further collaborations. In addition, the graduate program offers a platform for networking with international partners, who are regularly invited to the events.

14.2 Management of the Cluster

The Coordination Office, which was established at the University of Hohenheim to manage the research program and the cluster initiative, coordinates the interdisciplinary cooperation between the participating subprojects, organizes annual status seminars and carries out public relations work on the activities of the partners. In this way, it assumes important tasks with regard to the overarching goals, the support of regional and supra-regional networking and increasing the visibility of Baden-Württemberg's bioeconomy research. The coordination office represents the cluster initiative to external audiences, for example at trade fairs and conferences, and supports the partners in initiating cooperations and follow-up projects and in joint publications.

The organization of regular scientific events promotes discourse with stakeholders outside the program and increases the visibility of Baden-Württemberg as an innovative bioeconomy region. The international bioeconomy congresses (2014, 2017, 2020), which were each attended by around 350 participants, demonstrate the breadth of bioeconomy topics and contribute to an active communication strategy. Current topics are addressed in smaller event.

A steering committee consisting of representatives of the member organizations from different disciplines has been established to manage the Baden-Württemberg bioeconomy research program.

14.3 Vision and Mission

The background to Baden-Württemberg's funding of bioeconomy research since 2013 was, on the one hand, the political will to promote structural change and, on the other hand, the recommendation of the strategy committee that top-ranking research institutions can complement each other very well in the field of the bioeconomy and that their strengths and potentials can be expanded through appropriate funding and cooperation.

In order to build up a Baden-Württemberg bioeconomy profile and at the same time establish concrete cooperations through consolidation in strategically selected research areas, topics were identified that have the greatest possible potential for innovation and unique selling proposition as well as high potential for implementation of the results in the Baden-Württemberg economy. The aim of the cooperation is the interdisciplinary and transdisciplinary analysis of exemplary bioeconomy systems, i.e. value chains starting from raw materials, through conversion and utilization, to products, including economic, social and ecological aspects, and taking into account the effects on the environment and society. Using examples from the fields of food, animal feed, materials and energy, the research networks demonstrate the possibilities of a bioeconomy and integrate different perspectives and disciplines, including societal challenges and sustainability assessment. A similar focus on approaches to solving societal challenges can also be found in the national research strategy (BMBF, 2010).

Through the funding of the research networks, Baden-Württemberg has set up its profile in the areas of microalgae, lignocellulose and biogas. With the second round of funding and a continuation of the research, innovation and education cluster, this profile will be extended to new areas of research in future.

Each of the research networks displays a systemic approach with close links between all disciplines involved in the value chains and also the close integration of accompanying social science research. In addition, Baden-Württemberg institutions were quick to promote the combination of bioeconomy with information technology, modeling and simulation. This focus contributed, among other things, to the establishment of a competence center for biointelligence with the goal of linking bioeconomy and *smart-manufacturing* approaches (Bauernhansl et al., 2019).

The cluster initiative, which is composed of universities and research institutes, is characterized by a distinct strategy for promoting young scientists. This strategy is shaped not only by the joint graduate program, but also by corresponding master's degree courses as well as programs and support schemes for young founders at the member universities.

Since the transformation to a bioeconomy as a sustainable form of economy can only succeed if all sectors involved follow a joint strategy including the integration of economic, ecological and social issues, the program involved stakeholders from industry and society already at the conception stage. This interactive process is now being continued in the discussion of the results.

In addition, the cluster initiative participates in interregional exchange for the further development of the bioeconomy, in particular with regard to interdisciplinary research, education and training concepts, and arranges cooperation partners for regional, supraregional and international projects.

14.4 Benchmarking and Success Criteria

The Baden-Württemberg research strategy "Positioning the bioeconomy in the system" was developed by a group of experts on behalf of the Ministry of Science, Research and the Arts (MWK). It is based on a SWOT analysis which first identified the strengths of research institutions in Baden-Württemberg in order to identify unique selling points and future potential.

The aim of project funding within the framework of the Baden-Württemberg bioeconomy research program was initially the development of scientific know-how. This know-how is exploited in the form of publications and patents, as well as in proposals for follow-up projects. More than 120 scientific publications have already resulted from the research program (as review articles, see also Bahrs & Angenendt, 2018; Dahmen et al., 2018; Rösch et al., 2018). Another important success criterion for the program is the future transfer of research results into practice. For this reason, transfer measures were specifically supported in the second funding round of the research program launched in December 2017.

In addition to project funding, the research strategy had, from the outset, a structure-building component at its forefront, which aims to initiate cooperation and regional networking between actors along the value chain. The complexity of interdisciplinary value chains requires active interface management. For this reason, networking measures are recommended as high priority in current bioeconomy strategies (e.g. Hüsing et al., 2017; EC, 2017, 2018), and this has proved very successful in the Baden-Württemberg research program.

The report by Spatial Foresight et al. (2017) lists Baden-Württemberg as one of the bioeconomy regions with the largest “Bioeconomy Research and Innovation Maturity Index”. The Bioeconomy Maturity Index assesses regions with respect to their bioeconomy research and innovation activities, structural and strategic measures, and also innovation capacity.

Since 2017, Baden-Württemberg has been advancing the development of the state strategy “Sustainable Bioeconomy for Baden-Württemberg” to promote the implementation of a sustainable bioeconomy in practice (UM, 2016; MLR, 2017; UM and MLR, 2019).

14.5 Experience to Date

The Baden-Württemberg bioeconomy research program has succeeded in bringing together scientists from the disciplines of agricultural and plant sciences, forestry, environmental and engineering sciences, social and economic sciences, and biodiversity research, who - despite their regional proximity - were previously not so well connected. This led to the expansion of potential synergies through cooperation between Baden-Württemberg’s universities, colleges and non-university research institutions. New interdisciplinary research collaborations and training formats in the field of the bioeconomy have also been developed.

The consistently interdisciplinary approach encompassing the entire biobased value network has proven to be very productive for the further development of the bioeconomy, but at the same time also a great challenge. Bringing experts together in interdisciplinary research and training networks requires mutual understanding, the development of a common technical language and a cross-disciplinary mindset. This necessitates the development of respect for the different methodological approaches and perspectives of other disciplines. Opportunities have been created for regular personal exchange between researchers. The exchange within the network has been promoted through the organization of regular strategy and steering committee meetings, annual status seminars, meetings of the interdisciplinary research networks and also of the young scientists within the framework of the graduate program BBW ForWerts. In addition, the cluster initiative is actively involved in external communication, promoting interdisciplinary exchange and discourse on new research results by organizing scientific events and initiating joint publications.

In the field of education, the BBW ForWerts bioeconomy graduate program has produced scientists with a broad range of interests, high potential for an innovation mindset and capacity for interdisciplinary and systems-based thinking and working. In addition, cross-institutional exchange on training concepts has emerged and teaching collaborations in Master’s programs have been developed, resulting in, for example, the textbook “Bioeconomy – Shaping the Transition to a Sustainable, Biobased Economy”, written with the participation of several research partners from the bioeconomy research program (Lewandowski, 2017). The training of young professionals for the bioeconomy is assigned increasing importance in current strategy papers (European Bioeconomy Stakeholders Manifesto, 2017; EC, 2017; Bioökonomierat, 2018). Through cooperation and exchange on bioeconomy training concepts, Baden-Württemberg has created an excellent starting position for the establishment of bioeconomy modules in other courses of study.

Following the successful establishment of the Baden-Württemberg research program supported by MWK funding, the biggest challenge will now be to keep the cluster initiative active in the long term. The initiative is currently being expanded into a bioeconomy research, innovation and education cluster. A lasting continuation of the network will require the installation of a coordination office and an administration office for graduate training, the long-term funding of which still needs to be secured. Thanks to the strong networking within the research program, Baden-Württemberg universities and research institutions are now attracting more national and European funding for joint bioeconomy projects. In addition, greater use is being made of existing structures for technology transfer and start-ups.

In order to increase the transfer of generated knowledge into application, in June 2019, the Baden-Württemberg state government adopted the state strategy "Sustainable Bioeconomy for Baden-Württemberg" (UM and MLR, 2019). The declared goal is to set Baden-Württemberg up as a model state for a sustainable and circular economy. The strategy was developed in dialogue with stakeholders from science, business, politics and society for implementation from 2020 onwards.

References

Bahrs, E., & Angenendt, E. (2018). Status quo and perspectives of biogas production for energy and material utilization. *GCB Bioenergy*. https://doi.org/10.1111/gcbb.12548

Bauernhansl, T., Brecher, C., Drossel, W.-G., Gumbsch, P., Hompel, M., & Wolperdinger, M. (Eds.). (2019). *Biointelligenz – Eine neue Perspektive für nachhaltige industrielle Wertschöpfung (BIOTRAIN)*. Fraunhofer.

Bioökonomierat. (2018). Thesen zur Gestaltung der Bioökonomiepolitik. https://biooekonomierat.de/fileadmin/Publikationen/empfehlungen/BO__Thesenpapier_final_2.pdf. Accessed: 03.06.2019.

BMBF (Bundesministerium für Bildung und Forschung). (2010). Nationale Forschungsstrategie Bioökonomie 2030. Unser Weg zu einer biobasierten Wirtschaft. https://www.bmbf.de/upload_filestore/pub/Nationale_Forschungsstrategie_Biooekonomie_2030.pdf. Accessed: 03.06.2019.

Dahmen, N., Lewandowski, I., Zibek, S., & Weidtmann, A. (2018). Integrated lignocellulosic value chains in a growing bioeconomy: Status quo and perspectives. *GCB Bioenergy*. https://doi.org/10.1111/gcbb.12586

European Bioeconomy Stakeholders Manifesto. (2017). https://ec.europa.eu/research/bioeconomy/pdf/european_bioeconomy_stakeholders_manifesto.pdf#view=fit&pagemode=none. Accessed: 24.05.2019.

European Commission, Directorate-General for Research and Innovation. (2017). *Review of the 2012 European bioeconomy strategy*. EU Publications. https://doi.org/10.2777/8814

European Commission, Directorate-General for Research and Innovation. (2018). *A sustainable bioeconomy for Europe: Strengthening the connection between economy, society and the environment – Updated bioeconomy strategy*. EU Publications. https://doi.org/10.2777/478385

Hüsing, B., Kulicke, M., Wydra, S., Stahlecker, T., Aichinger, H., & Meyer, N. (2017). Evaluation der "Nationalen Forschungsstrategie BioÖkonomie 2030" – Wirksamkeit der Initiativen des BMBF – Erfolg der geförderten Vorhaben – Empfehlungen der strategischen Weiterentwicklung. Abschlussbericht. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2017/Evaluation_NFSB_Kurzbericht.pdf. Accessed: 03.06.2019.

Lewandowski, I. (Ed.). (2017). *Bioeconomy – Shaping the transition to a sustainable, biobased economy*. Springer International Publishing.

MLR (Ministerium für Ländlichen Raum und Verbraucherschutz). (2017). Bioökonomie in Baden-Württemberg – Wertschöpfung mit Zukunft. https://mlr.baden-wuerttemberg.de/fileadmin/redaktion/m-mlr/intern/dateien/publikationen/Wald/Biooekonomie.pdf. Accessed: 03.06.2019.

MWK (Ministerium für Wissenschaft, Forschung und Kunst). (2013). Bioökonomie im System aufstellen – Konzept für eine baden-württembergische Forschungsstrategie „Bioökonomie". https://www.baden-wuerttemberg.de/fileadmin/redaktion/dateien/PDF/Broschuere_Konzept-baden-wuerttembergische-Forschungsstrategie-Biooekonomie.pdf. Accessed: 03.06.2019.

Rösch, C., Roßmann, M., & Weickert, S. (2018). Microalgae for integrated food and fuel production. *GCB Bioenergy*. https://doi.org/10.1111/gcbb.12579

Spatial Foresight, SWECO, ÖIR, t33, Nordregio, Berman Group, Infyde. (2017). Bioeconomy development in EU regions. Mapping of EU member states'/regions' research and innovation plans

& strategies for smart specialisation (RIS3) on Bioeconomy for 2014–2020. https://ec.europa.eu/research/bioeconomy/pdf/publications/bioeconomy_development_in_eu_regions.pdf. Accessed: 03.06.2019.

UM (Ministerium für Umwelt, Klima und Energiewirtschaft). (2016). Drucksache 16/989 Landtag von Baden-Württemberg. Chancen der Bioökonomie für Umwelt- und Ressourcenschutz nutzen. https://www.landtag-bw.de/files/live/sites/LTBW/files/dokumente/WP16/Drucksachen/0000/16_0989_D.pdf. Accessed: 03.06.2019.

UM (Ministerium für Umwelt, Klima und Energiewirtschaft) und MLR (Ministerium für Ländlichen Raum und Verbraucherschutz). (2019). Landesstrategie Nachhaltige Bioökonomie Baden-Württemberg. https://stm.baden-wuerttemberg.de/fileadmin/redaktion/m-mlr/intern/dateien/PDFs/Bio%C3%B6konomie/Landesstrategie_Nachhaltige_Bio%C3%B6konomie.pdf. Accessed: 09.06.2019.

Dr. Annette Weidtmann

(born 1969) studied biology at the University of Würzburg and completed her doctorate in the faculty for process engineering, environmental engineering and materials science at the Technical University of Berlin. Since 2015, she has headed the coordination office of the Baden-Württemberg Bioeconomy Research Program and is responsible for the coordination of the interdisciplinary network, project development, science communication and strategy development.

Prof. Dr. Nicolaus Dahmen

(born 1962) studied chemistry at the Ruhr University in Bochum. After completing his doctorate in the field of mixed-phase thermodynamics, he worked on supercritical fluids as a medium for chemical reactions and new separation techniques at the former Karlsruhe Research Centre from 1992 onwards. He qualified as a professor in this field at the University of Heidelberg in 2010. Since 2005, he has been working on the thermochemical conversion of biomass into fuels. He was also involved in the construction of the bioliq pilot plant for the production of synthetic fuels from biomass at the Karlsruhe Institute of Technology (KIT), where he is responsible for scientific coordination. Since 2014, he has been teaching in his position as senior scientist at the KIT Faculty of Chemical Engineering and Process Engineering.

Prof. Dr. Thomas Hirth

(born 1962) studied chemistry at the University of Karlsruhe and received his doctorate in physical chemistry in 1992. He then worked for the Fraunhofer-Gesellschaft for more than 20 years, most recently as head of the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) in Stuttgart and professor at the University of Stuttgart. During this time, he worked intensively on the material use of biomass, the development and implementation of biorefinery concepts and the development of bioeconomy strategies. He is also the author of numerous publications and textbooks. Since 2016, he has been Vice President for Innovation and International Affairs at the Karlsruhe Institute of Technology (KIT). Thomas Hirth was a member of the Bioeconomy Council of the Federal Government and Chairman of the Steering Committee of the Bioeconomy Research Strategy of the State of Baden-Württemberg. He is also active in numerous functions, e.g. as a member of the German Research Foundation's Review Board for Process Engineering and as spokesperson for the Think Tank Industrial Resource Strategies.

Prof. Dr. Thomas Rausch

(born 1953) studied biology and chemistry at the Johann Wolfgang Goethe University in Frankfurt. He researches mechanisms of metabolism control in plants. Since 1993, he has been a professor at the Centre for Organismal Studies at the Ruprecht-Karls-Universität in Heidelberg, where he heads the Department of Plant Molecular Physiology. His current research focuses on sugar, secondary and lignin metabolism. Since 2013, he has coordinated the Heidelberg Molecular Life Sciences Research Council and is co-director of the Marsilius Kolleg (Centre for Advanced Study; 2014 to 2020). Since 2014, he has been leading the interdisciplinary graduate program Bioeconomy Baden-Württemberg – Research into Innovative Value Chains (BBW ForWerts).

Prof. Dr. Iris Lewandowski

(born 1964) studied agricultural sciences at the Universities of Göttingen and Hohenheim. She completed her doctorate in 1992 at the University of Hohenheim, where she qualified as a professor in 2000. She then worked for ten years in the Netherlands, first at Utrecht University and later as Biomass Research and Development Program Manager at Shell Global Solutions. She researches sustainable systems for agricultural production of biomass and its utilization options. She is head of the department Biobased Resources in the Bioeconomy and also the international Master's program 'Bioeconomy' at the University of Hohenheim. As Chief Bioeconomy Officer she coordinates the bioeconomy activities of the University of Hohenheim and is currently scientific spokesperson for the European Bioeconomy University.

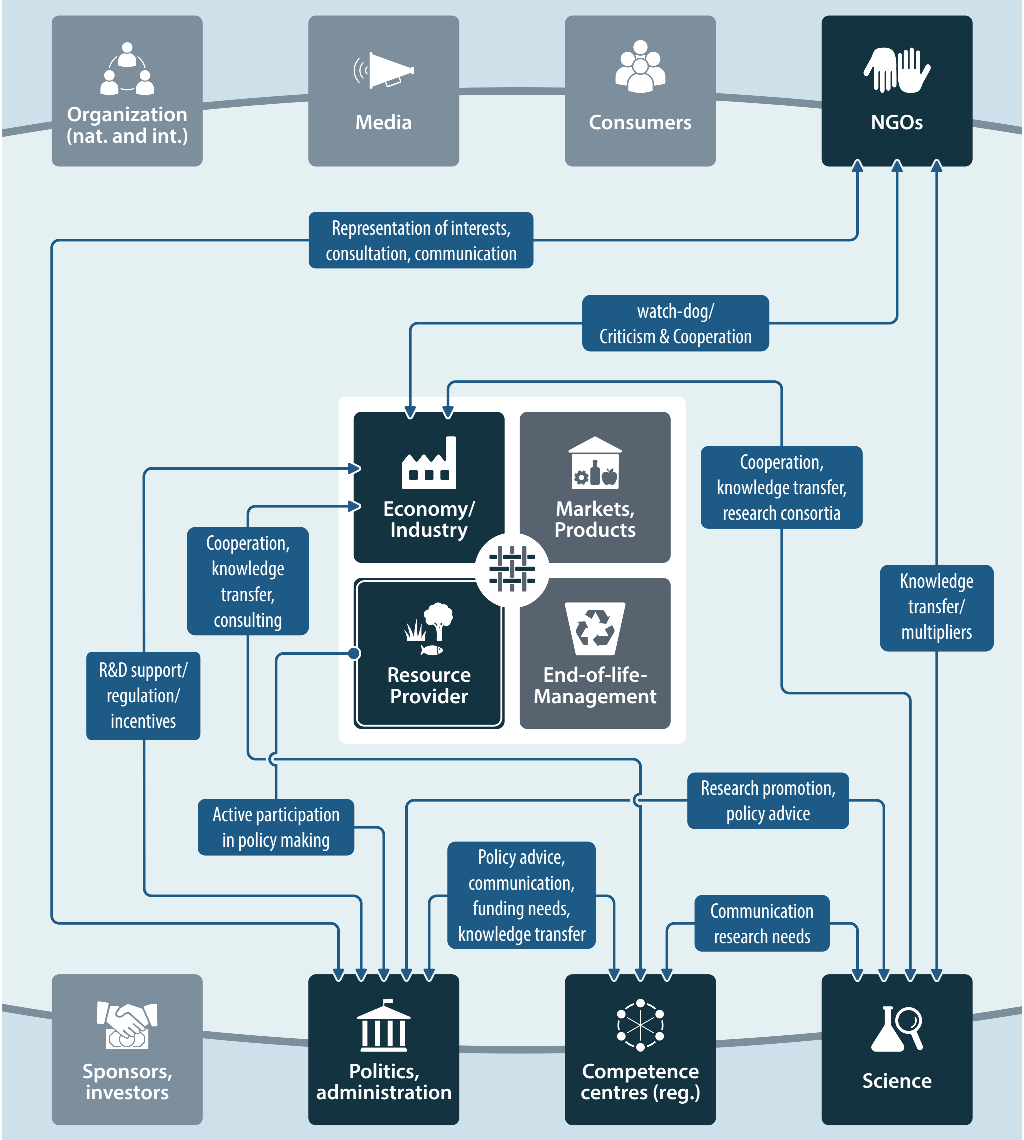
Bioeconomy in Bavaria

Benjamin Nummert

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_15

15.1 Cluster Partners and Contributions



Resource Provider

- Agriculture and forestry, Bavarian Farmers Association, Competence Center for Nutrition, Associations for promoting the production and sale of agricultural products, e.g. Verein zur Förderung des Heil- und Gewürzpflanzenanbaus in Bayern e. V. (Association for the Promotion of Medicinal and Aromatic Plants in Bavaria)

Economy/Industry

- Clusters (belonging to Cluster Initative Bavaria): Cluster Forestry and Wood in Bavaria, Chemie-Cluster Bayern GmbH, Umwelt Cluster Bayern, Cluster Neue Werkstoffe), Cluster Industrial Biotechnology, Regional Clusters (e.g. BioCampus GmbH incl. Gründerzentrum, BioPark Regensburg, IZB – Innovation and Start-Up Centers for Biotechnology in Planegg-Martinsried and Freising-Weihenstephan
- Innovation networks (e.g. IBB Netzwerk GmbH, Bayern Innovativ GmbH)
- Industry associations (e.g. The Bavarian Chemical Associations -VCI Bavaria, Verband der Bayerischen Textil- und Bekleidungsindustrie e. V.)

Markets, Products

- Food, wood construction, bio-based materials (e.g. WPC, films, varnishes, oils, paints), detergents and cleaning agents, cosmetics, medicine, basic chemicals, consumer products, automotive, energy (both solid and gaseous energy sources)

End-of-life-Management

- Municipal waste management companies (e.g. ZAW Straubing), Gütegemeinschaft Kompost Region Bayern e. V., OmniCert Umweltgutachter GmbH

Organizations (nat. and int.)

- Not Bavaria-specific: EU, UN, federal government

Media

- No Bavaria-specific media with explicit reference to the bioeconomy, Bayerisches Landwirtschaftliches Wochenblatt (Bavarian Agricultural Weekly)

Consumers

- Bavarian Consumer Advice Centre

NGOs

- Civil society, Association for Nature Conservation in Bavaria e. V., State Association for the Protection of Birds, Working Group for Rural Agriculture

Sponsors, investors

- Bayerische Forschungsallianz GmbH (BayFor), Bayerische Forschungsstiftung, Invest in Bavaria (Settlement Agency of the Free State of Bavaria), Bio-based Industries Consortium (not Bavaria-specific), Bavarian State Ministries (Department-specific funding programmes), LfA Förderbank Bayern, Bayern Kapital

Politics, administration

- Bavarian Ministry of Economic Affairs, Regional Development and Energy (StMWi), Bavarian State Ministry of Food, Agriculture and Forestry (StMELF), Bavarian State Ministry for the Environment and Consumer Protection (StMUV), Interministerial Working Group on Renewable Resources and Bioeconomy, Bavarian State Research Centre for Agriculture (LfL), Bavarian State Office for the Environment (LfU)

Competence centres (reg.)

- Competence Centre for Renewable Resources (KoNaRo): C.A.R.M.E.N. e. V., Technologie- & Förderzentrum, TUM Campus Straubing for Biotechnology and Sustainability, Expert Council Bioeconomy Bavaria; Extended: Straubing Region of Renewable Resources (incl. BioCampus, Zweckverband Hafen Straubing-Sand)
- Munich Planegg/Martinsried: concentrated settlement of biotechnology companies (incl. innovations)

Science

- Universities, research institutions, e.g. Technical University of Munich (esp. TUM Campus Straubing for Biotechnology und Sustainability), Ludwig-Maximilians-Universität München, Friedrich–Alexander University Erlangen–Nürnberg, Weihenstephan-Triesdorf University of Applied Sciences, Rosenheim Technical University of Applied Sciences, Fraunhofer IGB Straubing, Fraunhofer UMSICHT Sulzbach-Rosenberg, Ifo – Innovation and Start-Up Centers for Biotechnology in Planegg-Martinsried and Freising-Weihenstephan)

The development of the bioeconomy in Bavaria is taking place with a systemic framework for action provided by the Bavarian Ministry of Economyic Affairs, Regional Devlopment and Energy[1] and dedicated “bioeconomy cluster”. A wide variety of actors make a significant contribution to the development of the bioeconomy in Bavaria. They shape this process by

- influence the shaping of political framework conditions,
- promote innovation in science and industry on the basis of research and development,
- networking bioeconomy actors with each other, and
- lead the social discourse on bioeconomy issues.

In 2015, the Bavarian State Ministry of Food, Agriculture and Forestry (StMELF) started the development of an overarching policy framework with the initiative “Bioeconomy for Bavaria!” (StMELF, 2018b). As part of this initiative, the Bioeconomy Council Bavaria (SVB) was convened. Since the beginning of 2019, the Bavarian Ministry of Economy Affairs, Regional Devlopment and Energy (StMWi) has been in charge of the bioeconomy. Accordingly, the SVB, as an independent advisory body, develops and formulates recommendations for action for the development of a bioeconomy strategy, political framework conditions and for the promotion of social dialogue to the StMWi and other departments of the Bavarian state government, which are also concerned with the further development of the bioeconomy. The StMWi supports the bioeconomy in particular through funding measures in the areas of research and development, *upscaling* and company establishment, as well as funding measures for the further development of bioenergy (StMWi, 2018b). Equally noteworthy is the technology support provided by the StMWi, in particular the planned construction of a multi-purpose demonstration plant in Straubing. This is intended to offer science and industry the opportunity to develop products and processes from laboratory scale to market maturity (StMWi, 2016). In the budget of the Free State of Bavaria for 2019/2020, the state parliament allocated €40 million for the construction of the facility (StMWi, 2019a). The Bavarian State Ministry for the Environment and Consumer Protection (StMUV) promotes the protection of natural resources and the increase of resource

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[1] ► Bioökonomiestrategie Bayern: Wirtschaftsministerium Bayern

efficiency as well as the associated development of a Bavarian resource strategy (e.g. research project BayBioTech) (StMUV, 2016). In addition, bioeconomy was included in the Bavarian Sustainability Strategy (StMUV, 2017). Furthermore, an interministerial working group facilitates intensive topic-specific coordination between the departments of the Bavarian state government (Bioökonomierat, 2017).

Against the background of the megatrends of sustainability and climate protection, the industrial use of renewable raw materials is gaining importance. However, regulations that have already been implemented in the course of EU climate policy and EU bioeconomy strategy are also increasing attention to this topic at company level. Thus, in addition to *top-down control* by the responsible state ministries, the shaping of the bioeconomy is also based on sector- and company-specific initiatives. In particular, economic interests such as cost and resource efficiency, the reduction of dependence on raw material imports through regionally produced raw materials, and the prospect of sustainable economic growth represent a motivation for company- and actor-specific projects for the further development of the bioeconomy (SVB, 2015). Furthermore, in the course of sustainability initiatives, many economic sectors are striving to create value chain networks in order to tap into by-product streams arising in existing production processes for additional innovative value creation (SVB, 2015). The "Forestry and Wood Cluster", "Biotechnology Cluster" (focus on health), "Chemistry Cluster", "Industrial Biotechnology Cluster" and the "New Materials Cluster" – funded as part of the Bavarian Cluster Offensive – play an important role. This funding is already being continued in the fourth period (2020–2023) (StMWi, 2019b). The task of clusters is to network companies or companies and research institutions. Accordingly, a large number of bioeconomy activities are primarily based on sector- and company-specific, economically motivated initiatives by industry or trade associations and clusters already mentioned (SVB, 2015).

The aim is to strengthen entire value chains from research to the final product through cooperation and to support the practical transfer of research results into new products and services (StMWi, 2017). In addition, cross-cluster projects increasingly create space for new cross-sector collaborations and technology transfer (e.g. Cluster Forst und Holz in Bayern, 2017). Other sector-specific networks provide platforms for knowledge and practice transfer of research results into industrial applications (e.g. IBB Netzwerk GmbH, 2018; Bayern Innovativ GmbH, 2018b) or for alliances to market and promote the use of renewable raw materials (e.g. proHolz Bayern, 2018a). Furthermore, regional clusters (e.g. BioCampus GmbH, BioPark Regensburg, Innovations- und Gründerzentrum Biotechnologie (IZB) in Martinsried and Freising) support economic development and networking and create synergies between established companies in the field of renewable raw materials.

The three pillars of the Competence Centre for Renewable Resources (KoNaRo) in Straubing play an equally central role: C.A.R.M.E.N. e. V., the Technologie- und Förderzentrum (TFZ) and the TUM Campus for Biotechnology and Sustainability (TUMCS) advise, promote and conduct research there to increase material and energy use (KoNaRo, 2018). As a supra-regional contact point, C.A.R.M.E.N. e. V. advises business, science and consumers on industrial and energetic biomass use as well as renewable energies and resource efficiency. The association combines science with practice by communicating research and development needs and initiating and supporting demonstration projects (C.A.R.M.E.N. e. V., 2018). As an institution directly assigned to the StMELF, the TFZ develops and supervises funding programmes and conducts applied research on the cultivation and use of renewable raw materials. In this function, the TFZ is a cooperation partner of numerous universities, research institutes and companies as well as a supporter of knowledge transfer in industry, politics and society (TFZ, 2018). The TUMCS conducts basic research in the energetic and material use of renewable raw materials and their economics (TUMCS, 2018a). The "Bio-, Electro- and Chemocatalysis BioCat" branch of the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) is also located at KoNaRo. There, the focus is on the development of new chemical catalysts and biocatalysts and their application in technical synthetic and electrochemical processes (Fraunhofer IGB, 2018).

The development of the bioeconomy also benefits from a broad-based research landscape that varies from region to region. For example, around 270 biotechnology and pharmaceutical companies are active in the Greater Munich area (in particular Martinsried/Planegg), which develop innovations in industrial and medical biotechnology, supported by the Innovation Network Industrial Biotechnology Bavaria GmbH and the Biotechnology Innovation and Start-up Centre (BioM, 2018). While in the region around Freising there is a particular focus on agriculture and forestry as well as the food industry (e.g. TU München, Weihenstephan-Triesdorf University of Applied Sciences, Fraunhofer IVV – Institute for Process Engineering and Packaging), the focus in Straubing is on research in the field of sustainable material and energy use of renewable raw materials as well as economic aspects of production and marketing (TUMCS, 2018b). The future expansion of the TUMCS will provide further research, education and training in the field of bioeconomy. The range of courses already includes bachelor's and master's degree programmes on topics related to renewable raw materials, the chemistry of biogenic raw materials, bionics and business administration with a focus on renewable raw materials. With the start of the winter semester 2018/2019, an interdisciplinary course of study will be established specifically on the topic complex of bioeconomy (TUMCS, 2018c). In addition, a new centre for natural materials and innovative substances will be established in Waldkraiburg (Bayerische Staatsregierung, 2018). Interdisciplinary cooperation projects between universities and research institutions also contribute, for example, to the promotion of resource-conserving biotechnology (BayBiotech), to the harmonisation of assessment methods for biomass energy use (ExpRessBio) and to the promotion of the circular economy on the basis of a Bavarian resource strategy (FORCycle).

This diversity of actors in Bavaria offers a great framework for action. An analysis by the SVB describes the good availability of raw materials from agriculture and forestry as well as the diversity of companies located in different sectors as an opportunity for the development of the bioeconomy. Networks enabling the use of renewable raw materials can be established and optimised. Existing centres of competence offer the opportunity to establish material cycles and ensure efficient recycling and full utilisation of existing resources (SVB, 2015). In this context, the demonstration plant of Clariant AG in Straubing should be highlighted as a pilot project: In Germany's largest demonstration plant of this kind, the operators developed a process for the production of ethanol based on agricultural residues to market maturity. Up to 1000 t of cellulosic ethanol are produced there annually from around 4500 t of raw material (Clariant, 2018b; SVB, 2017f). In September 2018, Clariant started construction of its first own commercial plant in Craiova, Romania. The plant is expected to come on stream in 2020 and to produce 50,000 t of ethanol per year from grain straw. The plant will employ approximately

Fig. 15.1 Demonstration plant of Clariant AG in Straubing. (Source: Clariant AG (Photo Rötzer))

120 people from the region, who will be trained for this purpose at Clariant's biotechnology center in Planegg and at the demonstration plant in Straubing (Clariant, 2018a) (Fig. 15.1).

15.2 Vision and Mission

Based on their individual and sector-specific objectives, many actors from politics, business, science and civil society are pursuing the vision of a transformation to a sustainable economy and way of life based on renewable raw materials within the framework of various forms of organisation.

Since 2015, the Bioeconomy Council Bavaria has been working as an independent advisory body to develop impulses for a sustainable bioeconomy in Bavaria. The SVB first formulated principles for the development of a sustainable bioeconomy. The vision of the SVB expressed therein, based on a systematic understanding of the bioeconomy, can provide a framework for the activities of the actors mentioned at the beginning. It clarifies the claim to shape the bioeconomy within the framework of reconciling climate protection, biodiversity, resource efficiency, securing prosperity and global justice as well as the interconnection of scientific-technical, economic and social innovation in a post-fossil society (SVB, 2017a):

> In Bavaria, the bioeconomy is the guiding principle for the development and implementation of sustainable and biobased ways of living and doing business. Through the provision and use of renewable resources as well as the development and linking of knowledge, it significantly contributes to the sustainable development of Bavaria. Its aim is to protect the ecosystem as the basis of life and to achieve a climate-neutral society by reducing the consumption of fossil resources as far as possible. It puts economic and technical innovation at the service of responsible use of natural resources (SVB, 2017a, p. 3).

In addition, the departments of the Bavarian state government responsible for the subject have begun developing a bioeconomy strategy (StMELF, 2018b). As early as 2015, the Bavarian State Ministry of Food, Agriculture and Forestry launched the initiative "Bioeconomy for Bavaria". Its focus is on the identification of challenges for the development of the bioeconomy as well as the concretisation of fields of action for the design of policy measures (StMELF, 2015). The development of an overarching policy framework, adapted to the regional conditions in Bavaria, is intended to support a change in values in favour of a handling of natural resources geared towards conservation and optimum quality. This includes, inter alia, the sustainable use of the resources soil and water as well as the synthesis of modern technology and traditional management methods in agriculture and forestry (SVB, 2015).In addition, the interdisciplinary, cross-sectoral use of expertise can strengthen innovation processes within the bioeconomy (proHolz Bayern, 2018b). These cooperations are particularly triggered by business associations and clusters as well as political support. Sector-specific clusters and associations as well as initiatives of individual companies promote both the intra-sectoral and cross-sectoral development of (research) cooperations for the development of innovative applications of renewable raw materials. The sectors of the forestry and timber industry, agriculture, the food industry, chemistry and biotechnology are the main focus areas of the bioeconomy in Bavaria. The existing clusters and regional associations enable strong networks of Bavarian companies and also create a link between industry and science to promote knowledge transfer. For example, Chemie Cluster Bayern GmbH pursues the vision of being a "market developer" (Chemie Cluster Bayern GmbH, 2018) with the "Value Creation Pact for Chemistry" to identify new markets for existing products, technologies and services while promoting innovations in the sector. The Cluster Forst und Holz in Bayern gGmbH also aims to be at the forefront of the European forestry and timber industry in terms of innovation, forest management, technology and wood use (Cluster Forst und Holz in Bayern, 2018). In addition to these sector-specific clusters, Bayern Innovativ GmbH acts at interfaces between a wide variety of sectors and technologies with the aim of increasing innovation dynamics and technology and knowledge transfer in Bavaria by implementing own clusters such asEnergy Technology, Automotive and New Materials clusters as well as "cross-clustering" with other Bavarian clusters (Bayern Innovativ GmbH, 2018a).

The research landscape covers central areas of the bioeconomy. The high density of universities, research institutes and educational institutions offers cutting-edge research in the field of basic and application-oriented research as well as the training of qualified specialists. In some regions, centres of excellence have emerged in specific areas of the bioeconomy (e.g. Martinsried, Freising, Straubing, Munich) (SVB, 2015).

The multitude of actors and their networking described above is a characteristic feature of the bioeconomy development process in Bavaria. In addition, Bavaria offers attractive conditions as a business and high-tech location alongside a high-performance agricultural and forestry sector. The availability of raw materials and the variety of companies from different sectors located here represent an opportunity for the development of the bioeconomy with regard to the networking and optimisation of innovative value chains (ibid.).

15.3 Management of the Cluster

As explained above, there is no centrally developed framework for action of a separately created "bioeconomy cluster". The activities presented show a distinctive structure of independent actors that can address the broad spectrum of the bioeconomy concept due to their diversity. This includes a combination of *bottom-up initiatives* (networking, research and cooperation projects) of Bavaria-based companies and research institutions as well as a supporting role of political framework conditions *(top-down)*. The close “internal” networking of economic sectors through clustering and innovation platforms strengthen research and development activities and the development of new value creation opportunities.

As outlined in the previous sections, many independent actors are driving the development of the bioeconomy in a wide range of economic sectors. For example, cluster organisations, companies, associations and members of civil society are developing sector-specific bioeconomy agendas – the area of the wood-based bioeconomy serves as an example here – or individual projects based on the objectives and business models of individual companies. Thus, depending on the need for cooperation and research, research alliances are established or cross-industry cooperation takes place. Both are supported by the industry-specific clusters promoted within the framework of the Bavarian Cluster Offensive. Increasingly, cross-industry activities can be noted with regard to the development of innovative materials, methods and processes. The joint projects of the Cluster Forst und Holz in Bayern gGmbH, Chemie Cluster Bayern GmbH and Bayern Innovativ GmbH illustrate this.

Individual regions distinguish themselves by naming themselves on the basis of their areas of competence. Straubing, for example, chose the name “Straubing – Region of Renewable Resources”. The name refers, among other things, to the broad expertise of the institutions of the Competence Centre for Renewable Resources, the research institutes located there, and the companies located in the industrial park, including the port specialising in biomass logistics and the start-up centre (Straubing Region Nawaro, 2018). In addition, four regions hold the title “Bioenergy Region” as winners of a nationwide competition (Archental, Straubing-Bogen, Bayreuth, Oberland). The aim of the competition, which was carried out by the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), was to promote innovative concepts for exploiting bioenergy development opportunities and to create model regions for the communication and sustainable use of bioenergy (FNR, 2018).

To promote social discourse on the use of biogenic raw materials, many institutions already provide information, often in the form of specialist events – although not always explicitly under the name “bioeconomy”. Examples include specialist conferences within the framework of research cooperations or cluster and innovation platforms (e.g. Bayern Innovativ, IBB Netzwerk GmbH, Cluster Forst und Holz) and the Bavarian State Ministries. In the context of the event “Opportunities for a sustainable bioeconomy in Bavaria” organised by the SVB, an impetus was given in 2017 to the debate on the necessary framework conditions for shaping a sustainable bioeconomy. This discourse continues to take place primarily in specialist circles. In order to provide information about the advantages of the energetic and material use of renewable raw materials for the general public, C.A.R.M.E.N. e. V., the TFZ or the Ökoenergie-Institut Bayern, for example, develop information materials and appear at trade and consumer fairs. Core topics include materials, building with renewable raw materials, biofuels, heat and power generation from renewable raw materials and renewable energies.

Despite the diverse activities discussed, both the awareness of the concept of bioeconomy and the availability of information on areas of application and handling of the use or possibilities of use of renewable raw materials in Bavaria vary. A cross-sectoral exchange of information and knowledge could further strengthen this knowledge and the use of renewable raw materials (SVB, 2015).

15.4 Benchmark and Success Criteria

As explained at the outset, in 2017 the Bioeconomy Council Bavaria formulated a vision for shaping the bioeconomy as a contribution to sustainable development. This vision contributes to a discourse on general objectives of the bioeconomy and enables a formulation of goals against which the Bavarian partners can examine their measures to promote the production, processing and use of biogenic raw materials in the future. In its policy paper, the SVB discusses fields of action and necessary conditions which, as “ethical guidelines” (Vogt, 2016), should ensure the design of a sustainable bio-based economy and way of life. Through its impulses for shaping regional and supra-regional, consistent policy frameworks, the SVB aims to support the transformation of existing production and consumption patterns in favour of a sustainable, post-fossil society (SVB, 2017f). Accordingly, the SVB promotes the development of a Bavarian policy strategy through its advisory activities, which is to be adapted to regional conditions in a targeted manner (SVB, 2017f). In the brochure “Bioeconomy for Bavaria!”, the StMELF provides for a specifically Bavarian accent in the understanding and strategic orientation of the bioeconomy. Thus, in contrast to other bioeconomy strategies, which focus exclusively on residual and waste materials, the StMELF focuses on the inclusion of the targeted cultivation of renewable raw materials. In addition, the StMELF pursues a technology-open approach without specifying the raw materials or processing methods used and the development of a comprehensive research and development framework to support application-oriented projects (StMELF, 2015). Furthermore, the StMELF formulates the goal of increasingly orienting economic activity towards natural material cycles and increasing resource efficiency by expanding cascade and combined use. In order to ensure the transformation to a sustainable biobased economy, the StMELF relies on domestic biomass cultivation based on clear sustainability criteria to avoid potential restrictions on food security or the impairment of natural livelihoods. These criteria must also apply to imported biomass. In addition, the ministry aims to remove any market barriers for biobased products, strengthen networks for horizontal and vertical cooperation and provide start-up assistance for young companies. The advantages of a bio-based economy and lifestyle are to be actively communicated in order to increase the acceptance of the desired transformation through transparency and participation (StMELF, 2015). In the context of this development, the SRP emphasises the need to guarantee standards for environmental and social compatibility and to ensure a participatory design of the bioeconomy by intensifying the dialogue with all societal stakeholders, including business, consumer and environmental associations, civil society associations (NGOs), churches as well as representatives of science. This requires communication formats that inform and involve stakeholders in the development of the bioeconomy on the opportunities, but also in a forward-looking way on possible critical issues (SVB, 2017e).

Biotechnology is considered a key technology for this transformation. Bavaria is the leading biotechnology location in Germany, with around 25% of companies, around 30% of employees and around 25% of sales (StMWi, 2018a). The Bavarian state government is pursuing the goal of making Bavaria the leading biotechnology location in Europe as well, not only in terms of the number of companies, but also in terms of sales and employment figures. Over the past ten years, the State of Bavaria has invested some €600 million in biotechnology. In addition to the expansion of research at universities and non-university research institutions, this funding also flows primarily into the support of industry networks and the establishment and expansion of technology-oriented start-up centers (ibid.).

The actors listed have formulated objectives in their agendas. A central benchmarking to check the measures for their implementation is not yet planned.

15.5 Experiences

Bavarian forestry and agriculture provide a large number of high-quality biogenic raw materials. In addition to the food industry, the products provided are used as renewable raw materials in material and energy applications. In total, raw materials for *non-food use* were cultivated on around 490,000 ha of agricultural land in Bavaria in 2016. Thereby, the energetic use is very pronounced (451,000 ha for energy production compared to 39,000 ha for a material use) (StMELF, 2018a). Moreover, according to the Federal Forest Inventory, an average of 22 million fm of[2] raw wood was harvested annually in Bavaria between 2003 and 2012. Energy use also currently predominates in forestry: 60% of the wood was used for energy (Cluster Forst und Holz in Bayern, 2016).

Favoured by small-scale agriculture and the associated large number of farms, as well as corresponding support measures under the Renewable Energy Sources Act (EEG), Bavaria has the most biogas on-site electricity generation plants (2017: 2493) and the highest installed electrical rated output (1025 MWel) in a federal state comparison. This is distributed among many smaller plants (average electrical plant capacity: 284 kWel) (LfL, 2017). This strong expansion of renewable energies based on biogenic raw materials was promoted by the presence of active knowledge and consulting networks (e.g. C.A.R.M.E.N. e. V., TFZ, Öko-Energie-Institut).

The good availability of raw materials and the potential of the business location, where the production and use of biogenic raw materials is of important economic and social significance, enable an expansion of biomass utilisation, particularly in the area of industrial use. In this area, few cross-sectoral value chains have been established so far due to unfavourable framework conditions – especially price competitiveness in direct competition with fossil-based products. However, in the area of advanced biofuels, the establishment of new value chains and the use of synergy effects are already evident and need to be further developed (SVB, 2015). With regard to the development of biomass value chains, it is important to note that feedstock use can be complementary in different use cases. For this purpose, material use should be treated equally to energy use and the efficiency of the entire value chain should be considered (SVB, 2017a).

Against this background, the high level of competence and networking within the economic sectors and scientific disciplines is to be seen as positive. Cross-sectoral networking is being increasingly intensified, and regional competence centres are being created or have been created for focus areas in research and development and for the use of biogenic raw materials. Industry and innovation networks promote the transfer of research results into practice. However, small and medium-sized enterprises (SMEs) in particular still face the challenge of devoting sufficient resources to the economic implementation of product and process innovations. In order to take this into

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[2] cubic meters of raw wood.

account, a multi-purpose demonstration facility for testing and scaling biotechnological processes is to be built in Straubing.

Since industry cooperations sometimes do not come about because in funded projects the protection of intellectual property, which is important for industrial companies, and their later use is often difficult to manage, the SVB also recommends, in addition to research funding at universities and colleges, to expand funding programmes for application-oriented research in SMEs and industry and, against this background, to pay special attention to the handling of intellectual property. This applies in particular to projects where the funded work takes place within networks (SVB, 2017d).

In addition, many materials and products containing renewable raw materials compete directly with conventional products made from fossil raw materials. Since their success also depends on the price of oil, they cannot always exploit their advantages – both ecological and technical. In order to promote products derived from the bioeconomy, policymakers should adapt or avoid laws and regulations that hinder their sale. For example, innovative products should already be considered in current legislation, such as the Packaging Act (SVB, 2017c). At the same time, direct incentives should be introduced to strengthen the demand for bio-based products. These steps are not to be carried out exclusively at the state level. The federal and European level should also be addressed for the above-mentioned objectives. In addition, the intensification of measures in the field of public relations is necessary in order to strengthen consumer awareness for sustainable consumption and to increase the acceptance of product innovations. The public should be made aware of the necessity and opportunities of the bioeconomy through appropriate information, and given the opportunity to play a responsible role in shaping the desired transformation. Small, possibly even decentralised exhibitions, events, teaching content at schools, training centres and also universities could enable broad-based knowledge transfer (SVB, 2017b).

References

Bayerische Staatsregierung. (2018). Das Beste für Bayern – Regierungserklärung des Bayerische Ministerpräsidenten Dr. Markus Söder, MdL, am 18. April 2018 vor dem Bayerischen Landtag. http://bayern.de/wp-content/uploads/2018/04/das_beste_fuer_bayern.pdf. Accessed: 10.09.2018.

Bayern Innovativ GmbH. (2018a). Unsere Mission. https://www.bayern-innovativ.de/cluster-neue-werkstoffe/seite/cluster-neue-werkstoffe. Accessed: 09.09.2018.

Bayern Innovativ GmbH. (2018b). WiProNa – Netzwerk für Nachhaltigkeit. http://www.bayern-innovativ.de/wiprona. Accessed: 11.06.2018.

BioM (Biotechnologie Cluster Management für München & Bayern). (2018). München ist ein führender Biotechnologie-Standort. https://www.bio-m.org/zahlen-und-fakten/muenchner-biotech-cluster.html. Accessed: 11.06.2018.

Bioökonomierat. (2017). Die Bioökonomie wird vermehrt von Bund und Ländern getragen. http://biooekonomierat.de/aktuelles/biooekonomie-im-bund-und-in-den-laendern/. Accessed: 11.06.2018.

C.A.R.M.E.N. e. V. (2018). Nachwachsende Rohstoffe, Erneuerbare Energien und nachhaltige Ressourcennutzung. https://www.carmen-ev.de/infothek/c-a-r-m-e-n-e-v. Accessed: 11.06.2018.

Chemie Cluster Bayern GmbH. (2018). Unsere Geschichte. http://chemiecluster-bayern.de/ueber-uns/unsere-geschichte/. Accessed: 09.09.2018.

Clariant Produkte (Deutschland) GmbH. (2018a). Spatenstich für die Sunliquid Cellulose-Ethanolanlage von Clariant in Rumänien. https://www.clariant.com/de/Corporate/News/2018/09/Groundbreaking-for-Clariantrsquos-sunliquidreg-cellulosic-ethanol-plant-in-Romanianbsp. Accessed: 17.10.2018.

Clariant Produkte (Deutschland) GmbH. (2018b). Zellulose-Ethanol aus Agrarreststoffen – Think ahead, think sunliquid. https://www.clariant.com/de/Business-Units/New-Businesses/Biotech-and-Biobased-Chemicals/Sunliquid. Accessed: 11.06.2018.

Cluster Forst und Holz in Bayern. (2016). Clusterstudie Forst, Holz und Papier 2015 – Klimaschutz, Wirtschaftswachstum und Zukunftschance für Bayern und seinen ländlichen Raum. https://

www.cluster-forstholzbayern.de/images/clusterstudie2015/Clusterstudie_ForstHolzPapier_Bayern_2015.pdf. Accessed: 11.06.2018.

Cluster Forst und Holz in Bayern. (2017). Cross-Cluster-Projekt HoKuRo erfolgreich abgeschlossen. https://www.cluster-forstholzbayern.de/de/informationen/unsere-aktionen/1690-cross-cluster-projekt-hokuro-erfolgreich-abgeschlossen. Accessed: 01.10.2018.

Cluster Forst und Holz in Bayern. (2018). Agenda Forst und Holz in Bayern 2030. https://www.cluster-forstholzbayern.de/de/?option=com_content & view=article & id=1559. Accessed: 09.09.2018.

FNR (Fachagentur Nachwachsende Rohstoffe). (2018). Fördermaßnahme Bioenergie-Regionen. https://bioenergie.fnr.de/bioenergie-regionen/foerdermassnahme/. Accessed: 11.06.2018.

Fraunhofer IGB (Institut für Grenzflächen- und Bioverfahrenstechnik). (2018). Bio-, Elektro- und Chemokatalyse BioCat, Institutsteil Straubing. https://www.igb.fraunhofer.de/de/forschung/kompetenzen/biocat.html. Accessed: 01.10.2018.

IBB Netzwerk GmbH (Industrielle Biotechnologie Bayern Netzwerk GmbH). (2018). Website. https://www.ibbnetzwerk-gmbh.com/de/startseite/. Accessed: 11.06.2018.

KoNaRo (Kompetenzzentrum für Nachwachsende Rohstoffe). (2018). Kompetenzfelder. http://www.konaro.de/ueber-uns/kompetenzfelder. Accessed: 11.06.2018.

LfL (Bayerische Landesanstalt für Landwirtschaft). (2017). Biogas in Zahlen – Statistik zur bayerischen Biogasproduktion. http://www.lfl.bayern.de/iba/energie/031607/. Accessed: 11.06.2018.

proHolz Bayern GmbH. (2018a). Holz als Quelle einer nachhaltigen Bioökonomie und Ressource der Zukunft. https://proholz-bayern.de/pressemitteilungen/der-wald-steckt-voller-neuer-moeglichkeiten-holz-als-quelle-einer-nachhaltigen-biooekonomie-und-ressource-der-zukunft/. Accessed: 11.06.2018.

proHolz Bayern GmbH. (2018b). Über uns https://proholz-bayern.de/ueber-uns/. Accessed: 11.06.2018.

StMELF (Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten). (2015). Bioökonomie für Bayern!. https://www.bestellen.bayern.de/application/eshop_app000004?SID=540189955 & ACTIONxSESSxSHOWPIC(BILDxKEY:%2708102015%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27). Accessed: 11.06.2018.

StMELF (Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten). (2018a). Bayerischer Agrarbericht 2018. http://www.agrarbericht-2018.bayern.de/politik-strategien/index.html. Accessed: 11.06.2018.

StMELF (Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten). (2018b). Bioökonomie für Bayern! Chancen der grünen Ressourcen nutzen. http://www.stmelf.bayern.de/nachwachsende_rohstoffe/103865/index.php. Accessed: 11.06.2018.

StMUV (Bayerisches Staatsministerium für Umwelt und Verbraucherschutz). (2016). Bayerische Ressourcenstrategie. http://www.stmuv.bayern.de/themen/ressourcenschutz/ressourcenstrategie/index.htm. Accessed: 11.06.2018.

StMUV (Bayerisches Staatsministerium für Umwelt und Verbraucherschutz). (2017). Bayerische Nachhaltigkeitsstrategie – Erhaltung und Bewirtschaftung der natürlichen Ressourcen. http://www.nachhaltigkeit.bayern.de/strategie/natuerliche_ressourcen/index.htm. Accessed: 11.06.2018.

StMWi (Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Technologie). (2018a). Biotechnologie. https://www.stmwi.bayern.de/innovation-technologie/schwerpunkte/biotechnologie/. Accessed: 11.06.2018.

StMWi (Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie). (2018b). Technologieförderung. https://www.stmwi.bayern.de/service/foerderprogramme/technologiefoerderung/. Accessed: 12.06.2018.

StMWi (Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie). (2019a). 40 Millionen Euro für neue Mehrzweckanlage für die Produktion von biobasierten Chemikalien. https://www.stmwi.bayern.de/presse/pressemitteilungen/pressemitteilung/pm/141-2019/. Accessed: 19.06.2019.

StMWi (Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie). (2019b). „Cluster Offensive Bayern" wird in der vierten Förderperiode fortgeführt. https://www.stmwi.bayern.de/presse/pressemitteilungen/pressemitteilung/pm/134-2019/. Accessed: 19.06.2019.

StMWi (Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Technologie; zum Zeitpunkt der Publikation: Bayerisches Staatsministerium für Wirtschaft und Medien, Energie und Technologie). (2016). Aigner: „Wir investieren 20 Millionen Euro in die Zukunft der Biotechnologie". https://www.stmwi.bayern.de/presse/pressemitteilungen/pressemitteilung/pm/98-2016/. Accessed: 11.06.2018.

StMWi (Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Technologie; zum Zeitpunkt der Publikation: Bayerisches Staatsministerium für Wirtschaft und Medien, Energie und Technologie). (2017). Cluster Offensive Bayern; Im Netzwerk zum Erfolg. https://www.cluster-bayern.de/fileadmin/

user_upload/stmwi/Publikationen/2017/2017-06-12_Cluster-Offensive_Bayern.pdf. Accessed: 11.06.2018.
Straubing Region NawaRo (Straubing – Region der nachwachsenden Rohstoffe). (2018). Die Region. http://www.straubing-region-nawaro.de/index.cfm?cid=166. Accessed: 11.06.2018.
SVB (Sachverständigenrat Bioökonomie Bayern). (2015). Die Bioökonomie in Bayern – Ausgangssituation und Potenziale. http://www.biooekonomierat-bayern.de/dateien/Publikationen/SVB_2016_Die_Bio%C3%B6konomie_in_Bayern_Broschuere.pdf. Accessed: 11.06.2018.
SVB (Sachverständigenrat Bioökonomie Bayern). (2017a). Die Grundsätze der Bioökonomie in Bayern. http://www.biooekonomierat-bayern.de/dateien/Publikationen/SVB_Grunds%C3%A4tze_der_Bio%C3%B6konomie_in_Bayern.pdf. Accessed: 11.06.2018.
SVB (Sachverständigenrat Bioökonomie Bayern). (2017b). Schwerpunktthema 1-G-Bioethanoltechnologie im Raffinerieverbund. http://www.biooekonomierat-bayern.de/dateien/Publikationen/SVB-Schwerpunktthema_1G--Bioethanoltechnologie_im_Bioraffinerieverbund.pdf. Accessed: 11.06.2018.
SVB (Sachverständigenrat Bioökonomie Bayern) (2017c). Schwerpunktthema Biologisch abbaubare Werkstoffe aus nachwachsenden Rohstoffen. http://www.biooekonomierat-bayern.de/dateien/Publikationen/SVB-Schwerpunktthema_Bioabbaubare_Werkstoffe_aus_NawaRo.pdf. Accessed: 11.06.2018.
SVB (Sachverständigenrat Bioökonomie Bayern). (2017d). Schwerpunktthema Drop-In-Biokunststoffe. http://www.biooekonomierat--bayern.de/dateien/Publikationen/SVB-Schwerpunktthema_Drop-In-Biokunststoffe.pdf. Accessed: 11.06.2018.
SVB (Sachverständigenrat Bioökonomie Bayern). (2017e). Schwerpunktthema Kommunikation und ethische Leitwerte. http://www.biooekonomierat--bayern.de/dateien/Publikationen/Schwerpunktthema_Kommunikation_und_ethische_Leitwerte.pdf. Accessed: 11.06.2018.
SVB (Sachverständigenrat Bioökonomie Bayern). (2017f). Schwerpunktthema Zellulose-Ethanol. http://www.biooekonomierat-bayern.de/dateien/Publikationen/SVB-Schwerpunktthema_Zelluloseethanol.pdf. Accessed: 11.06.2018.
TFZ (Technologie- und Förderzentrum). (2018). Organisation. http://www.tfz.bayern.de/tfz/organisation/index.php. Accessed: 11.06.2018.
TUMCS (TUM Campus Straubing). (2018a). Campus Straubing für Biotechnologie und Nachhaltigkeit. Nachwachsende Rohstoffe (NawaRo), Erneuerbare Energien und Bio-Ökonomie in Forschung und Lehre. http://www.cs.tum.de/de/campus-straubing/. Accessed: 12.06.2018.
TUMCS (TUM Campus Straubing). (2018b). Forschung. http://www.cs.tum.de/de/forschung/. Accessed: 12.06.2018.
TUMCS (TUM Campus Straubing). (2018c). Meilenstein für richtungsweisen Forschung und Lehre – Spatenstich für neues Labor- und Hörsaalgebäude am künftigen Universitätsstandort Straubing. http://www.cs.tum.de/de/meilenstein-fuer-richtungsweise-forschung-und-lehre/. Accessed: 12.06.2018.
Vogt, M. (2016). Ethische Fragen der Bioökonomie. Straubing 7.3.2016, Vortrag C.A.R.M.E.N. Forum. http://www.biooekonomierat-bayern.de/dateien/Publikationen/M.Vogt_Ethische_Fragen_der_Bio%C3%B6konomie_03.2016.pdf. Accessed: 10.12.2018.

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16

Bioeconomy Networks in Europe

Nora Szarka and Ronny Kittler

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_16

16.1 Introduction

In 2012, the European Commission (EC) adopted and launched the EU Bioeconomy Strategy "Innovating for sustainable Growth: a Bioeconomy for Europe" to address current and future environmental challenges and to initiate a shift towards a non-fossil fuel European economy. The overarching goals are:

> Ensuring food security, managing natural resources sustainably, reducing dependence on non-renewable resources, mitigating and adapting to climate change, transforming production, promoting sustainable production of renewable resources from agriculture, fisheries and aquaculture and their transformation into food, feed, fibre, bio-based products and bioenergy, while creating jobs and maintaining European competitiveness. (EC, 2018b, n.d.)

The EU approach is being taken forward in most EU Member States through the development of national and regional bioeconomy strategies – already 19 Member States have or are preparing a bioeconomy strategy – or similar strategic document (Spatial Foresight, 2017).

In 2013, the European Bioeconomy Stakeholder Panel was established to assemble a pool of experts from a wide range of stakeholders. It includes large and small industrial companies, governmental and non-governmental organisations, associations, biomass producers and regions, and research institutions, each active in different sectors of the bioeconomy. The Stakeholder Panel strengthens collaboration across Europe, was involved in the EU Bioeconomy Strategy review process and published the European Bioeconomy Stakeholders Manifesto in 2017 (Bioeconomy Stakeholders Panel, 2017). The Manifesto aims to highlight the challenges and opportunities in developing bioeconomy strategies in European countries and to increase stakeholders' motivation to invest in the bioeconomy transformation. A key objective of the Manifesto is to initiate and promote stakeholder collaboration across sectors, along and across value chains, and to facilitate *scale-up* and market uptake processes. The Manifesto recommends actions to expand interregional and transnational collaboration and to build regional cooperation, infrastructure and clusters. Both regional and cross-regional clusters are crucial for strengthening regional competences and supporting knowledge exchange in the context of the European Union bioeconomy (Bioeconomy Stakeholders Panel, 2017).

The following chapter provides an overview of the status of regional, national and transnational bioeconomy clusters in the EU-28. In a first step, the different definitions of the terms "cluster" and "bioeconomy" are elaborated in order to outline the respective self-image of the European bioeconomy clusters. In a second step, 32 bioeconomy clusters are analysed and the respective approaches and developments are described and compared.

16.2 Cluster Definitions in Europe

The most commonly used cluster definition comes from Porter, who defines a cluster as "a geographic group of interconnected firms and related institutions in a particular field" that are "linked by commonalities and externalities" (Porter, 2008). Clusters may include *downstream*, product or service firms, various suppliers with specialized inputs and services, financial institutions, institutions for specialized training, research and technical assistance, and standardization bodies (ibid.).

The EC defines clusters more broadly as

> a group of firms, related economic actors, and institutions that are located near each other and have reached a sufficient scale to develop specialised expertise, services,

> resources, suppliers and skills. (EC, 2008, p. 2).

The Federal Ministry of Education and Research (BMBF) describes clusters as the bringing together of research, industry, public authorities and other organisations within a thematic field of activity. The geographical and thematic proximity creates a platform for information, communication, cooperation and exchange (BMBF, 2018).

Depending on the respective national framework and cluster policy, the definitions and legal forms of clusters are very diverse throughout Europe. For example, in Hungary there is no legal definition or defined organisational form of a cluster. However, when a cluster is established, information on the common objective, management and budget should be provided by the body initiating the cluster (European Cluster Collaboration Platform (ECCP).[1] Especially in Central and Eastern Europe, the development and policy of clusters does not have as a long history as in Western and Northern Europe. Denmark, France, Germany, Italy, Ireland, the Netherlands, Portugal, Spain and the United Kingdom have already implemented national or regional cluster strategies and/or mechanisms to support cluster development in the 1990s. In particular, the Nordic countries (Finland, Sweden, Norway) have created strong national cluster institutions under the umbrella of the national government to support their development (Ketels, 2004).

The creation and further development of clusters and cluster services is supported by several regional, national and EU policies (Sölvell et al., 2003). In Germany, the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Ministry of Education and Research (BMBF) support the development of efficient and highly innovative clusters. Successful examples are the "go-cluster" programme (which supports the improvement of cluster management and international competitiveness) and the "Leading-Edge Cluster Competition" for the creation of cluster strategies and their implementation in the area of the German New High-Tech Strategy. The BMBF's "Entrepreneurial Regions" programme family supports the development of innovation alliances in the new Länder with the aim of promoting structural change. In addition to national initiatives, several German federal states – particularly Bavaria and Baden-Württemberg – have launched numerous measures to support cluster development based on the regions' individual strengths and structures.

Norway, Finland and Sweden also have specific cluster programmes to implement national strategies. In Norway, the Norwegian Innovation Cluster Programme (a joint initiative of the Industrial Development Corporation of Norway and the Norwegian Research Council) aims to initiate and strengthen cooperative development activities in clusters of different maturity (Norwegian Innovation Clusters, 2018). Finland launched the OSKE expert programme in the early 1990s, which led to the establishment of 13 competence centres bringing together research, industry, technology parks and regional authorities (Synocus Group, 2009). The flagship project of Swedish cluster policy is "Vinnväxt – Regional Growth through Dynamic Innovation Systems", a programme implemented since 2001 by VINNOVA, the Swedish Innovation Agency. Through a competitive process, regional clusters are selected for a 10-year programme with up to €one million in funding per year and parallel process support for growth (Ketels, 2009; Vinnova, 2016). At the European

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[1] For more information, see: ► https://www.clusterplattform.de/CLUSTER/Navigation/DE/Home/home.html, ► http://www.spitzencluster.de/ and ► http://ec.europa.eu/growth/industry/policy/cluster_en

level, funding schemes for cluster creation and development, cross-clustering and cluster internationalisation are available under COSME and Horizon2020 (EC, 2014). Through the extensive cluster funding programmes, clusters have become a model of success in industrial cooperation across Europe. The Cluster Panorama counts over 3000 "strong clusters" across Europe.[2] Among the top 20% of European clusters, 103 are world leaders (across all measured performance dimensions) (Ketels & Protsiv, 2016). The European Cluster Panorama shows several hotspots in the Benelux, the Baltic Sea Region, France, Germany, Ireland and the United Kingdom (EC, 2018a).

Despite the different definitions of a cluster and among the national or regional cluster policy approaches, some common features of clusters can be identified:

- They are characterised by geographical proximity and significant thematic/sectoral overlap.
- They are considered to be an important tool for increasing industrial competitiveness and innovation in enterprises.
- They integrate research institutions, public institutions, funding bodies and other relevant stakeholders.
- They facilitate technology and knowledge transfer between research and industry as well as *scale-up* and market uptake.
- They are seen as drivers of regional development and job creation by supporting the implementation of regional and/or national development strategies or smart specialisation strategies.
- They tend to focus on innovative and high-tech sectors.

16.3 Definitions and Strategies of the Bioeconomy

In contrast to the concept of clusters and cluster policy, the conceptualisation of the bioeconomy and its strategic implementation is a relatively new approach in the European Union – and beyond. Germany was among the first countries worldwide to publish strategies for the bioeconomy: in 2010 a "National Research Strategy Bioeconomy 2030" (BMBF, 2010) and in 2013 a holistic and comprehensive "National Policy Strategy on Bioeconomy" (BMEL, 2014). Since then – and in line with the European Union's ambitions to implement the EU Bioeconomy Strategy – 19 countries have produced or are preparing specific national and/or regional bioeconomy strategies or similar documents.

The German strategy defines bioeconomy as

> the knowledge-based production and use of renewable resources, in order to provide products, processes and services in all areas of the economy, within the framework of an economic system that is viable for the future [1]. The concept of the bioeconomy encompasses all economic sectors and their associated commercial services, involved in producing, working or processing, using or trading with renewable resources – such as plants, animals and micro-organisms and products made from them. (BMEL, 2014).

According to the German Bioeconomy Council, bioeconomy is defined as "the production and use of biological resources (including knowledge) to provide products, processes and services in all sectors of the economy within the framework of a sustainable economy" (Bioökonomierat, 2018).

The EU Bioeconomy Strategy defines the bioeconomy as

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[2] The strength of a cluster captures the overall size, specialisation, productivity and dynamism. "Strong clusters" they are defined as capturing the top 20% of regions by specialization in each cluster category.

> it encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy. (EC, 2014, p. 3).

In other words, "[t]he bioeconomy encompasses those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and microorganisms – to produce food, materials and energy" (EC, 2018b, n.d.).

The definitions and concepts of the bioeconomy vary across Europe. This results from different strategic goals and technology priorities as well as the diversity of natural endowments and the geographical location of the respective countries.

In Belgium

> the bioeconomy encompasses both the production of renewable biological resources and the use of these resources and residual flows. Specifically, the bioeconomy includes, among others, the following sectors: agriculture, forestry, fisheries, agri-food, wood processing, pulp and paper, environmental engineering, construction, energy and industries such as textiles, chemicals and biotechnology, end-user/consumer and logistics sectors. (Flanders Biobased Valley, 2018, n.d.)

The United Kingdom defines bioeconomy as

> "The bioeconomy is the economic opportunity of using biology to help solve challenges we face in agriculture, energy, health and more, which has the potential to deliver economic, environmental and social benefits to the UK. The bioeconomy includes all economic activity derived from bio-based products and processes. These have the potential to contribute to sustainable and resource efficient solutions to the challenges we face in food, chemicals, materials, energy production, health and environmental protection." (Department for Business, Energy, & Industrial Strategy, 2016, p. 3)

Finland

> refers to an economy that relies on renewable natural resources to produce food, energy, products and services. The bioeconomy will reduce our dependence on fossil natural resources, prevent biodiversity loss and create new economic growth and jobs in line with the principles of sustainable development. . (Bioeconomy Finland, 2018, n.d.)

In France, bioeconomy is understood as "the photosynthesis economy and, more generally, the living world economy".

> The bioeconomy encompasses the whole range of activities linked to bioresource production, use and processing. The purpose of bioresources is to provide a sustainable response to the need for food and to part of society's requirements for materials and energy, as well as providing society with ecosystem services. (République Française, 2017, n.d.)

In Slovenia, the bioeconomy

> "can be described in terms of an economy that 'encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy." (BERST, 2015, p. 3).

Although all countries define the bioeconomy as the production and conversion of biomass into value-added products, the focus and objectives differ. For example, in Germany the main areas are agriculture, health, food and energy, while in Finland the focus is on efficient resource use, forest-based biomass upgrading and green chemistry (Staffas et al., 2013). Portugal and Iceland focus heavily on oceans and blue growth in their strategic approach to the bioeconomy. Thus, the national focus of the bioeconomy varies by sector (e.g. wood sector, biopharmaceuticals and biotechnology, food and feed, biofuels, green chemistry). In some countries (such as Bulgaria, the Czech Republic, Hungary and Croatia), on the other hand, the bioeconomy is mostly limited to traditional individual bioeconomy sectors such as the wood industry, agriculture and biofuels.

16.4 Criteria for the Analysis of Bioeconomy Clusters

Both terms, cluster and bioeconomy, are very heterogeneous in the countries of the European Union in their concrete definition, in what is understood by them and which areas they cover in each case. There is therefore no blueprint for the "bioeconomy cluster" as such. A bioeconomy cluster is defined more by its actual coverage of sectors and activities than by the mere name "bioeconomy". For a status quo analysis of bioeconomy clusters in Europe, some minimum criteria are used to select suitable clusters for analysis.

Definition/Sector Coverage The cluster should include at least two target sectors and industries that ideally combine cascading/coupling of material and energy use in cross-value chains. Clusters focusing exclusively on biotech and biopharmaceuticals, agri-food production or traditional wood industries are not included.

Size/Composition of Stakeholders The cluster should have a minimum size of 30 participants. They should represent at least two different stakeholder groups (small and large industries, research, governmental and non-governmental organisations). Ideally, the cluster covers all relevant stakeholders. For newly established clusters (initiatives), an exception regarding the minimum size will be applied.

Excellence/Certification The cluster should have been assessed for its management quality and hold a Certificate of Cluster Management Excellence issued by the European Cluster Excellence Initiative (ECEI), or alternatively a similar certificate.

In order to identify and select relevant clusters based on the defined criteria, the European Cluster Collaboration Platform (ECCP) was analysed as a first step (DG GROW & EC, 2018). The ECCP contains information profiles of over 795 cluster organisations in Europe. Of these 795 clusters, 519 clusters have more than 51 members and 276 consist of 50 or less members. The search engine does not offer a sectoral industry "bioeconomy", so the search was conducted by independently selecting all relevant sectoral bioeconomy industries – i.e. downstream chemical products, food processing and manufacturing, wood products and forestry. Hundred clusters were identified when applying the defined selection criteria. The results were reviewed individually to select only the clusters combining at least two sectoral industries. In a second step, a literature and desktop analysis was conducted to also cover new cluster initiatives and to add relevant information.

The selection process yielded a total of 32 valid "bioeconomy clusters", which were further characterised and analysed. The overview map in ◘ Fig. 16.1 contains some main characteristics such as name, country, year of foundation, number of members, biomass types (input), sectoral and industrial focus (output) and maturity (megacluster, cluster initiative, cluster,).

16.5 Analysis of Bioeconomy Clusters in Europe

Bioeconomy clusters are active and developing across Europe. A "bioeconomy cluster triangle" between Germany (with three bioeconomy clusters), France, the Baltic Sea region (Denmark, Sweden, Poland) and Belgium and the Netherlands in the centre forms the most developed area of cluster development and activity. Western European clusters in particular form transnational mega-clusters such as 3Bi – European Bioeconomy Intercluster (DE, NL, FR, UK) or BIG-C – Bio Innovation Growth Mega Cluster (DE, NL, BE) in order to better connect regions, sectors, value chains as well as technology transfer and investments in terms of infrastructure.

The majority of clusters have a regional focus. Croatia, Denmark, Finland, France, Greece, Italy, the Netherlands, Norway, Romania, Slovenia and the UK are active

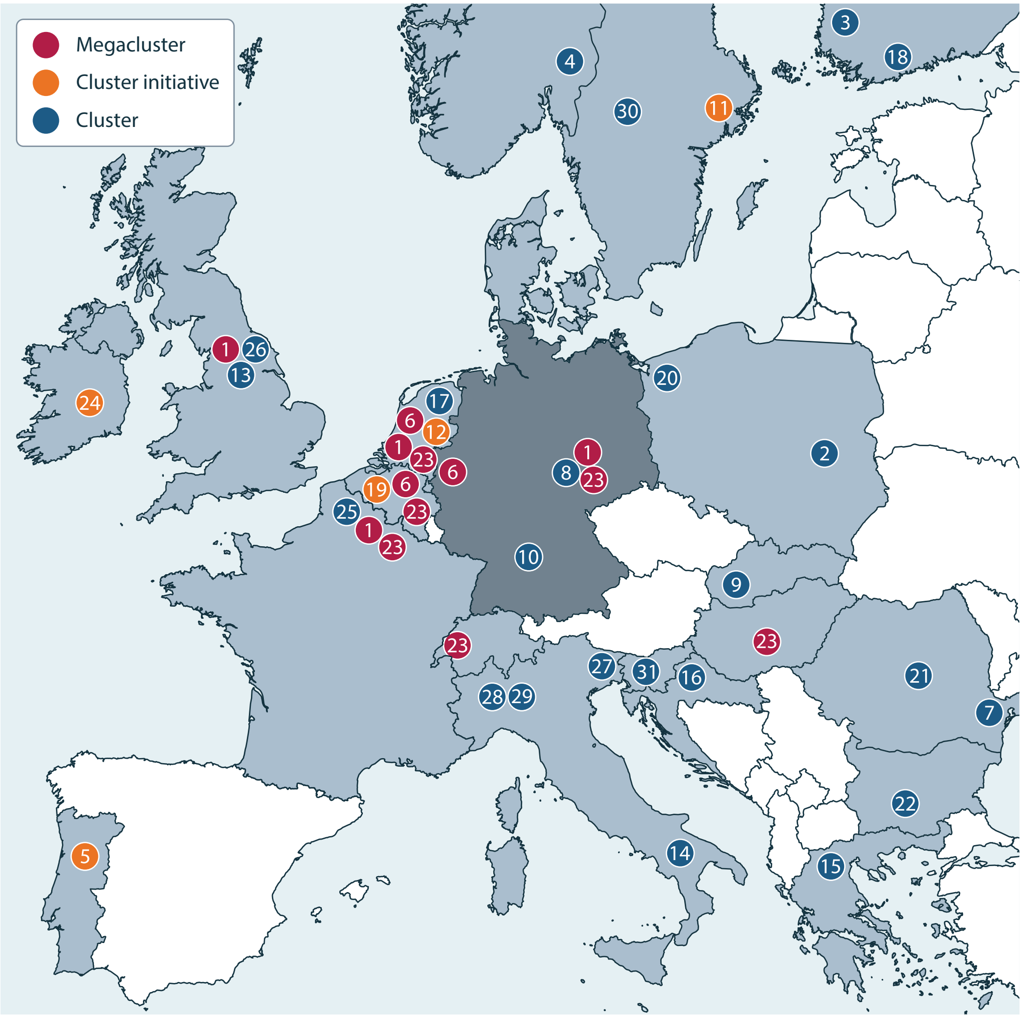

Fig. 16.1 Overview map of the selected bioeconomy clusters in Europe. (Source: Own representation)

	Cluster name	▶*	👤*	Input*	Output*
🔴 1	3Bi	2015	4**	🌳 🌾 🌿 🗑	⚗↓
🔵 2	AgroBioCluster	2014	47	🌾	🚜 🍴
🔵 3	Arctic Smart Rural Community	2016	60	🌾	🚜 🍴 ⚡
🔵 4	Arena Heidner	2012	43	🌾	🚜 🍴 🐄 ⌂ 📖
🟠 5	Association BLC3 – Technology and Innovation Campus	2010	21	⊘	-
🔴 6	Bio Innovation Growth mega Cluster BIG-C Flanders	2004	3	🌳 🌾 🗑	⚗↓ ⚗↑ 🍴
🔵 7	BIODANUBIUS	2014	28	🌾	🚜 🍴 💼
🔵 8	BioEconomy Cluster Central Germany	2011	109	🌳	🪑 ⚗↑ 🧴
🔵 9	Bioeconomy Cluster Nitra	2015	16	🌾 🗑	🚜 🍴 🌲
🔵 10	biomastec	2011	31	🌳	🚜 🍴 ⚡
🟠 11	Biorefinery of the Future	2003	36	🌳	📦 🪑
🟠 12	Biorizon	2010	-	⊘	💊 📖
🔵 13	BioVale	2014	40	🗑	⚗↑ 🚜 🍴
🔵 14	Cluster Lucano di Bioeconomia	2016	52	🌾	⚗↑ 🚜 🍴
🔵 15	Cluster of Bioenergy & Environment of W. Macedonia	2014	34	🌳 🌾 🗑	♻ 📖 💼
🔵 16	Croatian Wood Cluster	2013	77	🌳	🪑 🌲
🔵 17	Dutch Biorefinery Cluster	2010	17	🌳 🌾 🗑	📦 ⚗↓ ⚡
🔵 18	Finnish Bioeconomy Cluster FIBIC	2007	19	-	-
🟠 19	Flander biobased valley	2005	20	🌳 🌾 🗑	📖 💼
🔵 20	Green Chemistry Cluster	2007	60	🌾	📦 ⚗↓ 🚜
🔵 21	GREEN ENERGY Romanian Innovative Biomass Cluster	2011	70	🌳 🌾 🗑	🚜 ♻ 💼
🔵 22	Green Synergy Cluster	2011	34	🗑	♻
🔴 23	IAR – The French Bioeconomy Cluster	2005	380	🌳 🌾 🌿	🚜 🍴
🔵 24	Irish Bioeconomy Foundation	2016	6	🌾 🌿	💊 🍴 🧴
🔵 25	MATIKEM	2008	87	⊘	📦 ⚗↑
🔵 26	North East of England Process Industry Cluster (NEPIC)	2002	410	⊘	💊 ⚗↓ ⚗↑
🔵 27	Parco Agroalimentare FVG - Agrifood & BioEc. Clus. Agcy.	2006	21	-	🚜 🍴
🔵 28	SPRING – Italian Cluster of Green Chemistry	2014	105	🌳 🌾 🗑	🌳 ⚗↓ 📖
🔵 29	The Lombardy Green Chemistry cluster	2013	46	🌳	💊 🪑 ⚗↓
🔵 30	The Paper Province ekonomisk förening	1999	115	🌳	📦 ⚙ 🪑
🔵 31	Wood Industry Cluster	2000	105	🌳	🪑

Cluster: 🔴 Megacluster 🔵 Cluster 🟠 Cluster initiative ▶ Founded 👤 Members

Input: 🌳 Forest/wood 🌾 Agriculture/livestock 🌿 Algae 🗑 Waste ⊘ Unspecified

Output: 💊 Biopharmaceutical 📦 Paper and packaging 🌲 Forestry ⚗↑ Upstream chemical products
⚗↓ Downstream chemical products ⚙ Production engineering and heavy mechanical engineering
🪑 Wood products 🚜 Agricultural inputs and services 🐄 Animal husbandry 💼 Business Services
⚡ Power generation and transmission 🧴 Plastics 🍴 Treatment and processing of foodstuffs
♻ Environmental Services 📖 Education and knowledge ⌂ Biogas and anaerobic digestion

* the data are based on a literature search **** the cluster members are clusters**

Fig. 16.1 (continued)

Fig. 16.2 Development of (analysed) cluster foundations in Europe. (Source: Own representation)

across the bioeconomy. In addition to the national cluster, for example in Finland, France, Italy, Romania and the UK, there are also regional clusters.

Most of the 32 clusters analysed were founded from 2005 onwards. From this year onwards, a slight upward dynamic in start-up activities can be observed. Only five clusters started operations in the years 1999–2004 (◘ Fig. 16.2). The first operable clusters are mainly located in Northern and Western Europe (e.g. Sweden, Great Britain, Finland, Norway). In recent years, Eastern European clusters have also increased significantly (e.g. Romania, Slovakia).

Some clusters started with a focus on green energy (e.g. Flanders Biobased Valley as Ghent Bio-Energy Valley) or focused on the forest sector, which turned to bioeconomy themes for the first time in recent years (e.g. Finish Forest Cluster, reorganised as Finish Bioeconomy Cluster in 2012). This development seems to be happening again in Eastern Europe, where existing clusters (wood, green electricity) are expanding coverage to other sectors and becoming a "bioeconomy cluster".

In France, Germany, Italy and Sweden, bioeconomy clusters have been newly created to better link different sectors and value chains. In these countries, such clustering has also been supported by national policies and public funding.

With regard to the size of 32 clusters analysed, the picture is very diverse and there is no obvious correlation between the number of members and the national or regional focus. The number of participants ranges from 16 to 913 cluster members. The smallest cluster is the recently established regional bioeconomy cluster Nitra (Slovakia) with 16 participants, while the regional North East of England Process Industry Cluster (UK) has 420 participants. Among the national clusters, the number of participants varies just as significantly, with the Danish Biomass Innovation Network (INBIOM) having 913 members and the Finnish National Bioeconomy Cluster (FIBIC) having 17 members.

For 32 clusters, it was possible to obtain detailed information on the cluster composition. The industrial partners have the highest share among them (◘ Fig. 16.3). On average, 65% of the cluster members are small and medium-sized enterprises (SMEs) and another 10% belong to large industry. There are some minor deviations from these averages: for example, the Danish INBIOM network with 74% SMEs and the UK BioVale cluster with only 40% of SME members.

With one exception, partners from research and industry are represented in

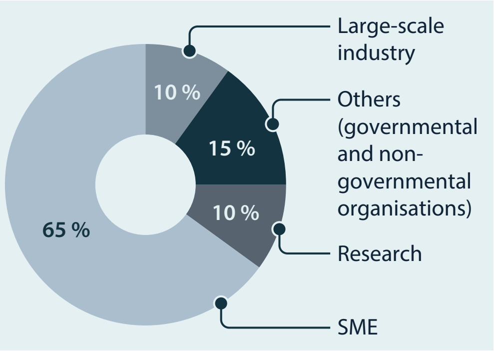

Fig. 16.3 Composition of the analyzed clusters. (Source: Own representation)

all clusters. More than half of the analysed group also engages other partners and institutions (triple helix approach[3]). Research and large companies account for an averag of 10% of all participants.

Looking at sectoral coverage, agricultural inputs and services are covered by 13 clusters and food processing and manufacturing by 12 clusters. These two represent the most important sectors. In addition, wood products and downstream chemical products are the second most covered sectors with six to seven clusters each. Interestingly, the education and knowledge sector is the third most covered sector (Fig. 16.4). This appears to be an important sector, especially in the case of the bioeconomy, which is a relatively new concept for businesses, consumers and also educational institutions.

16.6 Conclusion and Outlook

Bioeconomy clusters are at odds with the "typical" cluster definition, which refers (among other things) to an entity with thematic proximity of its members. The challenge for bioeconomy (clusters) is to overcome this "silo thinking" and attract members from different sectors in order to achieve cross-sectoral and previously unconnected cooperation.

The establishment of a cluster, be it regional or national, does not follow one specific concept. Some clusters were newly established and other clusters extended their scope towards the bioeconomy, starting from a specialisation in, for example, green energy or wood. Bioeconomy clusters are more advanced in Western and Northern Europe, due to earlier cluster policies and the availability of public funding to support cluster formation. Southern and Eastern European countries are on the way to closing this gap, partly due to available EU funds. As in Western and Northern Europe, there are two lines of development. On the one hand, new bioeconomy clusters are being created (Poland and Slovakia), and on the other hand, existing clusters are being reorganised or thematically expanded (Romania, Slovenia).

In most cases, the clusters were established with the support of national or regional cluster policies. In some countries, the clusters were established before an official bioeconomy strategy was launched (e.g. Finland, France, Italy, Poland, Slovakia, UK).

Strong political support through a national bioeconomy strategy and an associated funding mechanism is certainly the driver for strong clustering in Belgium, Germany and the Netherlands, as well as a stimulating factor for the further development of existing clusters in all European countries. The possibility to apply for public funding in addition to membership fees stimulates the growth of clusters.

The majority of clusters have a regional focus – in some countries national and regional clusters also coexist. Regionalism is in line with the concept of the bioeconomy, which focuses on regionally available biomass and more regionally closed circular

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[3] In the triple helix approach of a knowledge economy, university, industry and government were initially defined as the main institutions (Leydesdorff, 2010).

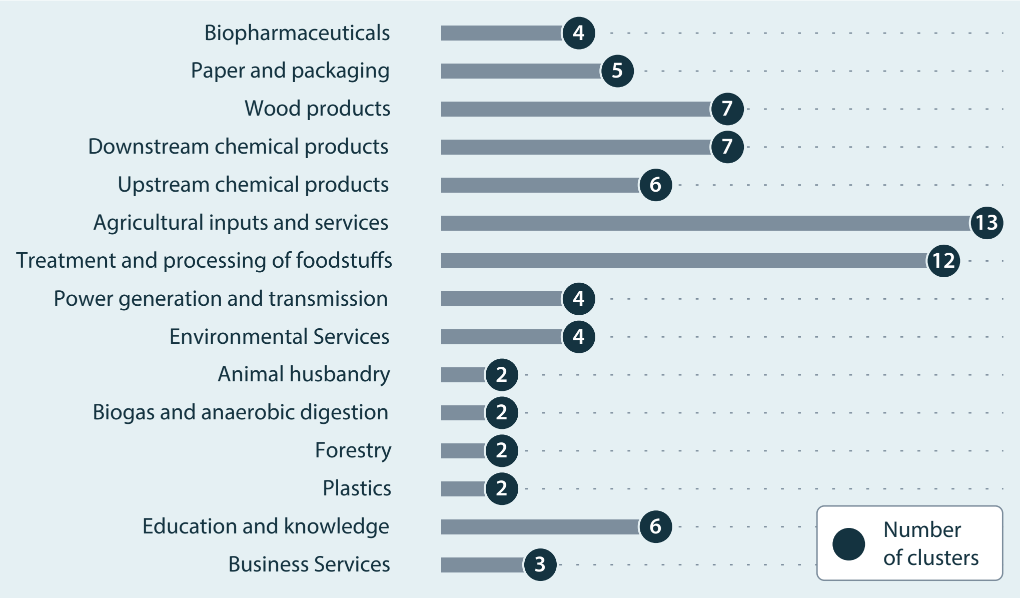

Fig. 16.4 Sectoral industries covered by the clusters. (Source: Own representation)

bioeconomies. Nevertheless, the tendency to form megaclusters shows that transnational and cross-national cooperation is becoming increasingly important. This may be the case for better sourcing of biomass in adjacent regions and marketing of intermediate products across regions and borders. Moreover, the bioeconomy requires high investments in infrastructure and technology research (especially related to biorefineries). Therefore, cooperation is needed with the aim of joint infrastructure and investment as well as research and technology transfer.

In terms of sectoral coverage, there seems to be a strong focus on four industries, namely agriculture, food production, wood and chemicals. The focus is on sourcing biomass for the chemical industry and future biorefineries. This bioeconomy approach, targeting green chemistry and high-value products, is found in most of the advanced clusters of the "Bioeconomy Cluster Triangle". A broader connection to other sectors such as construction and plastics could further increase synergies. The majority of the clusters work with biomass resources from forestry and agriculture. The use of biowaste and residual streams is limited to a few Western European countries.

From the analysis of clusters in Europe, insights can be gained regarding their definition, trends or their role:

- According to the classical understanding of clusters, clusters concentrate on one or two sectors (e.g. the chemical industry, food and luxury food industry, automotive industry, agriculture and forestry, etc.).
- To enable cross-innovation, cross-cluster initiatives are increasingly emerging, although their main focus is still strongly sectoral. In contrast, the bioeconomy spans multiple industries and sectors.
- A cluster is usually strongly industry-driven, whereas the bioeconomy – depending on the country – is strongly policy- and industry-driven and is intended to increasingly involve society in the transformation processes.
- Clusters are an important pillar of the bioeconomy transformation (technology

and product development etc.) to make this possible on the part of the industry as well.

- In order to be able to accompany this transformation politically, scientifically and socially, overarching platforms are emerging in which associations, NGOs, the media, etc. are also involved.

It should be noted that further developments have taken place in this topic area since this chapter was drafted, but these could not be presented here. In the meantime, for example, a new EU bioeconomy strategy has been published, the German bioeconomy strategy has been newly published and new clusters and hubs have been established (such as in the EU project Power4Bio).[4]

References

BERST (Building Regional BioEconomics). (2015). *Case study (BERST region): Slovenia*. https://berst.vito.be/sites/biobased.vito.be/files/Case%20Study%20%28BERST%20region%29%20Slovenia.pdf. Accessed 11 Dec 2018.

Bioeconomy Finland. (2018). *Finnish bioeconomy strategy*. http://www.bioeconomy.fi/facts-and-contacts/finnish-bioeconomy-strategy/. Accessed 26 Mar 2018.

Bioeconomy Stakeholders Panel. (2017). *European Bioeconomy Stakeholders Manifesto*. https://ec.europa.eu/research/bioeconomy/pdf/european_bioeconomy_stakeholders_manifesto.pdf. Accessed 6 Mar 2018.

Bioökonomierat. (2018). *What is bioeconomy?* http://biooekonomierat.de/en/bioeconomy/. Accessed 11 Dec 2018.

BMBF (Bundesministerium für Bildung und Forschung). (2010). *Nationale Forschungsstrategie BioÖkonomie 2030. Unser Weg zu einer bio-basierten Wirtschaft*. https://www.bmbf.de/pub/Nationale_Forschungsstrategie_Biooekonomie_2030.pdf. Accessed 5 Dec 2018.

BMBF (Bundesministerium für Bildung und Forschung). (2018). *Clusterpolitik*. http://www.clusterplattform.de/CLUSTER/Navigation/DE/Clusterpolitik/clusterpolitik.html;jsessionid=B2872D60C336DDBF061DEC168E3B6D61. Accessed 6 Feb 2018.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2014). *National Policy strategy on Bioeconomy. Renewable resources and biotechnological processes as a basis for food, industry and energy*. http://www.bmel.de/SharedDocs/Downloads/EN/Publications/NatPolicyStrategyBioeconomy.pdf?__blob=publicationFile. Accessed 26 Mar 2018.

Deperatment for Business, Energy & Industrial Strategy. (2016). *UK Bioeconomy. Call for evidence*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/579732/uk-bioeconomy-call-for-evidence.pdf. Accessed 26 Mar 2018.

DG Grow & EC (European Commission). (2018). *The European Cluster Collaboration Platform (ECCP)*. https://www.clustercollaboration.eu/. Accessed 22 Feb 2018.

EC (European Commission). (2008). *Towards world-class clusters in the European Union: Implementing the broad-based innovation strategy*. https://op.europa.eu/de/publication-detail/-/publication/9a71ba5a-07c1-4d93-a07d-36579a2a1a16 Accessed: 17 Sept 2021.

EC (European Commission). (2014). *For a European Industrial Renaissance*. https://www.kowi.de/Portaldata/2/Resources/fp/2014-COM-Industrial-Renaissance.pdf Accessed: 17 Sept 2021.

EC (European Commission). (2018a). *EU cluster portal. Internal Market, Industry, Entrepreneursjop and SMEs*. http://ec.europa.eu/growth/industry/policy/cluster_en. Accessed 6 Feb 2018.

EC (European Commission). (2018b). *Horizon 2020. Policies, information and services*. http://ec.europa.eu/programmes/horizon2020/en/h2020-section/bioeconomy. Accessed 26 Feb 2018.

Flanders Biobased Valley. (2018). *Who if FBBV? mission*. https://www.h2020-superbio.eu/partners/flanders-biobased-valley Accessed: 17 Sept 2021.

Ketels, C. H. (2004). *European clusters. Structual change in Europe 3 – Innovative city and business regions*. Hagbarth Publications. https://www.hbs.edu/faculty/Publication%20Files/Ketels_European_Clusters_2004_b69f9f19-35c6-4626-b8c2-84c6cbcf1459.pdf. Accessed 23 Aug 2019.

Ketels, C. H. (2009). *Clusters, cluster policy, and Swedish competitiveness in the global economy*. Expert report to Sweden's Globalisation Council. https://www.government.se/49b731/contentassets/d668d31368c7492f9d2ca4970e8cf57b/clusters-cluster-policy-and-swedish-competitiveness-in-the-global-economy. Accessed 11 Dec 2018.

Ketels, C. H., & Protsiv, S. (2016). *European cluster panorama 2016. European cluster obersvatory report*. ec.europa.eu/DocsRoom/documents/20381/attachments/1/translations/en/renditions/native. Accessed 26 Mar 2018.

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[4] ► https://power4bio.eu/

Leydesdorff, L. (2010). *The knowledge-based economy and the triple helix model. Annual review of information science and technology*. https://arxiv.org/ftp/arxiv/papers/1201/1201.4553.pdf. Accessed 11 Dec 2018.

Norwegian Innovations Clusters. (2018). *Norwegian innovation clusters*. http://www.innovationclusters.no/english. Accessed 26 Mar 2018.

Porter, M. (2008). *On competition*. Harvard Business Review Press.

République Française. (2017). *A bioeconomy strategy for France. What is the bioeconomy? Ministère de l'agriculture et de l'alimentation*. https://agriculture.gouv.fr/telecharger/84625%3Ftoken%3De13f5ba7a8d26a552c8509c3c551418f. Accessed 20 Feb 2018.

Sölvell, Ö., Lindqvist, G., & Ketels, C. (2003). *The cluster initiative Greenbook*. https://www.hhs.se/contentassets/f51b706e1d644e9fa6c4d232abd09e63/greenbooksep03.pdf. Accessed 6 Mar 2018.

Spatial Foresight, SWECO, ÖIR, t33, Nordregio, Berman Group, Infyde. (2017). *Bioeconomy development in EU regions. Mapping of EU Member States'/regions' Research and Innovation plans & Strategies for Smart Specialisation (RIS3) on Bioeconomy for 2014–2020*. https://ec.europa.eu/research/bioeconomy/pdf/publications/bioeconomy_development_in_eu_regions.pdf. Accessed 11 Dec 2018.

Staffas, L., Gustavsson, M., & McCormick, K. (2013). Strategies and policies for the bioeconomy and bio-based economy: An analysis of official national approaches. *Sustainability*. https://doi.org/10.3390/su5062751

Synocus Group. (2009). *Workshop 6 – Lessons from the finnish cluster policy. Balancing local cluster development needs and a national innovation agenda in Center of Exertise Program*. http://www.tci-network.org/media/download/3315. Accessed 26 Mar 2018.

Vinnova. (2016). *Vinnväxt. A programme renewing and moving Sweden ahead. Regional growth through dynamic innovation systems*. https://rio.jrc.ec.europa.eu/en/file/8180/download%3Ftoken%3D3TWBZ38j. Accessed 6 Mar 2018.

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Framework Conditions and Enablers for the Bioeconomy

Contents

The German Bioeconomy Discourse

Franziska Wolff

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_17

17.1 Introduction

The political shaping and formability of an issue area depends to a significant degree on how societal actors – business, organized civil society, the media, the general public, etc. – perceive this issue area: Is it perceived as an opportunity, as a risk, as unavoidable, stoppable or shapeable? Where exactly are problems, problem causes and responsibilities identified, which approaches to solutions appear as thinkable, sayable and feasible? Language and discourse play a central role here: they frame content, assign meaning, guide associations and interpretations, shape notions and ideas, and thus ultimately construct "reality" (Berger & Luckmann, 1967) and public order (Majone, 1989). Language is said to have the ability to "make policy, creating signs and symbols that can shift power balances and influence institutions and policy content" (Hajer, 2008, p. 213).

Accordingly, discourses play a role in the political shaping of the bioeconomy. Whether and how policy-makers attempt to steer developments in biomass production, transformation and use depends, among other things, on whether central social forces are united in their perception, interpretation and assessment of the concept, or whether the discourse is marked by major differences and dissent. In this context, discourses and (material) interests are not independent of each other, but are interwoven (Blyth, 2003).

The discourse around the bioeconomy has some precursors and rivals. It overlaps with the broader sustainability discourse and with the discourses on a "green" or "circular" economy. It also builds on older strands of discourse, such as those on green genetic engineering, agrofuels, material biomass use, the commodification of nature and 'biopiracy'. Sectoral sub-discourses on the bioeconomy can also be observed in forestry (e.g. Kleinschmit et al., 2017), agriculture (e.g. Schmidt et al., 2012) or the health sector (e.g. Pavone & Goven, 2017). While analyses of these sub-discourses are already available, the author is not aware of any study of the German bioeconomy discourse in its breadth – i.e. across different sectors and stages of the value chain. Cross-sectoral studies such as those by Hausknost et al. (2017) or Birch and Tyfield (2012) refer to the European or international, not the German discourse.

Against this background, an argumentative discourse analysis of the bioeconomy discourse in Germany was conducted on behalf of the Federal Environment Agency (UBA)[1] in the research project "Sustainable Resource Use – Requirements for a Sustainable Bioeconomy from the 2030 Agenda/SDG Implementation". This chapter presents an overview of its method and results.

17.2 Method

Argumentative discourse analysis is a branch of discourse-analytical policy research that focuses on the argumentative structure of discourses and on the role of discourse coalitions supporting such argumentations. Discourses themselves are understood as an "ensembles of ideas, concepts, and categories" that give meaning to a phenomenon and are produced through specific practices (Hajer, 1995). The approach is complemented by elements of frame analysis. "Frames" are understood as interpretive frameworks that structure knowledge, assign meaning to information, and are at the same time normative and emotionally charged (Lakoff, 2010; Snow & Benford, 1988).

A total of 148 (almost exclusively German) texts by government, business and civil society actors and a number of media contributions were examined. The discourse arena of science was not considered, with

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[1] Research Code 3717 31,103 0. See Wolff (2019).

the exception of position papers of scientific advisory boards of the government.[2] In principle, texts relating to bioeconomy in different sectors and stages of the value chain were considered. The analysis spans a period from 2007 to the end of 2018. In order to identify the argumentative structures in the discourse field "bioeconomy", the basic understanding and framing of bioeconomy in the respective sub-discourse was first worked out, including benefits and limitations attributed to the bioeconomy, the human-nature relationship that emerges in the sub-discourse, the justice references and the actors considered relevant. In addition, the identified needs for regulation and approaches to regulation were examined, as well as the discursive strategies with which the respective discourse coalition seeks to strengthen its discourse.

17.3 Results

On the basis of the study, three sub-discourses and the discourse coalitions that support them are delineated from one another: an "affirmative", a "pragmatic" and a "critical" bioeconomy discourse. This division is not always clear-cut and should be understood primarily as a heuristic – a tool to structure the data. The affirmative bioeconomy discourse is the dominant sub-discourse.

17.3.1 The *Affirmative Bioeconomy Discourse*

The *affirmative bioeconomy discourse* emphasises the opportunities of the bioeconomy. It is supported by a number of state actors (including the German Federal Ministry of Agriculture, the Federal Ministry of Research, the Agency for Renewable Resources), the Bioeconomy Council as a scientific advisory body, and economic actors: "conventional" actors from agriculture and forestry as producers of biomass, as well as processors and users of biobased (intermediate) products. These include the biotechnology sector and the chemical industry, the bioenergy sector, the biofuel sector, the food industry and the automotive industry. The European Union's Bioeconomy Stakeholders Panel is also behind the affirmative discourse.

The sub-discourse frames bioeconomy as a global sustainability project with ecological benefits:

> » Scarce resources, a growing world population and advancing climate change pose major challenges for industry and society. […] The bioeconomy can help to find answers to this question. (BMBF and BMEL, 2014, foreword)

In this context, the bioeconomy is presented as virtually without alternative: "In view of the negative trends associated with the population explosion, the concept of the bioeconomy has become a necessary vision" (Scheper & Wagemann, 2012, p. 42). Bioeconomy is simultaneously pursued as an innovation and technology project that can strengthen economic growth and competitiveness at sectoral and national (or EU, OECD) level. A prominent role is attributed to research and development (R&D), in particular to the life and technical sciences with **biotechnology** as a "key technology". In some cases, the goal of overcoming sustainability challenges through the bioeconomy is supplemented by the goal of opening up growth opportunities: "Bioeconomy therefore also and especially stands for strengthening competitiveness as well as for growth and employment" (BMBF, 2010, p. 5). Basically, the affirmative bioeconomy dis-

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[2] The background to this is that the argumentations of scientific actors are rather indirectly relevant for the analysis of social discourse, i.e. to the extent that they are taken up by the participants in the discourse.

course argues within a market-based, growth-oriented paradigm of socio-economic development.The central risk in the context of the bioeconomy is seen in the physical limits of resource availability: “In order to meet this demand, the supply of biomass must develop faster than in the past” (DIB, 2013, p. 1).

Explicit references to justice are rarely found in the documents of economic actors, whereas state sponsors of the discourse at least mention the problem of competition for land and food security (hunger) in producing countries and also the North-South prosperity gap. In principle, they thus address aspects of distributive justice in the distribution of economic and social impacts of a bioeconomy, with a focus on emerging and developing countries. However, the impacts are framed as quantity problems, resource problems or pollution problems, rather than as distributional, equity or social problems. It is assumed that they can be solved technically – through the use of biotechnology or the digitalisation and automation of agriculture, etc. – through more efficient resource provision and use. The bioeconomy is thus presented as a *technological fix*.

A broad spectrum of primary production, industry and science are named as “relevant” actors in the bioeconomy, with the biotechnology sector and the life sciences being assigned a key function as mentioned.

The human-nature relationship in the affirmative bioeconomy discourse is strongly anthropocentric with a utilitarian bias. Nature is framed as a “**resource**” or a “**source of raw materials**” – that is, as things defined via their usefulness for humans. Intensive use of biological resources, including their biotechnological modifiability and patentability, are considered unproblematic.

As far as political strategies for promoting the bioeconomy are concerned, the affirmative discourse on the one hand calls for restraint on the part of the state (‘no red tape’), on the other for industrial policies securing and expanding biomass availability and increasing efficiency in biomass production and use. In addition, demands for ecological and social sustainability are made to varying degrees and in varying concreteness. In terms of language and rhetoric, the affirmative bioeconomy discourse attempts to convince through, among other things, a win-win-win argumentation. It also aims to convince by addressing certain trade-offs (including land use competition, food security), while largely ignoring others (including nature conservation, justice issues).

The discourse draws on terms and arguments from established environmental discourses and narratives, especially the sustainability and planetary boundaries discourses. It formulates some strong claims (“great challenges” of the global future, “great opportunities” through the bioeconomy) in strong language and occasionally also uses polarizing formulations and attributions for possible skeptics of the bioeconomy.

One of the contradictions of the affirmative bioeconomy discourse is that it pays little attention to the causes of the sustainability problems that the bioeconomy is supposed to “solve”, and therefore does not benchmark the bioeconomy’s opportunities and risks against alternative or complementary approaches to solving these original problems. Moreover, it appears uncertain whether the predicted ecological, economic and social benefits of the bioeconomy can be realised in view of intensifying land competition, new import dependencies and a global expansion of intensive biomass cultivation. It also seems contradictory that industrial bioeconomy protagonists are willing to receive billions in public subsidies, call on the government to promote societal acceptance of bioeconomic technologies and products and simultaneously urge for regulatory restraint. Finally, civic participation and social dialoguelag behind the announcements made by representatives of the affirmative discourse.

17.3.2 The *Pragmatic Bioeconomy Discourse*

The *pragmatic bioeconomy discourse* weighs up the opportunities and risks of the bioeconomy and proposes stringent sustainability standards. The mainstays of this discourse are environmentally oriented state actors (German Federal Ministry for the Environment, German Environment Agency) including scientific advisory boards (German Advisory Council on the Environment, German Advisory Council on Global Change, in some cases the German Advisory Council on Agricultural Policy) as well as a few civil societal actors and companies or business associations beyond the bioeconomy sectors proper (e.g. the water management sector).

Similar to the affirmative discourse, the pragmatic bioeconomy discourse sees the bioeconomy as an opportunity for sustainability in the global North and South. However, it rejects an undifferentiated classification of its sustainability potential. In the context of *bioenergy*, the WBGU justifies this as follows: 'On account of the many possible bioenergy pathways, their different characteristics, and the global linkages among their effects, it is not possible to arrive at a single sweeping assessment of bioenergy.' (WBGU, 2009, p. 2).

The discourse identifies as central limits of a bioeconomy the availability of *sustainably* produced or provided biomass – and thus possible impacts on climate protection, biodiversity, soils, water, etc.. Land use competition also represents such a limit for the discourse coalition because of its impact on food security. Among others, the role of indirect land use change (iLUC) is brought into play. The pragmatic discourse, therefore, formulates more clearly than the affirmative discourse that a bioeconomy should only be developed within **global sustainability guard rails** – economic motives for an expansion of the bioeconomy are put on the back burner.

The risks of the bioeconomy are weighted more heavily and more attention is paid to possible consequences for the countries of the Global South. The benefits of the bioeconomy as an innovation and technology project occupy a significantly weaker position. Expectations regarding growth and employment effects in the context of biomass and bioenergy are rather muted compared to those in the affirmative discourse; possible negative effects on land, food and feed prices are expected.

The pragmatic bioeconomy discourse addresses distributive justice with regard to ecological, economic and social impacts of the bioeconomy both in the Global South and in Germany, although social impacts are less considered at the national level.

In terms of "relevant" actors, farmers (especially in the Global South) occupy a more important position, and the research and biotechnology sector a less central position than in the affirmative discourse.

In the pragmatic bioeconomy discourse, the human-nature relationship is essentially anthropocentric, albeit with a 'protectionist' bias. The biotechnological alterability and designability of living things and the patentability of biological "innovation" are viewed cautiously to sceptically. No statements could be found on industrial biotechnology in the analysed texts.

As far as policy strategies are concerned, the disourse calls for a policy framework with strong environmental limits in subsidy programmes and regulation so as to ensure that the expansion of biomass use contributes to climate protection, does not restrict food security and does not degrade biodiversity. In addition, it is seen as important to combine biomass uses intelligently. The use of biomass should be weighed up against the use of other renewable energy sources (e.g., wind, sun) which collide less with food production, but also against the use of alternative technologies (such as electric mobility) or strategies (e.g. energy efficiency) with regard to the greatest climate mitigation potential. In addition to alternative funding policies and new regulatory standards for greater sustainability, approaches are proposed to scale back or end existing policies or to phase out certain non-sustainable technologies, biomass uses or practices. Finally, an international regulatory framework for the bioeconomy is called for, based on existing policy regimes (including on climate, biodiversity, desertification and in the context of the UN Food and Agriculture Organisation).

On a linguistic-rhetorical level, the pragmatic discourse seeks to gain support by openly discussing trade-offs, by seeking connectivity with the broader environmental and economic policy discourse of "ecological modernisation", and by remaining balanced in terms of both argumentation and language.

17.3.3 The *Critical Bioeconomy Discourse*

The *critical bioeconomy discourse* associates the "dominant" concept of the bioeconomy (shaped by the affirmative partial discourse) with more ecological and social risks than opportunities and calls for more fundamental change. The protagonists of the critical bioeconomy discourse are civil society organisations from environmental and nature conservation, development policy, the critical forest and agricultural communities, associations critical of genetic engineering in agriculture and the food industry, but also representatives of the German Green Party (Bündnis 90/Die Grünen) and the Greens-affiliated Böll Foundation.

The sub-discourse evaluates the concept of the bioeconomy as a "grand narrative". It raises the question of whether (and to what extent) it is a marketing concept to increase the legitimacy of less sustainable (partly explicitly controversial) industries. At the same time, however, the critical bioeconomy discourse questions the bioeconomy's claim to be a "big deal": "Can bioeconomy really save the world?" (Forum Umwelt und Entwicklung, 2018, p. 1). Discourse participants point out that the term "bioeconomy" would be a "**neologism**" and used in a deceptive way:

> » The actors of the bioeconomy also make use of these rhetorical devices. This begins with the misleading term 'bioeconomy' itself: This term, which is reminiscent of eco-labels, creates the impression that this is about a reorientation of the economy according to ecological principles, whereas the combination of 'bio' with 'economy' actually means nothing other than the complete commercial use and exploitation of nature. (Gottwald & Krätzer, 2014, p. 111)

The focus of the critical bioeconomy discourse is not on the opportunities, but on the ecological risks of the bioeconomy in the Global South as well as in the North. The issues addressed include increasing pressure on forests and sensitive ecosystems, the expansion of agro-industrial practices (monocultures, low crop rotations, high fertilizer and pesticide use), the "maizeification" of landscapes, greenhouse gas emissions from the conversion of arable land and its agro-industrial cultivation – which the bioeconomy is originally concerned with avoiding – as well as the risks of green genetic engineering and new breeding techniques. Threats to food security, local conflicts and expulsions as a result of *land grabbing* by foreign investors, job losses and increasing dependencies in agriculture are addressed as social consequences of land-use competition and the further diffusion of intensive agriculture.The sub-discourse criticises the dominant understanding of the bioeconomy as industry-driven, undemocratic and power-blind. Instead of a technology-centred substitution of fossil energies and raw materials, the bioeconomy must more comprehensively solve the socio-economic and socio-ecological challenges of climate mitigation, resource conservation and food security.

The critical bioeconomy discourse addresses questions of procedural justice and distributive justice (with regard to the ecological, social, economic) effects of the bioeconomy for Germany as well as for biomass exporting countries. To a greater extent than in the other sub-discourses, references to justice are also made to future generations.

The human-nature relationship of the partial discourse is partly anthropocentric (with a 'protectionist' character), partly biocentric. Nature is indeed understood as a resource, but as one that must be treated with care and precaution. Beyond its economic significance and ecological services, nature is also seen as having cultural or spiritual values. It is not only a "storehouse of raw materials" from which one may freely help oneself; the ever more efficient use of nature, its commercial exploitation and valorisation as well as the biotechnological modification of nature are problematised. On the one hand, this is justified by the fact that the exploitation of nature degrades ecosystems and the basis of human life. On the other hand, reference is made to an intrinsic value of nature – which is seen as "undermined" in the affirmative discourse. Implicitly, reference is made here to the value of a "respectful relationship with the environment". In bioethical terms, the discourse questions whether humans have the right at all to intervene biotechnologically in other living beings in order to satisfy their needs.

With regard to the need for political regulation and strategies, there is an overarching call for the bioeconomy to be embedded in a socio-ecological transformation:

> » Prosperity and quality of life in a world with finite resources must be redefined. Simply changing the resource base is not an option, and it must not be solely a matter of ensuring continued growth for the industrialised nations with a clear conscience. (NABU, 2018, n. p.) (own translation)

In addition, the representatives of the critical discourse are concerned with the democratisation of the bioeconomy (through civil/societal participation) and with strong guard rails for its sustainability here and in producer countries. In this respect, the critical discourse is characterised by a rights-based approach, a model of food sovereignty that goes beyond the primacy of food security, and a clear commitment to agro-ecological, GMO-free and (small-) farmer-based approaches to biomass production. Linguistically and rhetorically, the critical sub-discourse seeks to mobilise support by exposing material interests and rhetorical strategies of the affirmative bioeconomy discourse, pointing to trade-offs as well as ethical and justice implications, referring to politically-set sustainability goals (including the UN Sustainable Development Goals), "*naming*" problematic actors and "*shaming*" harmful practices at the local level (e.g. land grabbing, maize cultivation). The discourse coalition also uses irony and explicitly expresses concern and outrage.

17.4 Discussion and Conclusions

Of the three sub-discourses described, the affirmative bioeconomy discourse has established itself as the "dominant" sub-discourse. It shapes the understanding of the bioeconomy in government strategy documents and policies.

It should be noted that the three discourses on the bioeconomy are not static but have changed over time: For example, the affirmative bioeconomy discourse has opened up to ecological and social goals after the initial years, and the critical discourse, which was initially more focused on partial aspects such as the use of biomass for energy, industrial agriculture and genetic engineering, has increasingly turned to the overarching concept of the bioeconomy.

Although all three sub-discourses on the bioeconomy are based on a sustainability argumentation, a polarisation can be observed between them. It can be found in particular with regard to the overarching goals pursued with the bioeconomy, the implicit human-nature relationship and questions of distributive justice. The language used in the analysed documents is in part conducive to reinforcing this polarisation. Because polarisation reflects conflicts of goals and values, rather than "merely" conflicts of interest or means, aiming to straightforwardly negotiate a compromise position between antagonists has little prospect of success. This difficult situation could be addressed in (at least) two ways: On the one hand, the different goals and values could be made transparent and discussed between the carriers of the sub-discourses. On the other hand, an open, socio-political debate on the bioeconomy could be initiated. The prerequisite for both approaches would be a credibly strong role for civil society organisations and/or citizens in the definition, further development and implementation of the government's bioeconomy strategy and in its monitoring by the Bioeconomy Council.

References

Berger, P. L., & Luckmann, T. (1967). The social construction of reality. *A treatise in the sociology of knowledge*. New York: Anchor Books. (Reprint).

Birch, K., & Tyfield, D. (2012). Theorizing the bioeconomy. *Science, Technology and Human Values, 38*(3), 299–327.

Blyth, M. (2003). Structures do not come with an instruction sheet. Interests, ideas, and progress in political science. *Perspectives on Politics, 1*(4), 695–706.

BMBF (Bundesministerium für Bildung und Forschung). (2010). *Nationale Forschungsstrategie Bio-Ökonomie 2030. Unser Weg zu einer bio-basierten Wirtschaft*. https://www.bmbf.de/upload_filestore/pub/Nationale_Forschungsstrategie_Biooekonomie_2030.pdf. Accessed 20 Aug 2019.

BMBF (Bundesministerium für Bildung und Forschung) & BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2014). *Bioökonomie in Deutschland Chancen für eine biobasierte und nachhaltige Zukunft*. https://www.bmbf.de/upload_filestore/pub/Biooekonomie_in_Deutschland.pdf. Accessed 20 Aug 2019.

DIB (Deutsche Industrievereinigung Biotechnologie). (2013). *Diskussionspapier der Deutschen Industrievereinigung Biotechnologie (DIB) zur Bioökonomie*. https://www.vci.de/langfassungen-pdf/diskussionspapier-zur-biooekonomie.pdf. Accessed 20 Aug 2019.

Forum Umwelt und Entwicklung. (2018). *Rundbrief 1/2018. Mit Bioökonomie die Welt retten? Neue Geschäftsmodelle und alte Strukturen*. https://www.forumue.de/wp-content/uploads/2018/04/FORUM_rundbrief118_Bio%C3%B6konomie.pdf. Accessed 20 Aug 2019.

Gottwald, F.-T., & Krätzer, A. (2014). *Irrweg Bioökonomie. Kritik an einem totalitären Ansatz*. Suhrkamp.

Hajer, M. A. (1995). *The politics of environmental discourse: Ecological modernization and the policy process*. Claredon Press.

Hajer, M. A. (2008). Diskursanalyse in der Praxis. Koalitionen, Praktiken und Bedeutung. In F. Janning & K. Toens (Eds.), *Die Zukunft der Policy-Forschung. Theorien, Methoden, Anwendungen* (pp. 211–222). Wiesbaden.

Hausknost, D., Schriefl, E., Lauk, C., & Kalt, G. (2017). A transition to which bioeconomy? An exploration of diverging techno-political choices. *Sustainability, 9*(4), 669.

Kleinschmit, D., Arts, B., Giurca, A., Mustalahti, I., Sergent, A., & Pülzl, H. (2017). Environmental concerns in political bioeconomy discourses. *International Forestry Review, 19*, 41–55.

Lakoff, G. (2010). Why it matters how we frame the environment. *Environmental Communication, 4*(1), 70–81.

Majone, G. (1989). *Evidence, argument and persuasion in the policy process*. Yale University Press.

NABU (Naturschutzbund Deutschland). (2018). *Noch ganz am Anfang*. Viele offene Fragen beim Ausbau der Bioökonomie. https://www.nabu.de/umwelt-und-ressourcen/ressourcenschonung/biooekonomie/19308.html. Accessed 20 Aug 2019.

Pavone, V., & Goven, J. (Eds.). (2017). *Bioeconomies. Life, technology and capital in the 21st century*. Palgrave Macmillan.

Scheper, T., & Wagemann, K. (2012). "Bio-Technologien" ebnen den Weg zur Bioökonomie. Wie sich ganze Industrien durch biotechnologische Methoden verändern werden. *Itranskript, 7*(2012), 42–48.

Schmidt, O., Padel, S., & Levidow, L. (2012). The bioeconomy concept and knowledge base in a public goods and farmer perspective. *Bio-based and Applied Economics, 1*(1), 47–63.

Snow, D. A., & Benford, R. D. (1988). Ideology, frame resonance, and participant mobilization. *International Social Movement Research, 1*(1), 197–217.

WBGU (German Advisory Council on Global Change). (2009). *Future bioenergy and sustainable land use*. https://www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/hauptgutachten/hg2008/pdf/wbgu_jg2008_en.pdf. Accessed 30 Aug 2021.

Wolff, F. (2019). Der deutsche Bioökonomiediskurs: Schlüsselindustrie der Zukunft oder neue Ausbeutung der Natur? In Z. Kiresiewa, M. Hasenheit, F. Wolff, M. Möller, & B. Gesang (Eds.), *Bioökonomiekonzepte und Diskursanalyse. Teilbericht des Projekts "Nachhaltige Ressourcennutzung – Anforderungen an eine nachhaltige Bioökonomie aus der Agenda 2030/SDG-Umsetzung". TEXTE 78/2019* (pp. 68–128). Dessau-Roßlau.

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Innovation and Bioeconomy

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Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_18

18.1 Introduction

The ability to innovate and the innovative activity of national economies are regarded as key success criteria for economic growth. Since innovations are usually associated with extensive investments, they have multiplier and (capital) accumulation effects. Consequently, innovations are considered to be the engine of economic development (Vahs & Brem, 2015). Therefore the word innovation cannot be missing in publications and discourses on the topic of future industries, key technologies and growth (European Commission, 1994). In this context, it suffers a fate similar to that of the term sustainability, which since Brundlandt (1987) has developed into an arbitrary term that occurs everywhere, but whose actual meaning is increasingly fading into the background. It therefore makes sense to begin with a few definitions.

For example, the Enquete-Kommission (1998) states that

> Innovations are processes of renewal or process results, whereby these – depending on the level of explanation – can consist in new products, processes and services, but also in the result of social or organisational change. (Enquete-Kommission, 1998, p. 194)

The National Science Foundation (NSF) emphasises the process, making it clear that innovation is not the same as Invention:

> The innovation process encompasses the entire process from the creation of an idea to its widespread application in society; the process begins with identifying the problem or finding an idea, extends through problem solving and creating production capacity, and ends with the dissemination of the new product to the market. (following NSF, 2010, n.d.)

The OECD Oslo Manual (2005) states that innovation is the introduction of a new or significantly improved product (good or service) or process, a new marketing method or a new organisational method in business/economic practices, workplace organisation or external relations. Innovation activities are all scientific, technological, organisational, financial and commercial activities that actually or intentionally lead to the implementation of innovations. Some innovation activities being innovative in themselves, others being not new activities but necessary for the implementation of innovations. Innovation activities also include research and development that are not directly related to the development of a specific innovation (OECD, 2005). In publications on the topic of innovation management, authors such as Vahs and Brem (2015) are often cited, who define innovation as the targeted implementation of new technical, economic, organisational and social problem solutions that are aimed at achieving corporate goals in a novel way. They thus refer to the result-oriented view of entrepreneurial activity. They distinguish innovation from technology. Technology is understood as collected expert knowledge that builds on a theoretical basis and attempts to develop it further. The focus is on the question of the functional principle, its explanation and description. Only engineering translates the knowledge gained from technology into concrete products and processes. Finally, the activities of research and development bring about changes in technology and engineering. Thomas and Ford (1995) already emphasise that innovation requires more than just knowledge: “not simply the possession of knowledge, but rather the ability to apply that knowledge to a particular problem” (p. 275).

18.1.1 Invention and Innovation

The sustainable increase in corporate success is the starting point, core and goal of any investment in innovation (Hauschildt et al., 2016); for national economies, analogous considerations mean increasing competitiveness through innovation. However, it is significant that the respective understanding of innovation must always go beyond invention and that innovation management sees the shaping of the existing innovation system as its focus.

Invention (Latin *invenire* = to discover, to invent) refers to the results of research and development and is a necessary precursor to innovation; it describes the process from the generation of ideas to the first implementation of a new idea.

In contrast, innovation (Latin *innovare* = to renew) basically refers to the first economic implementation of an idea *(exploitation),* i.e. it refers to the economic use of knowledge and thus to economic success. It encompasses the market launch (in the narrower sense) through to market diffusion or market proof in the broader sense.

18.2 Capital Market, Sustainability and Bioeconomy

The Austrian national economist Joseph Alois Schumpeter defined innovation as the implementation of new combinations with which companies leave the well-trodden paths of the static economy in the pursuit of profit (Röpke & Stiller, 2006). According to Schumpeter, the implementation of new combinations can be understood as the introduction of new production methods, the opening up of new sales markets or new sources of supply (for raw materials or semi-finished products), the implementation of a reorganisation or the manufacturing of a new product.

Schumpeter is regarded as the originator of today's understanding of the causes and effects of innovation through his explanatory approaches to the medium- to long-term development of national economies – by linking technological, economical, psychological and sociological considerations. Schumpeter's idea of the implementation of new combinations, which do not occur continuously but discontinuously, directs the point of view from a superficially technical or technological orientation to an economic one and at the same time organisational problem: innovation is thus not only a topic of natural science and engineering, but equally of economics and management theory; markets and organisation are thus on an equal footing with engineering and production:

Consequently, the three dimensions of "Integrated Innovation Management" include

1. technical innovations (products, processes, knowledge),
2. organisational innovations (structures, cultures, systems, management) and
3. business-related innovations (renewal of the business model, the industry structure, the market structure, its boundaries and the rules of the game) (Zahn & Weidler, 1995).
4. A fourth dimension would have to be added, namely that of the social innovation (political innovation, new lifestyles) (Zapf, 1994).

The current innovation discussions reflect these considerations, as they make it clear that innovation is by no means a privilege of (industrial) companies, but is also of considerable importance for non-profit organisations and thus ultimately for society as a whole. These innovations are also referred to as "post-industrial innovations".

Schumpeter identifies two central groups of actors for the basic phenomenon of economic development in his work “Theory of Economic Development” (1912), namely the (a) dynamic entrepreneurs and the (b) dynamic financiers: the former achieve a competitive advantage through the new combination of production factors and obtain a pioneering position, which helps an economy to achieve higher productivity and a higher level of welfare. The latter make the growth process possible through adequate financing, which makes the combination of the various factors feasible in the first place.

This insight, which is now more than 100 years old, is more relevant than ever, given the continuing difficulties in accessing growth financing and venture capital, especially in Germany: Since 2014, a group of renowned entrepreneurs (CEOs and founders of high-tech companies) has been advocating catchy models with which to mobilise private capital (“1% for the future – making innovations succeed”) (E&Y Report, 2014 as well as Mietzsch, 2018) in order to bring about financing for the high-tech/high-risk businesses of biotech companies, as the editors explicitly put it. Thus, financiers of high-tech companies are rewarded for committing to a company for the long term by means of equity participation and also for taking loss risks by exempting income from taxation after a holding period of several years and by bearing losses themselves. This model is intended in particular to replace the federal government’s “expensive subsidy programs, which are unsuitable as an instrument”. At the same time, incentives should be created to establish new equity funds, with which companies should escape the “financing trap” and innovations could be brought to market.

18.3 Innovation Approaches in the Bioeconomy

In the bioeconomy, various definitions and (self-)understandings of “innovation” are represented, overlap or go hand in hand. For a simplified description here, innovation is understood as processes of renewal, or process results consisting of new products, processes and services, or as results of social and organisational change (transformation). These take place systemically, i.e. through interplay between different actors or groups of actors who are structurally and procedurally interwoven and form an innovation system through iterative interactions.

18.3.1 System Innovation

The bioeconomy as such is often also understood as a “system innovation”, as it is linked to the idea of a profound change in a wide range of economic sectors and thus also in society. In various strategies, for example, it is often emphasised that bioeconomic innovations should be set up “in the system”. The Institute for Innovation and Technology (IIT) at VDI/VDE Innovation + Technik GmbH, for example, states accordingly that system innovations are technologically based innovations,

> » that can be transformed into economically viable and socially accepted products or services if the necessary components and competencies can be integrated into functioning system architectures. They overcome organisational and technical boundaries, are characterised by a functioning interaction of different stakeholders along value creation processes and enable business models that can only be led to success through the acceptance of the relevant actors. (IIT n.d.; o. S.)

System innovations are seen as a necessary response to the pressure of global environmental change, such as climate change. In this context, there is also talk of “transitions to sustainable development” (Grin et al., 2010). On the one hand, these system innovations are characterised by significantly different knowledge bases and technical capabilities (Blind & Quitzow, 2016; Geels, 2002, 2004, 2005, 2006). On the other hand, consumer behavior and markets are also changing. Finally, infrastructures, policies and cultures need to change to enable system innovations. System innovations usually also require new research and development programs or innovation initiatives, but also legal and regulatory changes and improved governance mechanisms. The German "Energiewende" (energy transition) is often cited as an example of system innovation, which ultimately leads to comprehensive political, economic and social changes (SRU, 2013; WBGU, 2011). Finally, it is important to convince and involve all stakeholders relevant for implementation (from entrepreneurs, service providers and trainers, but also users, consumers, NGOs, such as trade unions, environmental associations, etc.) through effective, new methods.

Life sciences and biotechnology are often described as the basis of "systems innovation", which in turn can trigger a wave of invention (The Economist, 2015; Zinke et al., 2016).

18.3.2 Environmental/Ecological and Sustainability Innovations

The European Union (EU) defines eco-innovation in its Action Plan for Eco-Innovation as "any form of innovation that brings about or seeks to bring about substantial and demonstrable progress towards the goal of sustainable development by reducing environmental pressures, enhancing resilience to environmental pressures, or leading to more efficient and responsible use of natural resources" (Europäische Kommission, 2019, n.d.).

In their paper, Blind and Quitzow cite Rennings (2000), who defines environmental innovations as "actions taken by various actors, such as businesses and households, to develop, apply, or introduce new ideas, behaviors, products, and processes to reduce environmental impacts or contribute to other environmental sustainability goals" (Rennings, 2000 in Blind & Quitzow, 2016).

At the same time, policy papers like to express that the bioeconomy always goes hand in hand with ecological advantage, which is why it is often regarded as a "sustainability innovation" (Zinke et al., 2016). According to this understanding, the aim of bioeconomic approaches should be to produce new, sustainably produced products and services using knowledge and biological resources, thus combining economic growth with ecological compatibility (German Presidency of the Council of the European Union, 2007; OECD 1998, 2009; European Commission, 2012). The future belongs to solutions with low CO_2 *impact*: "The business success of tomorrow is born to the low carbon opportunities of today" (Christiana Figueres, Executive Secretary UNFCCC at the CEO Sustainability Forum 2011, p. 3).

18.3.3 Digital Innovations

In recent years, particular attention has been drawn to the advantageous linking of bioeconomy and digitalisation as a new system innovation. The synergies expected from this have led leading German protagonists in the field of as sustainable understood biotechnology to call for a linking of the approaches "biologisation" and "digitisation" at the political level as early as 2015. However, a linkage of these approaches on a political level is currently hardly the case, although recently (2019) some FhG institutes presented "biointelligent concepts" (Competence Center Biointelligence, 2019) in cooperation with with universities from Baden-Württemberg. More detailed information on the topic of the digital bioeconomy can be found in ▶ Chap. 9.

18.3.4 Innovation Approaches in Bioeconomy Strategies

Bioeconomy strategies reflect different understandings of the bioeconomy. They thus also define the fields in which innovations take place or should take place. Different groups of strategy and thus innovation approaches can be identified:

Technology-Oriented Approaches

- focus on the development and application of modern biotechnology and knowledge from the life sciences and highlight their innovation potential (USA/OECD),
- the uses of biotechnology in the health sector (such as individualised solutions in medicine and pharmaceuticals, so-called red biotechnology) are part of the bioeconomy,
- do not attach any outstanding importance to biomass as a raw material base and
- understand the bioeconomy as the transfer of life sciences knowledge into new, sustainable/ eco-efficient and competitive products (Europäische Kommission, 2005; German Presidency of the Council of the European Union, 2007).

Transformation-Oriented Approaches

- focus on the replacement of petrochemical-based processes and products by biobased ones, and
- include all sectors of the economy involved in the production, processing and use of biological resources.

Resource-Oriented Approaches

- have been gaining acceptance in Europe since around 2010 and
- describe a bio-based economy; they focus on the production of biological resources (plants, animals, microorganisms) and their conversion into bio-based products and bio-energy.

Business-Oriented Approaches

- are closely linked to resource-oriented approaches/definitions and
- in general, the bioeconomy includes agriculture and forestry as well as all manufacturing sectors and related services that develop, produce, process or in any way use biological resources (Bioeconomy Council, 2009a, b; Bioökonomie, 2012; BMBF, 2010; BMEL, 2014).

Goal-Oriented Approaches

These approaches still contain a normative component, as can be seen in the definition of the bioeconomy by the German Bioeconomy Council (▶ Chap. 1). All strategies share, to a greater or lesser extent, the expectation that new findings, particularly in the life sciences, and the resulting innovations will lead to economic growth, improved international competitiveness and new jobs. The expectations of the last decades for biotechnology and the life sciences are therefore being continued in this context.

In the vast majority of strategies, biotechnology is seen as a key technology. The aim is to integrate biotechnology across different sectors of the economy. In contrast to the past, the bioeconomy is also opening up to other fields of technology and innovation approaches.

In recent years, the integration of research and innovation has gained increasing political importance (Aguilar et al., 2013). This is also reflected in bioeconomy strategies. With the increasing importance of the goal of promoting innovation, various fields of action to improve the framework conditions for innovation are integrated into the strategies beyond research policy approaches. The integration of different policy fields is most pronounced in the Federal Government's interministerial policy strategy for the bioeconomy (BMEL, 2014). It is embedded in other strategies ranging from the High-Tech

Strategy 2020 (HTS) to the National Sustainability Strategy in order to ensure that bioeconomy policy is both a consistent part of a comprehensive technology and innovation policy as well as a part of the sustainability policy. Thus, from the perspective of innovation research, a necessary embedding in a present dynamic and innovative knowledge society takes place.

18.4 Germany as a Location for Innovation

In 2016 no other European country spent as much money on innovation as Germany, as the EFI Report and the studies of the eponymous Expert Commission on Research and Innovation of the German Federal Government impressively confirm (EFI, 2018 ff.). Innovation intensity measures the share of innovation expenditure by the German economy in relation to turnover. This was 3% in Germany in 2016, as much as in the previous year. According to the Centre for European Economic Research (ZEW), innovation expenditure by German companies amounted to €158.8 billion in 2016, of which over 75% was attributable to industry: Compared to the previous year, innovation expenditure increased by 2% (BMBF, 2018). The increase in innovation expenditure in 2016 was not only driven by large companies, but also by small and medium-sized enterprises (SMEs). Since the late 1990s, a gap in innovation intensity has increasingly opened up between large companies and SMEs. While large companies allocate 3.8% of turnover to financing innovation activities, the figure for SMEs is only 1.4%.

The innovator rate measures the proportion of companies that have introduced at least one product or process innovation within a 3-year period. Overall, around 36% of companies were innovators in 2016, compared with 35% in 2015. This means that the decline in the innovator rate that has been observed for several years, which can also be seen in most other EU member states, did not continue in Germany for the time being.

The industry sectors electronics, metrology and optics as well as pharmaceuticals, chemicals and other vehicle manufacturing have the highest innovator rates. In a European comparison, Germany continues to occupy a top position for this indicator. In 2016, the German economy achieved sales of €719 billion with product innovations, around 3% more than in the previous year. The share of sales with new products in total sales was almost unchanged in 2016 compared to the previous year at 13.6%. The share of sales generated with product innovations is above average, especially in industries that are intensively determined by research and development (R&D) (vehicle manufacturing, electrical industry and mechanical engineering).

The investments of science and industry in R&D are reflected in economic returns when inventions become innovations that reach the market and diffuse widely. Market novelties represent a higher degree of novelty, as the corresponding innovation has not been offered on the market before. More than 8% of all German companies were the first to introduce market novelties in 2016. The sales generated with them amounted to around €154 billion. The share of market novelties in total sales was around 3% in 2016.

The international competitiveness of knowledge-based economies is reflected in trade in research-intensive goods. In 2016, research-intensive products accounted for 46% of total world industrial exports. Of these, 16.4% were advanced technologies and 29.6% were high-value technology. The share of research-intensive products in total industrial trade in goods has been increasing again since 2013. In 2016, Germany's share of global trade in research-intensive goods was 11.6%. In a European comparison, Germany thus occupies a top position.

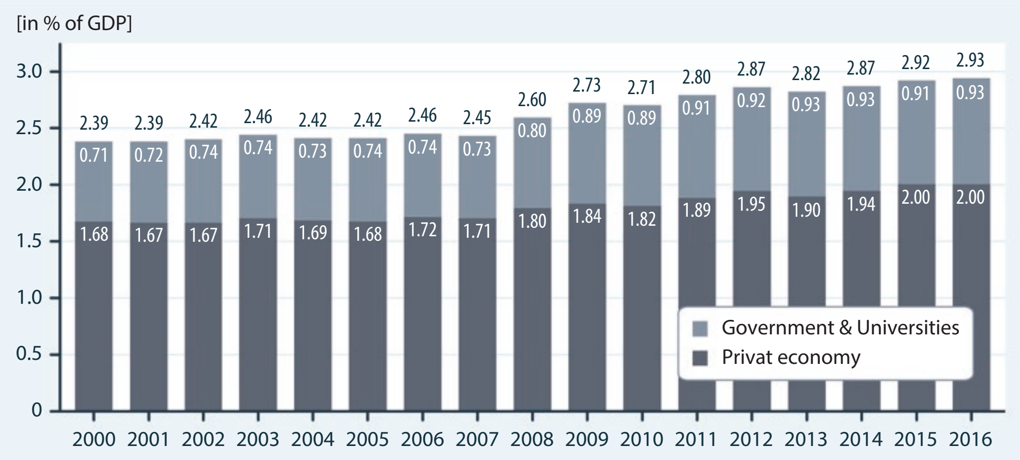
However, with a global share of 14.6%, China is now the largest exporter of research-intensive goods.

Germany is considered one of the most innovative economies in the world: this is reflected not only in the innovation ranking according to the European Innovation Scoreboard (EIS) of the European Commission (EC), but also in the two international innovation indices, the Global Innovation Index (GII, Cornell University) and the Global Competitiveness Index (GCI, INSEAD and WIPO), in which Germany is ranked between fifth and ninth place and is on a par with the USA, Japan and Sweden, and ahead of China and South Korea.

Germany's particular strengths are highlighted as the high share in R&D expenditure of private business enterprises and its patenting activities (◘ Fig. 18.1). In addition, the work of clusters is viewed positively. Switzerland leads various innovation rankings (BMBF, 2018).

Against this background, reference should also be made to the results of the current report of the EFI Commission 2019 (EFI, 2018 et seq.), which explicitly praises the High-Tech Strategy 2025 (Federal Government 2018; Bundesregierung (2018)) (adopted by the Federal Cabinet in September 2018): this formulates the goal of spending funds amounting to 3.5% of gross domestic product on R&D by 2025. It also refers to the importance of start-ups for the country's innovation capability and competitiveness: These pursue new business models, expand and modernise the range of products and services with their innovations. Start-ups from science play an important role in the transfer of knowledge and technology into practice. According to EFI, start-ups are also considered trend scouts and impulse generators for established companies. As cooperation partners of established companies, they contribute to the joint development and marketing of innovations.

Start-ups, and this is specifically emphasised in the EFI report, still have problems in Germany – especially in the growth phase – in obtaining venture capital. They also face specific challenges due to their size and their business models, which are partly set or influenced by legal framework conditions. Against this background, the Expert Commission makes the following recommendations, among others:



◘ **Fig. 18.1** Share of R&D expenditure in percentage of GDP and devided into public and privat spending. Higher amounts of privat R&D spending are accompanied by higher amounts of public spending as well. (Stifterverband für die deutsche Wirtschaft, 2016, p. 2)

- In order to promote start-ups from science, the start-up culture at universities must be further strengthened.
- Start-up education should be embedded in all degree programs.
- Universities and non-university research institutions should develop standard licence agreements for the transfer of rights to spun-off start-ups in order to enable start-ups to be licensed quickly.
- The framework conditions for private investment in start-ups are to improve further. Since there is a lack of anchor investors in Germany, the Expert Commission advocates providing incentives for institutional investors to invest more in venture capital. In addition, the VAT obligation for administrative services provided by fund managers should be abolished.

In countries such as the USA, Canada and Israel, functioning capital markets *(private equity markets)* for innovative companies have developed over decades. The success of these economic areas, especially in the pharmaceutical sector, but also in software/IT and the Internet, is largely due to these groups of actors. Interestingly, direct state intervention, subsidies or research funding in favour of new companies are of rather little importance in these economic areas. Instead, tax incentives on the investor side or the adaptation of capital market regulations to the needs of small and medium-sized enterprises (such as JOBSAct USA 2014) are used as instruments that can bring about enormous momentum.

The consideration of the EFI recommendations as well as the analogous adaptation of these exemplary, functioning innovation systems to the specific German and/or European conditions in each case are of decisive importance for the full exploitation of the potentials resulting from the life sciences for the bioeconomy.

18.5 Sustainable Finance

18.5.1 The Capital Market as a Driver of Sustainable Development

The publications of Sir Nicholas Stern, Chief Economist of the European Bank for Reconstruction and Development from 1994 to 1999 and Chief Economist and Vice-President of the World Bank from 2000 to 2003, in 2006 and 2009, which did nothing more than reverse the prevailing benefit-cost analyses of climate change mitigation, clearly made an impression on the financial community (Stern, 2006, 2009). Stern, for example, called for sustainability-oriented economics and posits that “greenhouse gas emissions represent the greatest market failure in the history of the world.” The global economic costs of climate change without further climate protection measures, according to one result, will burden global economic output by around 5–20% by 2050.

The most important catalysts for *sustainable finance development* are therefore the Paris Climate Change Conference in December 2015, at which the 2-degree target for limiting global warming was agreed, and the international agreement on the 17 Sustainable Development Goals (SDGs). In the context of these two initiatives, numerous new developments have also been initiated in the financial market. For example, at the beginning of 2016, the G20 states established a Green Finance Study Group (since renamed the Sustainable Finance Study Group) to address environmental aspects in the financial sector. Decisive impetus also came from the Task Force on Climate-related Financial Disclosures (TCFD), based at the Financial Stability Board, which has been working intensively on the development of voluntary and uniform disclosures on climate-related financial risks. The debate was further intensified by the establishment of the High-Level Expert

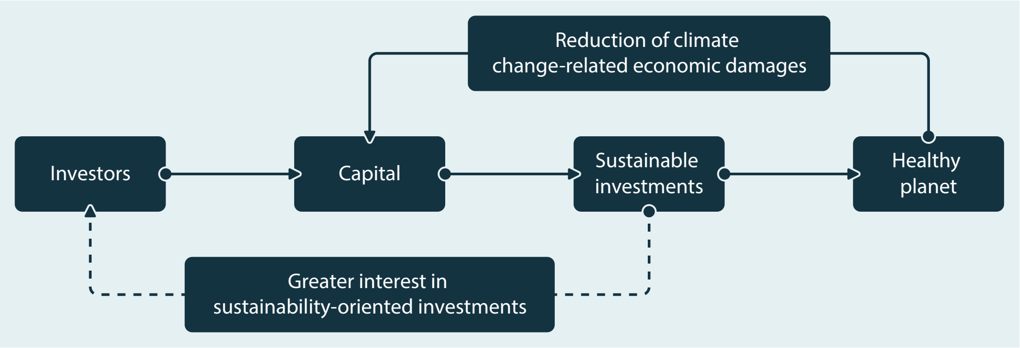
Group on Sustainable Finance (HLEG) by the European Commission at the end of 2016 (see also European Commission, 2012, 2013, 2014, 2015). The recommendations of these groups and bodies included the following

- the introduction of a *sustainable finance classification framework*,
- the revision of publication requirements,
- more transparent information for retail investors,
- the development of official European sustainability standards (e.g. for green bonds), and
- the stronger anchoring of sustainability aspects in the governance of financial institutions as well as in financial supervision.

Following on from this preparatory work, in 2018 the EC finally presented the EU Action Plan "Financing Sustainable Growth", which aims to direct capital flows towards sustainable investments in order to achieve sustainable and inclusive growth (European Commission, 2018) (◘ Fig. 18.2). It also aims to be able to manage the financial risks arising from climate change, resource depletion and environmental degradation, and social problems. Furthermore, the aspects of transparency and long-termism in financial and economic activities should be supported. The EU resolution on Sustainable Finance also commits the financial world to sustainability. It was adopted in the EU Parliament on 29 May 2018 by 455 votes (with 87 against and 92 abstentions). The report itself states that it is particularly important to have a policy framework that guides investments towards decarbonised, disaster-resilient and resource-efficient economic activities.

18.5.2 Sustainable Bioeconomy as an Investment Opportunity

A sustainable bioeconomy is seen as a promising investment opportunity by global financial markets: Private and institutional investors are increasingly interested in socially responsible forms of investment, also known as SRI *(sustainable and responsible investment)* or ESG-led investments, where ESG stands for *environmental-social-and-governance criteria,* i.e.: environmental, social and good corporate governance criteria. The focus is no longer solely on the desire for a clear conscience, which favors this investment segment. Rather, numerous investors are increasingly using the methodology of sustainability funds for the management of traditional investment funds: for example, sustainability criteria are also used as early warning systems by many fund com-



◘ **Fig. 18.2** EU Sustainable growth action plan – investing in a sustainable future for our planet. (Source: Illustration according to European Commission, 2018) panies such as DWS or Invesco Ltd. among others, in order to identify risks in good time before they are reflected in the quarterly reports of companies and thus in the share price (FNG, Berlin, n.d.).

In return for these investing strategies, securities of companies without corresponding sustainability efforts are restricted or sold off. Capital investments in the area of sustainable impact investing are growing steadily. According to the Forum for Sustainable and Responsible Investment (US SIF), at the end of 2017, approximately US$12 trillion in assets in the US were invested in SRI strategies. Numerous examples of this trend exist. For example, the World Bank announced at the end of 2017 that it would no longer invest in oil production projects or coal mining from 2019 onwards; only in exceptional cases to prevent social problems in poorer countries will this still be done in the future. The Norwegian parliament had already decided in mid-2015 to withdraw the sovereign wealth fund – with a volume of the equivalent of more than €800 billion one of the largest and most successful funds of its kind – from companies where climate-damaging coal transactions generate more than 30% of the business. At the same time, Allianz SE in Germany made the same strategic shift. In May 2018, Allianz followed suit and since then has refrained from individual insurance of coal-fired power plants and coal mining projects; by 2040, the company says it wants to have completely withdrawn from the coal business.

18.5.3 Significant Growth Potential of Sustainable Solutions

As early as 2010, Roland Berger estimated that the lead markets for environmental technology (including renewable energies, raw-material-efficient and energy-efficient products and processes, recycling and water treatment technologies) had a global sales volume of around US$ 1.7 trillion. By 2020, this figure is expected to reach around US$ 3.2 trillion, which would correspond to an average growth of 6.5%. In view of these targets, there are already numerous biobased solutions that make a sustainable bioeconomy an interesting investment with high returns. Analyses by the DIW, the Fraunhofer Institute for Innovation and Systems Research ISI and the strategy and management consultancy Roland Berger, commissioned by the Federal Ministry of Economics and Technology, show that from 2020 onwards environmental technologies will be more important in Germany than the entire automotive industry. These analyses once again demonstrate the effectiveness of “creative destruction” in Schumpeter’s sense.

18.6 Biotechnology – Driver of Sustainable Problem Solutions

One of the key disciplines underpinning a new economic cycle is biotechnology, which is highly innovative. Due to its broad positioning, its numerous fields of application and methods, and its consideration of the findings of millions of years of evolution, it offers a promising problem-solving potential based on resource optimisation and cycle management (Heiden & Zinke, 2006). In this context, biotechnology itself represents the integration of many disciplines and in turn interacts with many areas of science and technology. It represents a cross-sectional discipline that has long since transcended the classical disciplinary boundaries (see ► Chap. 9). By integrating *proteomics, metabolomics, transcriptomics, genomics, genetic engineering,* biochemistry, microbiology, bioinformatics and digitalisation, it stands as a *pars pro toto* for living *open innovation* (Heiden et al., 2001). On the one hand, it deals with questions of basic research, and on the other hand with very concrete questions of industrial practice or societal needs in a changing world. Broad penetration in the sense of a sustainable transformation of society as a whole will only be achieved if it is possible to involve all relevant stakeholders at an early stage focusing on all their needs. The normative analogies between the risk assessment of civilian use of nuclear energy on the one hand and the use of biotechnology/genetic engineering on the other can be attributed to some extend to the failure to involve all stakeholders and represents an obstacle to innovation today.

Even today, sustainability is not only seen in a positive light, but is always associated with “cost driving”: This was already noted by Dyllick et al. (1997): in 1995, around 77% of all companies surveyed on behalf of the European Commission stated that the legally induced environmental protection measures they had implemented had a cost-increasing effect. In ecologically particularly important industries the share of environmental protection investments of total investments ranged from 15% to 30%. As the Federal Statistical Office pointed out in 1996, current environmental protection expenditure in these sectors amounted to up to 5% of turnover. At the same time, however, 82% of all environmental protection investments in Germany in 1989 were still attributable to *end-of-pipe measures*. On the one hand, it is therefore not surprising that environmental protection measures are perceived by companies as a cost factor; on the other hand, however, this also disproves the frequently expressed prejudice that the presentation of the cost-increasing effect of environmental protection measures is purely a business defence strategy. In summary, additive responses (*end-of-pipe* or *add-on technologies*) to environmental protection requirements will probably always be a cost factor, but never a productivity factor.

By contrast, the situation is quite different with production-integrated environmental protection measures (PIUS), which reduce the use of raw materials and energy and, once implemented, cause lower running costs than *end-of-pipe technologies* (energy, material and personnel input). Production-integrated environmental protection measures can create both strategic and concrete competitive advantages. Environmental protection thus becomes a productivity factor (Bringezu, 1997).

However, this means for the understanding of **integrated or white biotechnology** that it can also be used in all other fields of application and contribute to sustainable development – for the company concerned as well as for society as a whole. And it is precisely this understanding that is reflected in the BIOECONOMY programs, which are being pursued with great verve by politicians and innovative companies worldwide.

The fascination and enormous potential of this technology can be seen in the interdisciplinary approach inherent in biotechnology, which has long since overcome the conventional boundaries of classical scientific fields. With its approaches, it will be possible to develop and establish energy- and resource-efficient processes and products on the market and to promote the change towards a sustainable society. Biotechnology is and will continue to be a driving force of a new, sustainability-oriented Kondratieff wave. This means that biotechnology is of a similar importance as it is currently attributed to digitalisation by some analysts and researchers. Perhaps we should even go as far as to describe this age as an era **of digitalisation and biologisation**.[1]

The success of the bioeconomy will be closely linked to innovations and research and development approaches in the field of digitalisation: On the one hand, this stands

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[1] Acatec prefers the concept of biological transformation.

for a comprehensive, currently only rudimentary, social change, on the other hand, for an industrial, in part quite revolutionary change. New digital technologies, such as cloud computing or big data, can realise a rapid networking of different industrial sectors and companies (SMEs, large companies and service providers): Material, machines and plants begin to communicate with each other in real time via the Internet in so-called smart production facilities *(smart factories)*, exchanging information and even coordinating complete manufacturing processes independently. At the same time, production and logistics can be linked along the entire industrial value chain. More resource- and energy-efficient production, process intensification, flexibility and individualisation (in manufacturing) will become possible, and this will significantly strengthen the competitiveness of companies (Fischer-Kowalski et al., 2014; Heiden & Zinke, 2006). Such objectives were already called for and published by the Enquete Commission "Protection of People and the Environment" of the 12th German Bundestag (1994): "Shaping the Industrial Society – Perspectives for a Sustainable Handling of Material and Substance Flows".

In such a networked world of business, new business models are also emerging at an enormous speed. Existing industry boundaries are being broken down, digital companies are conquering new markets and start-ups are challenging long-established market players in competition. In order to continue to survive in the market, it is particularly important for established companies to review the existing business model for possible potential for integrating these new technologies, to buy out start-ups if necessary and to develop completely new business models.

Schumpeter describes innovation as the creative destruction of what already exists (Schumpeter, 2006, 2008); and since all change brings with it resistance, for all the lip service paid to innovation in general, one should be prepared for the fact that innovations are not welcome in case of doubt. Thus, it is not surprising that D'Este et al. (2012) find that across industries, a strong relationship has been empirically established between the level of innovation activity and the extent of relevant financial, knowledge, market and regulatory barriers. For example, Hauschildt et al. (2016) in their book Innovation Management hold that the "history of innovation is a never-ending story of resistance to" the same (Hauschildt et al., 2016, p. 31). The authors sharpen their description of resistance to innovations in the following statement: "Resistance to innovations arises from the fact that the individual concerned is actually or supposedly unable to cope with these intellectual demands" (ibid., p. 40).

18.7 Will the New Kondratieff Wave Be a "Green" Wave?

The social insight into the urgency and necessity of transformation, as well as the availability and development of new key technologies (digitalisation, biologisation, environmental protection technologies …) will trigger a historically exemplary megatrend, which some authors already call a new, "green" (or sustainable) Kondratieff wave:

Five long growth waves can be identified since the Industrial Revolution at the end of the eighteenth century (see ◘ Figs. 18.3 and 18.4): the wave triggered by the steam engine, followed by the new wave triggered by the innovations of steel and railways. They were succeeded by chemistry and electricity, before petrochemistry and the automobile became established. The last wave so far was characterised by information and communication technologies.

Kondratieff waves	1st wave	2nd wave	3rd wave	4th wave	5th wave
Period	1780 - 1830	1830 - 1880	1880 - 1930	1930 - 1970	1970 till present
Basis innovation	Steam engine	Railway, steel	Electricity, chemistry	Automotive, petrochemistry	Information and communication technology, digitalization
Demand	Textile industry	Mass transport	Mass production	Individual mobility	Information, communication,-networking
Epoch	Early to late industrialization			Service economy	Knowledge society, Society of health and life sciences

■ **Fig. 18.3** Kondratieff cycles. (Source: Own representation based on Bullinger, FhG)

18.7.1 Departure through Crises

Common to all emerging waves of growth is the crisis that precedes each one and leads to the breaking of the old cycle (see ■ Fig. 18.4); from each crisis a new upswing emerges: be it the Panic of 1837, the Founders' Crisis of the late nineteenth century, the Great Depression of the 1930s, or even the two oil price crises of the 1970s of the twentieth century. The "creative destruction", as the Austrian economist Joseph Schumpeter put it, was always at the beginning of the new. Yet Nikolai Kondratieff already noted that a long cycle of growth, which permeates and transforms the economy and society, passes through a maturation phase, loses strength and finally ends in crisis. The newly created infrastructure remains and with the upswing of the next cycle the crisis is passed and survived.

The prerequisite for any new upswing are new underlying innovations and key technologies, which are carried across the board by growing demand. Demand, in turn, is driven by the productivity bottleneck factor. Only when this bottleneck factor has been overcome can new productivity gains be unleashed.

Clearly, crises are indispensable elements of our economic history: each of the Kondratieff cycles observed since the discovery of the steam engine at the end of the eighteenth century has ended in a crisis, followed by a long upswing. The resulting prosperity of a broad population over the past 200 years or so – especially in the industrialised countries – is probably unique in historical terms. Thus, one could agree with the statement of the Allianz Global Investors analysts (AGI, 2010) that the history of our prosperity is also the history of the associated crises.

The cycles described are thus always characterised by periods of technological upheaval and are similar in their consequences: old industries are being displaced by new ones; corporate cultures and processes change, new occupational fields are emerging and phases of long-term growth in prosperity lasting several years go hand in hand. In the past, these were always associated with rising CO_2 emissions, which will be different in the new cycle, as these develop-

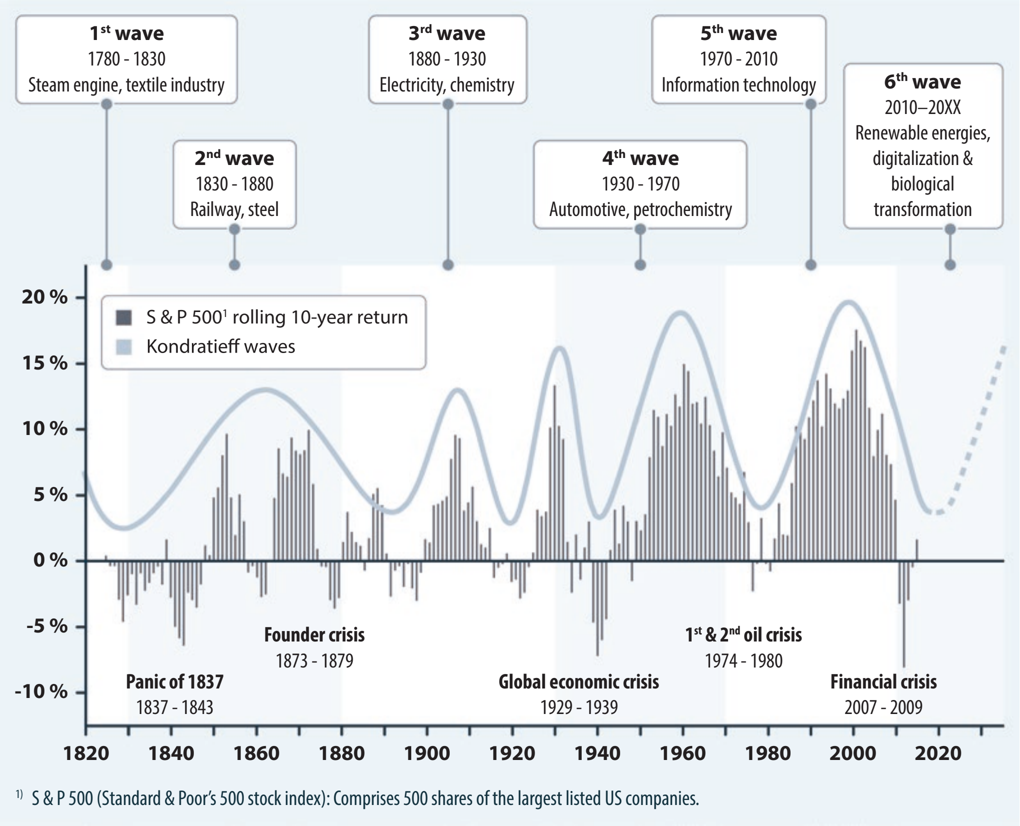

Fig. 18.4 Historical view of Kondratieff cycles: history of prosperity prosperity and associated crises. (Source: Illustration according to AGI, 2010)

ments focus on sustainable solutions and thus on decoupling prosperity and greenhouse gas emissions.

In the present and near future, we are experiencing changes in our knowledge-based society through innovations in the fields of communication technology, digitalisation, artificial intelligence and "biologisation" (biotechnology, *bioeconomy*), among others, which have already greatly changed our lives and will continue to do so in the future (see also Geels, 2005).

Moreover, we can attribute an important role of financial markets and their developments to each of the structural cycles considered: For example, high levels of debt, excessive speculation and inflated asset price bubbles played an important role, ultimately contributing to the termination of the respective cycles. Financial analysts even go so far as to attribute the decisive role in this downturn to them: At the same time, they also attribute to financial markets the role of accelerator of a new recovery[2]: after the crisis, entrepreneurs need a lot of money to spread and penetrate the more productive techniques in the market. Once the markets are developed, the demand for credit falls, real interest rates fall towards zero, and the process repeats itself. These cyclical processes with their different consequences are

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[2] For more information, see ► https://ch.allianzgi.com/en-gb/en-insights/market-updates/capital-markets-m-..onthly

now also the subject of popular business magazines and newspapers, such as Wirtschaftswoche or Handelsblatt (see, for example, Hanke, 2012 or Müller, 2010), whereby it is also emphasised that the view of economists on seemingly obvious analogies is quite differentiated.

18.8 Outlook

While in the previous economic cycles of the past 200 years the factor labour was the primary economic bottleneck factor, this role in the twenty-first century will be attributed to the bottleneck factors energy and raw material resources with their implicit environmental effects. This means that the focus is no longer on increasing labour productivity in order to secure our prosperity, but on increasing resource and energy productivity as a driver for securing quality of life, prosperity and peace.

Under the changed conditions of globalisation, demographic development, climate change and resource scarcity, as well as a growing sense of responsibility for the one world, growth will be generated in the future by sustainable solutions/innovations that contribute to the decoupling of quality of life (economic growth) and nature consumption (see Hennicke, 2010; Stern, 2006, 2009). This is precisely where biotechnology makes important contributions.

Bioeconomy and digitisation address all relevant megatrends through meaningful linkages, i.e. globalisation, urbanisation, demographic change, energy and resources, environmental and climate protection, health, mobility, knowledge-based society, and living and working (see Federal Government, 2018).

The success of this approach will essentially result from the successful participation of actors from the most diverse courses of life in society, thus addressing needs that exist not only at present but also in the long term and are also subject to enormous change in view of the global challenges facing society.

In order to fill such a far-reaching linkage with life in the long term, however, a courageous and formative policy is required that sets out to champion the issue, including through legislative, fiscal and interdepartmental – at both national and international level. The necessary instruments are well known. The urgency of such a call becomes apparent not only when looking at the distribution of R&D funds in the BMBF Report 2018, but especially when considering the situation of life science companies in comparison with the USA or other European countries.

Always keep in mind what Privy Councillor Johann Wolfgang von Goethe urged in his time: “It is not enough to know, one must also apply; it is not enough to want, one must also do.”

A sustainable bioeconomy and its underlying technologies will play the role of pacemaker and engine for establishing a major transformation. Digitalisation and biologisation, and especially their interconnection, are the drivers of a new dynamic of sustainably oriented growth, a “green” Kondratieff wave.

References

AGI (Allianz Global Investors Kapitalmarktanalyse). (2010). *Der 6. Kondratieff – Wohlstand in langen Wellen*. https://pfafi.de/wp-content/docs/4115722-1696571-AGI-Analysen—Trends-Der-6.-Kondratieff—Wohlstand-in-langen-Wellen.pdf

Aguilar, A., Magnien, E., & Thomas, C. (2013). Thirty years of European biotechnology programmes: From biomolecular engineering to the bioeconomy. *New Biotechnology, 30*(5), 410–425.

Bioökonomie (2012). Empfehlungen aus dem BioÖkonomieRat 04. Arbeitsperiode 2009–2012. *Weiterentwicklung des Förderinstrumentariums von öffentlicher und privater Forschung im Hinblick auf die Anforderungen der Bioökonomie-Empfehlungen des BioÖkonomieRats.* www.bioökonomierat.de. Accessed 30 Mar 2020.

BioÖkonomieRat. (2009a). Berichte aus dem BioÖkonomieRat 04. Arbeitsperiode 2009–2012. *Empfehlungen zum Aufbau einer wettbewerbsfähigen und nachhaltigen Bioökonomie – Beiträge der Industriellen Biotechnologie zum wirtschaftlichen Wandel in Deutschland; Positionspapier der AG Biotechnologie des BioÖkonomieRats.* www.bioökonomierat.de. Accessed 30 Mar 2020.

BioÖkonomieRat. (2009b). Empfehlungen aus dem BioÖkonomieRat 01. Arbeitsperiode 2009–2012. *Kompetenzen bündeln, Rahmenbedingungen verbessern,internationale Partnerschaften eingehen Erste Empfehlungen zum Forschungsfeld Bioökonomie in Deutschland.* www.bioökonomierat.de. Accessed 30 Mar 2020.

Blind, K., & Quitzow, R. (2016). Nachhaltige Innovationen. Aktueller Stand der Forschung und Ausblick aus innovationsökonomischer Perspektive. In G. Gordon & A. Nelke (Eds.), *CSR und Nachhaltige Innovation. Zukunftsfähigkeit durch soziale, ökonomische und ökologische Innovationen* (pp. 13–24). Springer Gabler.

BMBF. (2010). *Nationale Forschungsstrategie Bioökonomie 2030*. Unser Weg zu einer biobasierten Wirtschaft. bmbf.de/pub/biooeokonomie.pdf.

BMBF (Bundesministerium für Bildung und Forschung). (2018). *Bundesbericht Forschung und Innovation 2018. Forschungs- und innovationspolitische Ziele und Maßnahmen*. https://www.bmbf.de/upload_filestore/pub/Bufi_2018_Hauptband.pdf.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2014). *Nationale Politikstrategie Bioökonomie. Nachwachsende Ressourcen und biotechnologische Verfahren als Basis für Ernährung, Industrie und Energie*. https://www.bmel.de/SharedDocs/Downloads/Broschueren/BioOekonomiestrategie.pdf?__blob=publicationFile

Bringezu, S. (1997). *Umweltpolitik: Grundlagen, Strategien und Ansätze ökologisch zukunftsfähigen Wirtschaftens*. R. Oldenbourg.

Bundesregierung. (2018). *Forschung und Innovation für die Menschen. Die High-Tech Strategie 2025.* https://www.hightech-strategie.de/files/HTS2025.pdf

D'Este, P., Iammarino, S., Savona, M., & von Tunzelmann, N. (2012). What hampers innovation? Revealed barriers versus deterring barriers. *Research Policy, 21*(2), 482–488.

Dyllick, T., Belz, F., & Schneidewind, U. (1997). *Ökologie und Wettbewerbsfähigkeit von Unternehmen*. Hanser Fachbuch.

EFI Report. (2018). *Gutachten und Studien*. www.e-fi.de/gutachten-und-studien/gutachten

Enquete-Kommission "Schutz des Menschen und der Umwelt" des 12. Deutschen Bundestages. (1994). *Die Industriegesellschaft gestalten – Perspektiven für einen nachhaltigen Umgang mit Stoff- und Materialströmen*. http://dip21.bundestag.de/dip21/btd/12/082/1208260.pdf

Enquete-Kommission "Schutz des Menschen und der Umwelt" des 13. Deutschen Bundestages. (1998). *Konzept Nachhaltigkeit – Vom Leitbild zur Umsetzung*. http://dipbt.bundestag.de/doc/btd/13/112/1311200.pdf

Europäische Kommission. (2005). Janez POTOCNIK, Europäischer Kommissar für Wissenschaft und Forschung, stellt erstmals in seiner Rede das Konzept "Transforming life sciences knowledge into new, sustainable, eco efficient and competitive products" vor, im Rahmen der "Conference on Knowledge-based bio-economy", Brüssel, September 2005.

Europäische Kommission. (2019). *Der Aktionsplan für Öko-Innovationen*. https://ec.europa.eu/environment/ecoap/about-action-plan/objectives-methodology_de. Accessed 05 Sept 2019.

European Commission. (1994). *Growth, competitiveness and employment: The challenges and ways forward into the 21st century*. https://publications.europa.eu/en/publication-detail/-/publication/0d563bc1-f17e-48ab-bb2a-9dd9a31d5004

European Commission. (2012). *Innovating for sustainable growth. A bioeconomy for Europe*. http://bookshop.europa.eu/en/innovating-for-sustainable-growth-pbKI3212262

European Commission. (2013). *Options for strengthening responsible research and innovation: Report of the expert group on the state of art in Europe on responsible research and innovation*. https://ec.europa.eu/research/science-society/document_library/pdf_06/options-for-strengthening_en.pdf

European Commission. (2014). *Bioeconomy information system and observatory project*. Set up of the Bioeconomy Observatory. Methodology Report. https://biobs.jrc.ec.europa.eu

European Commission. (2015). *The Paris Protocol – A blueprint for tackling global climate change beyond 2020*. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1425546396765&uri=COM:2015:81:FIN

European Commission. (2018). *Financing sustainable growth*. European Commission Action Plan. https://ec.europa.eu/info/sites/info/files/180308-action-plan-sustainable-growth-factsheet_en.pdf. Accessed 05 Sept 2019.

E&Y Report (Ernst and Young). (2014). *1% für die Zukunft. Innovation zum Erfolg bringen*. Deutscher Biotechnologie-Report 2014. https://www.ey.com/Publication/vwLUAssets/ey-biotech-report-2014-1-prozent-fuer-die-zukunft/$FILE/ey-biotech-report-2014-1-prozent-fuer-die-zukunft.pdf. Accessed 05 Sept 2019.

Figueres, C. (2011). *CEO sustainability fourm*. Address by Christiana Figueres, Executive Secretary

United Framework Convention on Climate Change. https://unfccc.int/files/press/statements/application/pdf/110926_speech_ceo_sustainability.pdf. Accessed 05 Sept 2019.

Fischer-Kowalski, M., von Weizsäcker, E. U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Kemp, R., Romero Lanko, P., & Siriban Manalang, A. B. (2014). *Decoupling natural resource use and environmental impacts from economic growth: Report of the Working Group on Decoupling to the International Resource Panel*. http://www.gci.org.uk/Documents/Decoupling_Report_English.pdf. Accessed 16 Sept 2019.

FNG, Berlin. (n.d.). *Forum Nachhaltige Geldanlagen, Fachverband für Nachhaltige Geldanlagen in Deutschland, Österreich, Liechtenstein und Schweiz*. https://forum-ng.org/de

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. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy, 33*(6–7), 897–920.

Geels, F. W. (2005). *Technological transitions and system innovations: A co-evolutionary and socio-technical analysis*. Elgar.

Geels, F. W. (2006). *System innovations and transitions to sustainability: Challenges for innovation theory*. Paper, presented at the SPRU 40th Anniversary Conference, 11–13 September 2006.

German Presidency of the Council of the European Union. (2007). *En route to the knowledge-based bio-economy*. https://dechema.de/dechema_media/Downloads/Positionspapiere/Cologne_Paper-p-20000945.pdf

Grin, J., Rotmans, J., & Schot, J. (2010). *Transitions to sustainable development: New directions in the study of long term transformative change*. Routledge.

Hanke, U. (2012). *Trendsetter Deutschland: Energiewende wird zum Kondratieff-Zyklus*. Wirtschaftswoche 15.06.2012. https://www.wiwo.de/politik/konjunktur/trendsetter-deutschland-energiewende-wird-zum-kondratieff-zyklus/6756334.html. Accessed 16 Sept 2019.

Hauschildt, J., Salomo, S., Schultz, C., & Kock, A. (2016). *Innovationsmanagement* (6. Aufl.). München.

Heiden, S., & Zinke, H. (2006). *Weiße Biotechnologie – Industrie im Aufbruch*. BIOCOM AG.

Heiden, S., Burschel, C., & Erb, R. (2001). *Biotechnologie als interdisziplinäre Herausforderung*. Spektrum Akademischer Verlag.

Hennicke, P. (2010). *Ressourcen- und Klimaschutz: Ökologischer Imperativ und ökonomischer Megatrend?* Wuppertal Papers 183. Wuppertal Institut für Klima, Umwelt, Energie. http://epub.wupperinst.org/frontdoor/deliver/index/docId/3623/file/WP183.pdf. Accessed 05 Aug 2019.

IIT (Institut für Innovation und Technik). (n.d.). *SystemInnovation*. www.iit-berlin.de/de/themenfelder/systeminnovationen. Accessed 05 Aug 2019.

Kompetenzzentrum Biointelligenz. (2019). *Die Biointelligente Wertschöpfung*. White Paper des Kompetenzzentrums Biointelligenz. Fraunhofer. https://www.iao.fraunhofer.de/images/iao-news/bio-intelligenz.pdf

Mietzsch, A. (2018). Biotechnologie: Wo bleibt die industrielle Revolution? In A. Mietzsch (Ed.), *BioTechnologie Jahr 2018* (pp. 33–42). BIOCOM AG.

Müller, A. (2010). Theorie der langen Wellen: Das Comeback von Kondratieff. *Handelsblatt* 18.04.2010. https://www.handelsblatt.com/politik/konjunktur/oekonomie/nachrichten/theorie-der-langen-wellen-das-comeback-von-kondratieff/3414216.html?ticket=ST-5480308-XddoQ4moHhjGNZp7sTMj-ap5

NSF Directorate for Engineering. (2010). *The role of the National Science Foundation in the innovation ecosystem*. https://www.nsf.gov/eng/iip/innovation.pdf

OECD (Organisation for Economic Co-operation and Development). (1998). *Biotechnology for clean industrial products and processes – Towards industrial sustainibility*. http://www.oecd.org/science/emerging-tech/1895218.pdf

OECD (Organisation for Economic Co-operation and Development). (2005). *The measurement of scientific and technological activities: Proposed guidelines for collecting and interpreting innovation data*. Oslo manual, third edition' prepared by the working party of national experts on scientific and technology indicators. http://www.oecd.org/science/inno/2367614.pdf

OECD. (2009). *Strategiepapier "The Bioeconomy to 2030. Designing a Policy" OECD 2010*. http://www.oecd.org/document/18/0,3343,en_2649_34537_44776082_1_1_1_100.html

Rennings, K. (2000). Redefining innovation – Eco innovation research and the contribution from ecological economics. *Ecological Economics, 32*(2), 319–332.

Röpke, J., & Stiller, O. (Eds.). (2006). *Theorie der wirtschaftlichen Entwicklung: Nachdruck der 1. Auflage von 1912*. Duncker & Humblot.

Schumpeter, J. A. (2006). *Theorie der wirtschaftlichen Entwicklung: Nachdruck der ersten Auflage von*

1912. Berlin: Duncker & Humblot. Herausgegeben und ergänzt um die Einleitung von Jochen Röpke und Olaf Stiller (Erstveröffentlichung 1911).

Schumpeter, J. A. (2008). *Capitalism, socialism and democracy*. New York: Routledge. (Erstveröffentlichung 1942).

SRU (Sachverständigenrat für Umweltfragen). (2013). *Sondergutachten – Den Strommarkt der Zukunft gestalten*. https://www.umweltrat.de/SharedDocs/Downloads/DE/02_Sondergutachten/2012_2016/2013_10_SG_Strommarktdesign_Eckpunktepapier.pdf?__blob=publicationFile&v=4

Stern, N. (2006). *The economics of climate change. The Stern review*. Cambridge University Press.

Stern, N. (2009). *A blueprint for a safer planet. How to manage climate change and create a new era of progress and prosperity*. Bodley Head.

Stifterverband für die deutsche Wirtschaft. (2016). *Forschung und Entwicklung in der Wirtschaft 2016*. https://www.stifterverband.org/forschung-und-entwicklung/fue-erhebung-2016#branchen

The Economist. (2015). *The process of invention. Now and then*. https://www.economist.com/science-and-technology/2015/04/25/now-and-then. Accessed 16 Sept 2019.

Thomas, R., & Ford, D. (1995). Technology and networks. In K. Möller & D. Wilson (Eds.), *Business marketing: An interaction and network perspective* (pp. 263–290). Kluwer.

UNWCED: United Nations World Commission on Environment and Development (1987): Our Common Future (Brundtland Report).

Vahs, D., & Brem, A. (2015). *Innovationsmanagement: Von der Idee zur erfolgreichen Vermarktung* (5th ed.). Schäffer-Poeschl.

WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen). (2011). *Hauptgutachten – Welt im Wandel. Gesellschaftsvertrag für eine große Transformation*. https://issuu.com/wbgu/docs/wbgu_jg2011?e=37591641/69400318

Zahn, E., & Weidler, A. (1995). Integriertes Innovationsmanagement. In E. Zahn (Ed.), *Handbuch Technologiemanagement* (pp. 351–376). Schäfer-Poeschel.

Zapf, W. (1994). Über Soziale Innovationen. *Soziale Welt, 40*, 170–183.

Zinke, H., El-Chichakli, B., Dieckhoff, P., Wydra, S., & Hüsing, B. (2016). *Bioökonomie für die Industrienation. Ausgangslage für biobasierte Innovationen in Deutschland verbessern*. Bioökonomierat. https://biooekonomierat.de/fileadmin/Publikationen/berichte/Hintergrundpapier_ISA_Vero__ffentlichung.pdf

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19

Scenarios and Models for the Design of a Sustainable Bioeconomy

Rüdiger Schaldach and Daniela Thrän

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_19

19.1 Introduction

Scenarios are stories about the future that are intended to help us make current decisions. They pose hypothetical consequences of developments and events in order to draw attention to causal processes and decision-making moments. Stories of the future, by their very nature, handle many unknowns and their interactions. Moreover, various interactions can cancel each other out or reinforce each other: a defining example for Germany is the developments that ultimately led to the opening of the inner-German border. These were driven by mutually reinforcing political, economic, but also ecological, social and other factors. The effect – the opening of the border – was nevertheless very unexpected for almost all decision-makers.

In order to obtain an idea of the future – desired or also undesired – bioeconomy system, it is therefore necessary not only to have stories about the future, but also to underpin them with as precise a description as possible of the elements determining the system and their interactions. In the past, various system descriptions and system models have been developed based on this insight. Today, for example, processes in the Earth's climate system can be reproduced and better understood using highly complex mathematical Earth system models (Hurrell et al., 2013).

This chapter provides an overview of how the scenario technique can be applied to the bioeconomy system (► Sect. 19.2) and which models are available for describing the bioeconomy in order to specify the images of the future (► Sect. 19.3). In conclusion, the contribution that scenarios and models can make to supporting the sustainable design of the bioeconomy is classified (► Sect. 19.4).

19.2 Bioeconomy Scenarios

19.2.1 Basic Ideas of Scenario Development

Originally developed in military technology, scenario technology is a method of strategic planning, forecasting, but also impact assessment used in politics, science and business (Kosow & Gaßner, 2008). The aim is to analyse possible developments of the future and to present them in a coherent way. Alternative future situations are described, as well as paths leading to these future situations. In addition to showing how a hypothetical situation can come about in the future, variants and alternatives are presented and the options available at each stage for different actors to control the process going forward are shown. In this framework, the scenario technique aims in particular at

- the analysis of extreme future developments (positive or negative **extreme scenarios**)
- or particularly relevant images of the future or images that reflect current trends **(trend scenario).**

The type of scenario depends on the question to be answered.

In national and international policy, both types of scenarios have become established in recent years. In the field of climate and energy scenarios, for example, trend and target scenarios are contrasted: The former examine, for example, climate gas emissions if society would just continue its current activities regarding their (non-)reduction *(business as usual),* while target scenarios attempt to show ways in which, for example, Germany could operate in a climate-neutral manner by 2050. From this, concrete political recommendations for action can be derived that are necessary to achieve these goals.

For the bioeconomy, where the goals are still much more vaguely defined, what is needed are more explorative scenarios that first describe the possible impacts of certain developments and events. Political recommendations for action can also be derived from explorative scenarios, e.g. for dealing with biomasses that will be in particular demand in the future, but also for supporting the market entry of new products and services. Such scenarios are available, for example, for bioenergy policy in Germany (Thrän et al., 2017).

To arrive at scenarios, the first step is to roughly outline future development paths. In a second step, the factors that will have a central influence on the future are identified. These are, for example, population development, dietary habits, changes in land use or internet access in the population. For more complex, longer-term scenarios, the factors are often derived from background stories (so-called storylines), such as: “The role of the state is decreasing, there is a rapid globalization of the economy.” Subsequently, the development or development possibilities of these factors are projected in order to create future scenarios combinatorially from the possible development lines of the factors.

In order to pay sufficient attention to the main scenarios, inconsistent combinations are excluded (e.g. increasing drought and at the same time strongly increasing biomass production), similar scenarios are combined and the influencing variables that shape the future most strongly because they are very weighty and/or very uncertain are systematically derived (Jordan et al., 2019). The result is a set of development possibilities that funnel a kind of future space and do not reflect an exact picture of the future (◘ Fig. 19.1). In some cases, these are still classified and evaluated.

19.2.2 What Scenarios Are Conceivable for the Bioeconomy?

Bioeconomy scenarios can be used to explore the future and to bundle the many uncertainties into larger pictures of the future. These uncertainties include, for example, the availability of land, the usability for biomass production, the demand for food and especially meat, the demand for substitute products of the petrochemical and energy industries. Furthermore, future technological progress plays a central role, both for efficiency improvements along the chain (biomass production, processing and use) and for the market establishment of new products of biotechnology and synthetic biology. Finally, a more sustainable approach to nature and the implementation of the Sustainable Development Goals (SDGs), which include, for example, changes in human behaviour and consumption, can have a strong impact on the future (Nilsson & Costanza, 2015).

The factors influencing the development of tomorrow’s world are also referred to as drivers. They are wide-ranging for the bioeconomy and can differ depending on the issue. ◘ Figure 19.2 provides an overview of selected important drivers. For scenarios on further development in Germany, major global developments are usually adopted as boundary conditions. Established assumptions are also used for economic performance. For the bioeconomy-specific scenario assumptions, it is possible on the one hand to derive concrete developments for various scenarios (e.g. agricultural developments), but on the other hand integrated models are required (▸ Sect. 19.3) in order to arrive at estimates here. Even if scenarios claim to represent the range of future developments

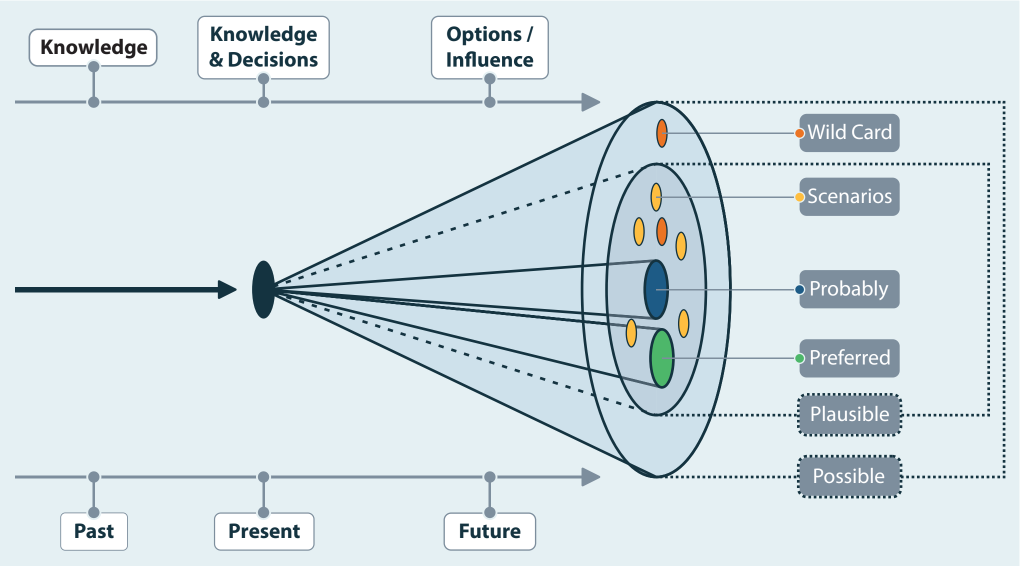

Fig. 19.1 The "future cone". There could be four different types of alternative futures: possible, plausible, probable and preferred – also called "the 4Ps". (Source: Own representation according to Kosow & Gaßner, 2008, p. 133)

in their possible breadth, extreme individual events (e.g. nuclear accidents), but also cultural changes (e.g. a move away from the knowledge society) and the associated impacts on the development of all other drivers are generally not taken into account, or only incompletely, because they are less easy to describe in terms of their causal relationships and dynamics and their impacts are hardly quantifiable.

19.2.3 Development of Sorylines as an Element of Scenario Design

The 15 drivers shown in Fig. 19.2 cannot all be displayed (third column of the table). However, the number of options becomes immeasurable even with far fewer drivers: If, for example, one alternative of two possible developments is assumed for each of ten drivers, this would result in 2^{10}, i.e. 512 possible scenarios. This not only involves a considerable amount of analysis and calculation, but is also beyond our imagination. In addition, the "haphazard" combination of development options also generates highly improbable scenarios (e.g. high demand for food due to meat consumption, low increases in agricultural yields and a high proportion of protected areas).

One way to create a manageable number of scenarios without reducing the number of drivers from the outset is to design narratives ("storylines"). One conceives a story of the future and modifies the drivers to fit this story. Narratives for the bioeconomy might be, for example, "The world is generally changing little, and the bioeconomy is making slow progress." Or, "Through very rapid and large technological advances, innovation richness, and rapid investment, society also provides very good development conditions for bioeconomy progress." Or: "Due to fragmentation and less democratic developments in many countries, a decentralized bioeconomy focused on domestic needs is developing in particular."

Population	Population and age distribution trends due to births, deaths and migration.	Is usually taken from large (international) scenarios (e.g. climate scenarios).
World Politics	Development of democratic systems, international exchange, competition and peacekeeping.	Usually taken from large international scenarios (e.g. climate scenarios).
Climate change	Development of temperature change, effects and measures for climate protection.	Usually taken from large international scenarios (e.g. climate
Economic performance	Development of the gross domestic product or comparable parameters.	Usually adopted from large national scenarios (e.g. Dellink et al. 2017).
Energy demand	How will the energy transition develop? Is energy generation decentralized or centralized? How much energy comes from biomass?	Specific assumptions for bioeconomy necessary on the basis of the energy scenarios
Technology development	How will the energy transition develop? Is energy generation decentralized or centralized? How much energy comes from biomass?	Specific assumptions for bioeconomy necessary on the basis of the energy scenarios
Agriculture	How is biomass produced (intensively or extensively) and what area-specific yields are associated with it?	Specific assumptions needed for bioeconomy
Forestry	How is forest management developing and what timber yields are associated with it?	Specific assumptions needed for bioeconomy
Protected areas	To what extent will land and water areas be protected?	Specific assumptions needed for bioeconomy
Nutrition	Which foods are consumed and to what extent? What is the range of dietary patterns?	Specific assumptions needed for bioeconomy
Goods consumption & recycling	How is resource efficiency developing? What is the nature and extent of the consumption of goods? Where are recycled materials used?	Specific assumptions needed for bioeconomy
Trade	To what extent are which goods traded? Which effects in third countries are caused by imports?	Only displayable via integrated models
Land use	How much land is available for biomass production? Which types of biomass cultivation are preferred?	Only displayable via integrated models
Water	How much water is available for the production of biomass? How does this affect land use and agriculture?	Only displayable via integrated models
Culture and values	What values determine people's behavior? How does this affect all the other influencing factors?	Usually not taken into account

Fig. 19.2 Factors influencing bioeconomy scenarios. (Source: Own representation)

19.2.4 Bioeconomy Scenarios for Germany and Europe

Bioeconomy scenarios were developed at European level to align the research and innovation agenda of the bioeconomy in Europe until 2050 with the key challenges (Mathijs et al., 2015). Future biomass supply growth and biomass demand growth for materials and energy were identified as particularly large uncertainties. For a growing biomass supply, the introduction of new technologies and the intensification of production were seen as key influencing factors. The growing demand for biomass for materials and energy was driven by general economic developments, but also by alternative options, i.e. the persistence of fossil raw materials and the availability of alternative renewable energies such as wind and photovoltaics.

Three different scenarios were defined in which the influencing variables develop differently and which are associated with different supply and demand quantities and qualities: a scenario with modest biomass supply and moderate biomass demand ("modest biomass supply"), a scenario in which supply and demand increase strongly ("bio-boom"), and a scenario in which demand increases but supply does not increase because new technologies do not develop to the necessary extent ("bio-scarcity"). Key parameters and characteristics of the three scenarios are summarized in ◘ Fig. 19.3. The scenario results show, for example, that if the supply of biomass increases slightly and demand increases strongly at the same time, on the one hand the demand cannot be met due to the high raw material prices and that additional policy measures are necessary to reduce negative side effects on land use (ibid.).

Comparable bioeconomy scenarios are not yet available for Germany. However, they are being developed from different perspectives. The most prominent German projects for the development of bioeconomy scenarios in recent times were "Scenarios of a Bioeconomy 2050 – Potentials, Conflicts of Objectives, Solution Strategies", which was led by the Thünen Institute for Market Analysis,[1] and "Future Pictures from the Life of a Bioeconomy (BioKompass)", which was led by Fraunhofer ISI.[2] First results were published by 2020 (e.g. Banse et al., 2020).

In the future, bioeconomy scenarios will increasingly have to be measured by the extent to which they have taken into account the expectations and preferences of the various bioeconomy actors in scenario development, and the extent to which they are also able to map the interactions and conflicting goals that will arise in the future in such a way that action knowledge can be derived from them. A central question here is how to deal with globally limited land and the biomasses produced on it, and what influence these limits should have or will have on national bioeconomy development strategies (Bringezu et al., 2021; Egenolf & Bringezu, 2019; O'Brien et al., 2015). For this purpose, integrated modelling in particular represent a promising tool.

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[1] For more information see ► https://www.thuenen.de/de/institutsuebergreifende-projekte/szenarien-einer-biooekonomie-2050-potenziale-zielkonflikte-loesungsstrategien/

[2] For more information see ► https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccv/2018/Zukunftsbilder_BioKompass_Langfassung.pdf

Scene title	Organic shortage	Modest Organic Offer	Organic Boom
Biomass supply (in billion t/year)	Low (13)	Medium (18)	Large (24)
Demand for materials and energy	Strong (plus 100 %)	Low (plus 50 %)	Strong (plus 100 %)
Demand for food and feed	According to FAO (plus 19 %)	According to FAO (plus 19 %)	According to FAO (plus 19 %)
R&D investment	Low (linked e.g. to public resistance to novel foods)	Necessary (associated with e.g. relatively low pressure to use bio-based innovations)	High (linked e.g. to public acceptance of novel foods)
Energy supply/ materials production	Still heavy use of fossil fuels; bio-based industries are established	More extensive use of solar & wind energy and other clean energy types	Biowaste is, among other things used for the production of bioenergy, fuels and materials
Effects on the areas	More land is being used for biomass production and high prices for agricultural commodities, combined with land grabbing and geopolitical tensions	Materials and energy can be produced sustainably	Breakthrough innovations, such as the use of new sources of biomass, e.g. insects and the marine environment, enable the sustainable provision of all biomasses.

Fig. 19.3 Scenarios to guide the research and innovation agenda of the bioeconomy in Europe 2050. Quantities refer to the year 2050; changes to the development 2015 to 2050. The biomass supply in 2015 was estimated to be about 12 billion t. (Source: Presentation of selected aspects based on: Mathijs et al., 2015)

19.3 Models for the Representation of the Bioeconomy

19.3.1 Basic Ideas of System Models

In systems science, a system is defined in simplified terms as an object in the real world that fulfils a specific purpose (Bossel, 1994). It is thus determined by a number of system elements that define its structure and its behaviour, which results from the interactions between these elements and the influences of external factors. With reference to the "bioeconomy circle", which describes the bioeconomy system in simplified form, the central system elements are markets, business/industry, resource providers and *end-of-life management*. These interact with each other and with the various framework actors. Models are simplified representations of a section of the real world. In this chapter, we understand "model" to mean the mathematical description of the structure and function of the "bioeconomy" system or of partial aspects of this system. Analogous to laboratory experiments in the natural sciences, mathematical models enable experiments (= calculations or simulations) to be carried out, for example on the behaviour of the modelled system under changing boundary conditions, without changing or even damaging the real system. A prominent example is the use of Earth system models to analyse the extent to which man-made greenhouse gas emissions influence the global climate (Anderson et al., 2016).

The question therefore arises as to how the bioeconomy system – in its current form but also in its various future images (scenarios) – can be modelled. The Bioeconomy Circle shows that a model-based representation of the structure and function of the bioeconomy system requires an overarching view of social, economic, political, technical and ecological processes, actors and their interactions. A model approach that represents this system in its entirety does not yet exist, but there are very mature models for individual areas and aspects that can be combined in different ways to answer specific questions in the context of the bioeconomy (O'Brien et al., 2017). The following sections first focus on modelling approaches for the domains of economy (markets and business/industry), land use and environment (resource providers) and for integrated modelling and analysis of interactions between these domains. Subsequently, models for the analysis of material flows between the central system elements of the bioeconomy and the resulting environmental impacts are presented.

19.3.1.1 Economic Models

Econometric models can be divided into macroeconomic and microeconomic approaches. The former describe the interplay of supply and demand at the level of national economies and aim at the global analysis of the effects of events, e.g. in the form of tariffs or a change in demand for goods, on the development of markets and trade flows. The most important representatives are computable numerical equilibrium models, which either cover the entire economy (CGE = Computable General Equilibrium Models) or only individual economic sectors.

Overall economic models have the advantage that interactions between different economic sectors can be mapped. Possible applications in relation to the use of biomass in the context of the bioeconomy can be found in market analyses of the food and bioenergy sectors, among others. A critical aspect of the application for mapping biomass flows is the comparatively coarse aggregation of products and raw materials (e.g. wood, agricultural goods). At the core of many CGE models is the Global Trade Analysis Project (GTAP) modeling approach (Aguiar et al., 2016). Models such as MAGNET (Woltjer & Kuiper, 2014) and MIRAGE (Bchir et al., 2002) extend this core with specific components, for example to analyze the environmental impacts of biofuels (Laborde & Valin, 2012).

In the area of sector-specific models, approaches for agriculture, forestry and energy are of particular interest for the bioeconomy. The level of detail of the products and sub-markets considered is in many cases much higher than in the overall economic models; precisely with the problem that there is no link to other sectors, which is problematic for the consideration of a bioeconomy, as strong linkages can arise in this case in particular, e.g. between agriculture, the energy industry and the chemical industry.

Microeconomic models represent decisions at the level of individuals, such as a person, a household, a company or a farm, often according to the premise of utility maximization. Agent-based modelling approaches are often used here, which enable simulation of the interactions between the individual and the resulting dynamic development, such as land use within a region (Matthews et al., 2007). Numerous publications document examples of the combination of these models with environmental models (An, 2012). Applications with relevance for the bioeconomy range from questions on technology and innovation diffusion to the analysis of the development of rural areas under changed political and economic conditions.

19.3.1.2 Land Use Models

Spatial allocation models for calculating land use changes play an important role in linking macroeconomic models and environmental models (Schaldach & Priess, 2008). They place agricultural and forestry production on a spatial grid and thus enable a detailed analysis of possible environmental impacts or the influence of environmental changes on market prices of agricultural goods, for example through negative impacts of climate change on crop yields. Examples of global models are ClueMondo (van Asselen & Verburg, 2013) and LandSHIFT (Schaldach et al., 2011).

19.3.1.3 Environmental Models

In the field of environmental models, a variety of different approaches can be found. Empirical environmental models are data-driven and mathematically establish a functional relationship between input and output data. Examples include approaches to calculate biological carbon storage as a function of climate, soil and management (Eggleston et al., 2006) and to determine biodiversity loss through land use (Alkemade et al., 2009; Newbold et al., 2015). In contrast, process-oriented models aim to simulate processes within real environmental systems (e.g. Rosenzweig et al., 2014). Compared to empirical approaches, they are much more data-intensive and their development and operation require considerably more effort. Process-oriented models cover a broad thematic spectrum, from soil-water-plant interactions in natural and managed ecosystems (e.g. Bondeau et al., 2007) to water fluxes (Arnold et al., 2012) to regional and global weather and climate patterns (McGuffie & Henderson-Sellers, 2005). Both types of environmental models are also used in combination with economic models. In relation to the bioeconomy system, environmental models are particularly relevant for describing crop yields under changing climate conditions and environmental impacts, such as deforestation for the establishment of new agricultural land or the discharge of nutrients and pollutants into water bodies by industrial processes or agriculture (business/industry, resource providers).

19.3.1.4 Integrated Models

The aim of integrated models is to represent economic processes, technical processes and environmental processes and their interactions on different spatial and temporal scales (Rotmans & van Asselt, 2001). An overview of existing integrated models is given by Stanton et al. (2009). At the technical level, this integration can be achieved by formulating the entire model using a unified mathematical approach or by coupling existing models (Hamilton et al., 2015). In the latter case, a key challenge is to provide a consistent database for all models involved as well as to implement appropriate communication channels between the models. An important representative for the second group of integrated models is the IMAGE model (Stehfest et al., 2014), which couples process-based environmental models on climate and plant growth, among others, with econometric model approaches for the energy and agricultural sectors. IMAGE aims at global analyses, with calculations at the level of world regions as well as on a geographical grid. The model is used in the field of policy advice, for example in the analysis of the consequences of anthropogenic climate change and the calculation of scenarios of future greenhouse gas emissions.

In the context of the bioeconomy, further examples are the global models GLOBIOM (Havlík et al., 2011) and MagPie (Lotze-Campen et al., 2008). Both couple an economic model for the agricultural sector with plant growth models, among other things, in order to simulate the influences of climate change on crop yields as well as the effects of a change in biomass demand on land use and the resulting environmental changes on a geographical grid.

19.3.1.5 Life Cycle Assessment Models

Life cycle assessments aim to analyse the environmental impacts along the entire life cycle of a product or service; from raw material extraction through production and use to disposal or recycling. They are usually based on a material and energy flow model that describes the individual processes involved in terms of their input and output variables. In the context of the bioeconomy system, these can play an important role, for example, in the certification of products, or the sustainable design of supply chains (O'Brien et al., 2017). Examples include studies on the sustainability of biofuels or of bio-based lubricants (e.g. Miller et al., 2007; Zah et al., 2009).

19.3.2 What Can Models Achieve in the Context of the Bioeconomy?

The model approaches presented are in their essence scientific instruments that enable researchers to formalise their knowledge of the bioeconomy system and to verify and expand it through experiments. Furthermore, models can play a central role in establishing a sustainable bioeconomy by providing valuable information to support decision-making processes for actors in politics and business, but also for consumers. Using examples from the fields of economics and the environment, it was possible to demonstrate that it is already possible with existing models to make well-founded statements on various sub-aspects of the bioeconomy system, for example on the development and associated environmental impacts of agriculture and forestry at national and international level, which can then be incorporated into the evaluation and design of policies. A very interesting example in this respect is the debate on indirect land use change and its impact on the greenhouse gas balance of biofuels through the cultivation of energy crops, which has been largely driven and supported by the results of modelling studies (Laborde & Valin, 2012; Lapola et al., 2010). In particular, integrated models can make an important contribution to the development of a deeper cross-disciplinary understanding of how different processes interact. The successful use of integrated models at the level of international climate policy indicates a high potential as an analytical tool also in the bioeconomy context. At the level of companies or products, life cycle assessments can provide valuable information for the sustainable design of supply and value chains. It should be noted at all levels that, particularly in the case of complex models, transparent documentation of the results and how they were obtained must be provided in order to ensure acceptance of the results by users (Uusitalo et al., 2015). In order to be able to evaluate the robustness of the model results, extensive tests on uncertainties due to the data basis used and the model structure are therefore necessary.

An important field of application for models are the scenario analyses already discussed in this chapter, which can be used to examine future development paths and their effects on society and the environment. These scenarios can include assumptions on policies, consumption patterns and framework conditions of international trade as well as assumptions on climate change. Examples range from analyses of the development potential of an agriculturally dominated region to future development paths of biomass requirements of an economy and the environmental impacts associated with its production, to support for the development of national and international strategies for a sustainable design of the bioeconomy in the context of a societal transformation process. There are a number of mature approaches to developing scenarios in the sense of co-design, i.e. through the collaboration of scientists, actors and stakeholders, initially in the form of narratives and then underpinning them with numerical model results or testing their plausibility (Alcamo, 2008).

The use of models within the framework of a system for monitoring the sustainability of the German bioeconomy promises another interesting contribution to the sustainable design of the bioeconomy at national level (O'Brien et al., 2017). In this framework, the calculation of so-called resource footprints can play a central role for the assessment of environmental impacts (Bringezu et al., 2021; Tukker et al., 2016) These describe the local and global environmental impacts of the consumption of a household, a region or, in this case, a nation. In these analyses, databases on trade flows of biomass and intermediate products, which are used in a similar form in macroeconomic models, are linked with land use and environmental models for the detailed location and quantification of the use of land and water resources in the regions of origin of the biogenic raw materials (Mekonnen & Hoekstra, 2011; O'Brien et al., 2015).

There is currently still a considerable need for research and development in order to integrate all aspects relevant to the bioeconomy into models. For example, factors such as technological change, a changing demand for biomass or aspects of the circular economy are not represented in economic and integrated models to a sufficiently detailed degree. Social aspects such as acceptance of technologies or demographic change are given as exogenous variables, e.g. in the form of scenario assumptions, and are not explicitly modelled. In particular, when mapping biomass flows in technical processes, there is a large gap between the very detailed methods of life cycle assessment and their representation in economic or integrated models. On the other hand, the increasing availability of high-resolution remote sensing and other environmental data, for example on biodiversity (Hudson et al., 2014), offers great potential for further developments, especially for environmental and land use modelling, which can be applied in the context of the bioeconomy.

Conclusion

The above examples have shown that scenarios and models can be valuable instruments for generating knowledge and supporting decision-making processes aimed at sustainable development of the bioeconomy. While in the case of the model approaches the bioeconomy system can be mapped in increasing detail through the gradual expansion of existing models, scenario development requires above all the social debate on future images of the bioeconomy. They provide orientation in shaping the paths to the future, for example which resources can be expected to be available and to what extent, or what efforts are necessary for a climate-neutral bioeconomy.

Scenarios and models geared to the bioeconomy system can provide basic decision-making support. In addition, they can also be used to regularly describe the impacts of developments in the bioeconomy and to put them to the test, e.g. in the context of monitoring (▶ Chap. 20).

References

Aguiar, A., Narayanan, B., & McDougall, R. (2016). An overview of the GTAP 9 data base. *Journal of Global Economic Analysis, 1*(1), 181–208.

Alcamo, J. (2008). Chapter six the SAS approach: Combining qualitative and quantitative knowledge in environmental scenarios. *Developments in Integrated Environmental Assessment, 2*, 123–150.

Alkemade, R., Van Oorschot, M., Miles, L., Nellemann, C., Bakkenes, M., & ten Brink, B. (2009). GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. *Ecosystems*. https://doi.org/10.1007/s10021-009-9229-5

An, L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling, 229*, 25–36.

Anderson, T. R., Hawkins, E., & Jones, P. D. (2016). CO2, the greenhouse effect and global warming: From the pioneering work of Arrhenius and Callendar to today's earth system models. *Endeavour*. https://doi.org/10.1016/j.endeavour.2016.07.002

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, D., van Griensven, A., van Liew, M. W., Kannan, N., & Jha, M. K. (2012). SWAT: Model use, calibration, and validation. *Transactions of the ASABE, 55*(4), 1491–1508.

Banse, M., Zander, K., Babayan, T., Bringezu, S., Dammer, L., Egenolf, V., Göpel, J., Haufe, H., Hempel, C., Hüfner, R., Millinger, M., Morland, C., Musonda, F., Partanen, A., Piotrowski, S., Schaldach, R., Schier, F., Schüngel, J., Sturm, N., Thrän, D., Weimar, H., Wilde, A., Will, S. (2020). Eine Biobasierte Zukunft in Deutschland - Szenarien und Gesellschaftliche Herausforderungen. *Johann Heinrich von Thünen-Institut, Braunschweig*. https://www.thuenen.de/media/institute/ma/Downloads/BEPASO-Broschuere.pdf. Accessed 01 Sept 2019.

Bchir, H., Decreux, Y., Guérin, J. L., & Jean, S. (2002). MIRAGE, a computable general equilibrium model for trade policy analysis. *CEPII*. https://www.gtap.agecon.purdue.edu/resources/download/1256.pdf. Accessed 01 Sept 2019.

Bondeau, A., Smith, P. C., Zaehle, S., Schaphoff, S., Lucht, W., Cramer, W., Gerten, D., Lotze-Campen, H., Müller, C., Reichstein, M., & Smith, B. (2007). Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Change Biology, 13*(3), 679–706.

Bossel, H. (1994). *Modellbildung und Simulation: Konzepte, Verfahren und Modelle zum Verhalten dynamischer Systeme; ein Lehr-und Arbeitsbuch*. Vieweg.

Bringezu, S., Distelkamp, M., Lutz, C., Wimmer, F., Schaldach, R., Hennenberg, K. J., Böttcher, H., & Egenolf, V. (2021). Environmental and socioeconomic footprints of the German bioeconomy. *Nature Sustainability, 1-9*. https://doi.org/10.1038/s41893-021-00725-3

Egenolf, V., & Bringezu, S. (2019). Conceptualization of an indicator system for assessing the sustainability of the bioeconomy. *Sustainability, 11*(2), 443.

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). *Intergovernmental panel on climate change guidelines for national greenhouse gas inventories, intergovernmental panel on climate change*. IPCC Secretariat.

Hamilton, S. H., ElSawah, S., Guillaume, J. H. A., Jakeman, A. J., & Pierce, S. A. (2015). Integrated assessment and modelling: Overview and synthesis of salient dimensions. *Environmental Modelling and Software*. https://doi.org/10.1016/j.envsoft.2014.12.005

Havlík, P., Schneider, U. A., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., Aoki, K., De Cara, S., Kindermann, G., Kraxner, F., Leduc, S., McCallum, I., Mosnier, A., Sauer, T., & Obersteiner, M. (2011). Global land-use implications of first and second generation biofuel targets. *Energy Policy*. https://doi.org/10.1016/j.enpol.2010.03.030 .

Hudson, L. N., Newbold, T., Contu, S., Hill, S. L. L., Lysenko, I., De Palma, A., … Purvis, A. (2014). The PREDICTS database: A global database of how local terrestrial biodiversity responds to human impacts. *Ecology and Evolution, 4*(24), 4701–4735.

Hurrell, J. W., Holland, M. M., Gent, P. R., Ghan, S., Kay, J. E., Kushner, P. J., … Marshall, S. (2013). The community earth system model: A framework for collaborative research. *Bulletin of the American Meteorological Society, 94*(9), 1339–1360.

Jordan, M., Lenz, V., Millinger, M., Oehmichen, K., & Thrän, D. (2019). Future competitive bioenergy technologies in the German heat sector: Findings from an economic optimization approach. *Energy, 189*, art. 116194. https://doi.org/10.1016/j.energy.2019.116194

Kosow, H., & Gaßner, R. (2008). *Methods of future and scenario analysis: Overview, assessment, and selection criteria*. DIE Studies 39. Bonn: Deutsches Institut für Entwicklungspolitik. https://www.ssoar.info/ssoar/handle/document/19366 . Accessed 01 Sept 2019.

Laborde, D., & Valin, H. (2012). Modeling land-use changes in a global CGE: Assessing the EU biofuel mandates with the MIRAGE-BioF model. *Climate Change Economics, 3*(03), 1250017.

Lapola, D. M., Schaldach, R., Alcamo, J., Bondeau, A., Koch, J., Koelking, C., & Priess, J. A. (2010). Indirect land-use changes can overcome carbon savings from biofuels in Brazil. *Proceedings of the National Academy of Sciences, 107*(8), 3388–3393.

Lotze-Campen, H., Müller, C., Bondeau, A., Rost, S., Popp, A., & Lucht, W. (2008). Global food demand, productivity growth, and the scarcity of land and water resources: A spatially explicit mathematical programming approach. *Agricultural Economics, 39*(3), 325–338.

Mathijs, E., Brunori, G., Carus, M., Griffon, M., Last, L., Gill, M., Koljonen, M., Lehoczky, OI, & Potthast, A. (2015). *Sustainable agriculture, forerstry and fisheries in the bioeconomy – A challenge for Europe*. Standing Committee on Agricultural Research 4th Foresight Exercise.

Matthews, R. B., Gilbert, N. G., Roach, A., Polhill, J. G., & Gotts, N. M. (2007). Agent-based land-use models: A review of applications. *Landscape Ecology, 22*(10), 1447–1459.

McGuffie, K., & Henderson-Sellers, A. (2005). *A climate modelling primer*. Wiley.

Mekonnen, M., & Hoekstra, A. Y. (2011). *National water footprint accounts: The green, blue and grey water footprint of production and consumption*. Value of water research report No. 50. Delft: Unesco-IHE Institute for Water Education. https://ris.utwente.nl/ws/portalfiles/portal/5146137/Report50-NationalWaterFootprints-Vol1.pdf . Accessed 1 Sept.2019.

Miller, S. A., Landis, A. E., Theis, T. L., & Reich, R. A. (2007). A comparative life cycle assessment of petroleum and soybean-based lubricants. *Environmental Science and Technology, 41*(11), 4143–4149.

Newbold, T., Hudson, L. N., Hill, S. L., Contu, S., Lysenko, I., Senior, R. A., … Purvis, A. (2015). Global effects of land use on local terrestrial biodiversity. *Nature, 520*(7545), 45–50.

Nilsson, M., & Costanza, R. (2015). Overall framework for the sustainable development goals. In A.-S. Stevance (Ed.), *Review of targets for the sustainable development goals: The science perspective* (pp. 7–12). International Council for Science (ICSU), International Social Science Council (ISSC).

O'Brien, M., Schütz, H., & Bringezu, S. (2015). The land footprint of the EU bioeconomy: Monitoring tools. Gaps and needs. *Land Use Policy, 47*, 235–246.

O'Brien, M., Wechsler, D., Bringezu, S., & Schaldach, R. (2017). Toward a systemic monitoring of the European bioeconomy: Gaps, needs and the integration of sustainability indicators and targets for global land use. *Land Use Policy, 66*, 162–171.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., … Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences, 111*(9), 3268–3273.

Rotmans, J., & van Asselt, M. B. A. (2001). Uncertainty management in integrated assessment modeling: Towards a pluralistic approach. *Environmental Monitoring and Assessment, 69*(2), 101–130.

Schaldach, R., & Priess, J. A. (2008). Integrated models of the land system: A review of modelling approaches on the regional to global scale. *Living Reviews in Landscape Research, 1*, 1.

Schaldach, R., Alcamo, J., Koch, J., Kölking, C., Lapola, D. M., Schüngel, J., & Priess, J. A. (2011). An integrated approach to modelling land-use change on continental and global scales. *Environmental Modelling and Software, 26*(8), 1041–1051.

Stanton, E. A., Ackerman, F., & Kartha, S. (2009). Inside the integrated assessment models: Four issues in climate economics. *Climate and Development, 1*(2), 166–184.

Stehfest, E., van Vuuren, D., Kram, T., & Bouwman, L. (Eds.). (2014). *Integrated assessment of global environmental change with IMAGE 3.0: Model description and policy applications*. PBL Netherlands Environmental Assessment Agency.

Thrän, D., Arendt, O., Banse, M., Braun, J., Fritsche, U., Gärtner, S., Hennenberg, K. J., Hünneke, K., Millinger, M., Ponitka, J., Rettenmaier, N., Schaldach, R., Schüngel, J., Wern, B., & Wolf, V. (2017). Strategy elements for a sustainable bioenergy policy based on scenarios and systems modeling: Germany as example. *Chemical Engineering and Technology, 40*(2), 211–226.

Tukker, A., Bulavskaya, T., Giljum, S., de Koning, A., Lutter, S., Simas, M., Stadler, K., & Wood, R. (2016). Environmental and resource footprints in a global context: Europe's structural deficit in resource endowments. *Global Environmental Change, 40*, 171–181.

Uusitalo, L., Lehikoinen, A., Helle, I., & Myrberg, K. (2015). An overview of methods to evaluate uncertainty of deterministic models in decision support. *Environmental Modelling and Software, 63*, 24–31.

Woltjer, G. B., & Kuiper, M. H. (2014). *The MAGNET model: Module description* (S. 14–057). Wageningen: LEI Wageningen University & Research Centre, LEI Report.

van Asselen, S., & Verburg, P. H. (2013). Land cover change or land-use intensification: Simulating land system change with a global-scale land change model. *Global Change Biology, 19*(12), 3648–3667.

Zah, R., Faist, M., Reinhard, J., & Birchmeier, D. (2009). Standardized and simplified life-cycle assessment (LCA) as a driver for more sustainable biofuels. *Journal of Cleaner Production, 17*(1), 102–105.

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20

Monitoring the Bioeconomy

Daniela Thrän

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_20

20.1 Introduction

Decision making requires appropriate information: for the analysis of a situation, for the development of goals, for the planning and implementation of action steps and for their control. Information-based decisions ideally ensure the commitment of the persons dependent on a decision to the respective decision through their validity, reliability and objectivity. Information can be qualitative or quantitative. In order to collect, organise, correlate and prepare this information in such a way that it can be used for decision-making, systematic and established recording and evaluation is required, which is also referred to as a monitoring system. Monitoring systems ideally provide information that enables retrospectives and from which future expectations can be developed.

In times of digitalisation, the collection, processing and use of information is becoming increasingly powerful. However, the formulation of targeted questions and the organisation of information into indicators that specifically and comprehensively reflect the questions are crucial. In addition, monitoring must be "manageable", meet user-specific requirements and be designed for the long term so that information can be compared over a long period of time. Only in this way can strategies be developed on the basis of monitoring.

Monitoring systems exist in all conceivable areas of application. However, monitoring the bioeconomy system is associated with challenges that are described below:

20.2 Monitoring Systems for the Bioeconomy

The bioeconomy is highly complex due to its intersectoral processing and decision-making levels. If we want to make statements about the bioeconomy and use them as a basis for decision-making, we need a monitoring approach that can be used to generate reliable, transparent, supra-individual and data-based statements. However, to design and orgnise thoae monitoring approaches, attention needs to given to some basis questions: Who wants to measure something? Why should something be measured? How and what should be measured? And what statements should and want to be made on the basis of these measurements? These core questions are challenging in accordance with the diversity of the bioeconomy.

Monitoring a bioeconomy in Germany has aready established in certain sub-sectors, e.g. the monitoring of the energy transition provides information on the development of electricity generation from biomass (BMWi, 2018), biodiversity monitoring provides comparable data on the status of and changes in biodiversity in order to carry out analyses of the causes of changes (Krüß, 2017), and in the economy, for example, the value added by the bioeconomy is reported (Ronzon & M'Barek, 2018). Various guidelines have also been formulated in the economic sector, the tracking of which can provide information on the development of the bioeconomy, such as the sustainability initiative of the chemical industry.[1]

However, if the bioeconomy is to be developed and managed as a system, these information systems are inadequate: the large number of actors and material flows and their effects in the most diverse sub-areas of economy, ecology and society (and their interdependencies), as well as the high dynamics in development, require a more far-reaching information base in order to manage the bioeconomy as a whole, but also to identify and reduce conflicts of objectives at an early stage. The requirements for such a system include the following five aspects:

1. **System definition:** Who defines the bioeconomy and how? Who and what "belongs" to it, who and what does not?

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[1] ► https://www.chemiehoch3.de/home.html.

Which areas, sectors and actors are understood to belong to the bioeconomy? On the basis of this definition(s), what should be the object of investigation for monitoring?

2. **Goal definition:** What are the clear, overarching (political, economic, scientific and societal) goals of the bioeconomy that underlie monitoring? Who makes what demands and expectations of the bioeconomy and should therefore be involved accordingly when defining the objectives of monitoring systems? Who/what body decides who is included?
3. **Indicator development:** How and by whom should these goals be underpinned with which indicators and measured in the long term? What are the implications for monitoring due to different target definitions?
4. **Networking with other indicator systems** : Which existing information and monitoring systems can be used and which need to be newly established specifically for the bioeconomy?
5. **Implementation and continuous further development:** How can it be ensured that the monitoring system is constantly adapted to new goals, agreements and findings in the bioeconomy?

The system definition determines what is attributed to the bioeconomy. It was shown in ► Chap. 2 that this is already defined differently within the economy, and that this has a direct impact on the indicator "value added by the bioeconomy". A system definition that tracks the development of the bioeconomy as a system is referred to as systemic monitoring. It must include both the different subsystems of the bioeconomy and:

- include the entire value and process chains and describe them with material flow and life cycle analyses,
- consider import and export of biomass as well as intermediate and final products, including an assessment of the respective local production conditions,
- include the different spatial resolutions in order to describe the development on a global scale as an aggregated measure as well as to provide disaggregated information on a local or regional level, and
- include key impacts such as wealth creation, value creation, innovation dynamics, land use, sustainability, and environmental and social effects.

The effects of the bioeconomy are intended effects, i.e. contributions to goals, or unintended effects, i.e. conflicts of goals. The more concretely the goals are defined, the easier it is to design monitoring systems. The objectives in the current bioeconomy strategies have so far been very broad. In its policy strategy, the German government has only set very general goals, such as "secure supply of the population in Germany with food of high quality and beyond, within the scope of possibilities, performance of the contribution to securing the world's food supply" (BMEL, 2014, p. 20), "strengthening the change from an economy based predominantly on fossil raw materials to a raw material-efficient economy increasingly based on renewable resources" (ibid.), etc., and has not quantified these. A monitoring system for these goals is thus also more difficult to develop than a monitoring system for achieving the energy transition or the Paris climate goals. Even if the bioeconomy goals are still vague, the Sustainable Development Goals (SDGs) provide a comprehensive starting point for the derivation of indicators that needs to be sharpened – taking into account the priorities of the various actors (Bogdanski, 2019; Zeug et al., 2019).

There is a strong need for representative and consistent data and indicators on the bioeconomy in Germany among stakeholders from politics, business, science and civil society, as well as other actors such as the media, financiers, etc., who are either directly involved in the bioeconomy or whose fields of action are affected by the bioeconomy. Of particular interest is information on the economic development of the bioeconomy, the availability and potential uses of resources, the ecological sustainability effects of the bioeconomy and the processes of social change associated with the bioeconomy (▶ Chap. 1 and ▶ Sect. 20.4). If the bioeconomy is understood as a dynamic system that exhibits a large number of interdependencies, then the aim of systemic monitoring should be explanatory models, i.e. causal analyses based on solid data. Such monitoring does not yet exist for the bioeconomy.

Nevertheless, it is not necessary to build up such a monitoring system from scratch. It can – and should – be linked to various indicators and models: For example, established measures of economic development can be used to classify the economic significance of the bioeconomy (▶ Chap. 2). Similarly, the resource relevance of the consumption of biobased products can be classified using, for example, climate footprints, land use per product or the water footprint, as described by Egenolf and Bringezu (Egenolf & Bringezu, 2018). The list can be continued and leads to the conclusion that systemic monitoring must ensure that the priorities and targets for the bioeconomy are appropriately mapped.

However, the priorities, objectives and impacts of the bioeconomy are not set in stone, but are subject to change over time: Today we see different opportunities and risks for the bioeconomy than, for example, ten years ago, when biomass seemed to be available in abundance and, on the other hand, the possibilities of biotechnology were much more limited. The regular review of the system description is therefore another important building block for systemic monitoring. It must be capable of learning and reacting to the diverse stakeholder expectations.

20.3 Stakeholder Expectations

The diversity of stakeholders runs like a thread through the bioeconomy. They act in many different ways and determine the bioeconomy system. A monitoring system must therefore provide substantial information for as many stakeholders as possible. A monitoring system oriented towards stakeholder needs must, on the one hand, concentrate on relevant parameters and indicators (key factors), and on the other hand, embed these in overarching narratives and scenarios that are coherent for the majority of stakeholders and thus meet with their approval.

As part of the BMBF's SYMOBIO monitoring project (Dimension 2, ▶ Sect. 20.4), an attempt was made to record and discuss the stakeholder priorities for bioeconomy monitoring. This was done as part of a series of workshops lasting several days, at which representatives from industry, science and civil society were invited. The 64 participants assessed the contribution of the bioeconomy to the achievement of the 169 sub-goals of the SDGs on the one hand and formulated their expectations of bioeconomy monitoring on the other. As the workshops took place within the various social groups, they primarily served to identify the location of the stakeholders involved. The resulting priorities were summarised for the 17 SDGs (Zeug et al., 2019) and, as expected, provided a heterogeneous picture (◘ Fig. 20.1).

This shows that all stakeholders rate the contribution of the bioeconomy to Goal 2 (No Hunger), Goal 12 (Sustainable Consumption and Production), Goal 13 (Climate Protection Measures), Goal 14 (Life under Water) and Goal 15 (Life on Land) very highly. A monitoring system must cover these areas accordingly well. However, the contribution to Goal 1 (No Poverty), Goal 7 (Affordable and Clean

Fig. 20.1 Analysis of the perspectives and interests of German stakeholder groups on the SDGs in the field of the bioeconomy. Relevances of the SDGs based on the relevance of the corresponding sub-goals of the stakeholder groups. The order of preference is determined by mean values of the relevance (Ø) of an SDG of all stakeholder groups. (Source: Own representation according to Zeug et al., 2019)

Energy) and Goal 8 (Decent Work and Economic Growth) is rated very differently. This heterogeneity can be taken as an indication for upcoming discourses and debates – for these, too, a good information basis is necessary and the monitoring system must be developed accordingly.

The following positions can also be identified from the discussion processes of the stakeholder workshop:

Stakeholders from the "Science" group emphasised that not only national but also global effects of a German, European or transnational bioeconomy must be taken into account in order to identify trade-offs, leakage effects and re- and backfire effects and to be able to avoid them in the future. The requirement for supra-regional balancing limits can be derived from this. Stakeholders in the business community were particularly interested in the legislative framework conditions for bioeconomic activities – especially at the international level – i.e. market access, raw material restrictions, trade restrictions, subsidies and financing options. In addition, price indicators for products and raw materials as well as political-economic instruments are relevant for them, e.g. the internalisation of externalities or physical material flows – ultimately information for strategic economic decisions in bioeconomy companies.

For the stakeholders in the "Society" group, the focus was on answering the question of the extent to which the bioeconomy merely represents a substitution of the resource base of the established economic system or represents an actual social change towards a more sustainable world. With regard to the identification of land conflicts, the effects on food prices and thus the nutritional situation of a growing population, as well as the ecological impacts, aspects that can provide data on these conflicting goals are of particular interest (Zeug et al., 2019).

20.4 Monitoring Activities in Germany and Internationally

Various monitoring concepts for the bioeconomy are currently being described and tested in Germany.

Wessler and von Braun (2017) generally advocate interlinking process monitoring of the two large areas of "resources and innovations" and "policy and governance" with results monitoring of the respective and prospective impacts of the bioeconomy. O'Brien et al. (2015) recommend the material flow-based representation of developments in the form of a large dashboard in which all major developments and control variables are plotted *(dashboard)*. Adler et al. (2015) suggest deriving easily measurable control indicators (e.g. value added achieved per unit of biomass used) based on key target indicators such as "increasing value added per unit of land used" and "increasing contribution to climate gas reduction through the bioeconomy" and complementing these with conservation indicators from environmental reporting. All of these approaches follow a systemic approach as described in ► Sect. 20.2, but choose different focal points.

Germany is currently working extensively on the establishment of a bioeconomy monitoring system. This is being promoted by three ministries and divided into "dimensions" (◘ Fig. 20.2). The Federal Ministry of Food and Agriculture (BMEL) (Dimension 1) is focusing on the provision of comprehensive data on biogenic raw materials and residues and their fate, the Federal Ministry for Economic Affairs and Energy (BMWi) (Dimension 2) on the provision of meaningful economic indicators and the development of bioeconomy-specific indicators, and the Federal Ministry of Education and Research (BMBF) (Dimension 3) on the systematic observation and modelling of the bioeconomy. The

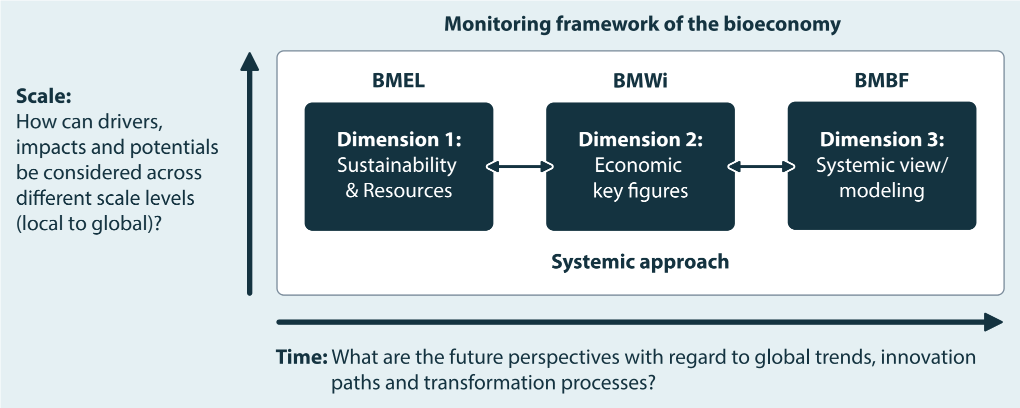

Fig. 20.2 Institutional division of tasks of the bioeconomy monitoring for Germany. (Source: Own representation based on O'Brien et al., 2015)

various planned contributions to systematic monitoring in detail:

- **Dimension 1**

The foundations are being developed for a Germany-wide bioeconomy monitoring system of current and future biomass flows and their evaluation. Accordingly, data on the resource base (biomass use/biomass potential) will be collected and processed and it will be analysed how much biomass is available for end users. Changes in the value chain as a result of future developments are taken into account. The focus of the activities is on the development of a solid data basis on factual developments, the development of summary balances and indicators, the bundling of data into meaningful key figures, and the development of an integrated concept for energy- and material flow-based, cross-sectoral macroeconomic sustainability accounting of the bioeconomy.

- **Dimension 2**

Economic key figures and indicators will be developed to monitor the progress of the bioeconomy and to make progress, obstacles and conflicting goals visible. In this way, all economic dimensions of the bioeconomy are to be made measurable. The focal points are the investigation of biomass flows and the use of by-products, the development of an indicator system for the investigation of the bioeconomy in its economic dimensions/NACE classifications (NACE = Nomenclature statistique des activités economiques dans la Communauté européene/Statistical Classification of Economic Activities in the European Community), analyses on the topics of innovations, patents and education, the provision of economic key figures and ecological balances as well as a detailed examination of the chemical and plastics industries.

- **Dimension 3**

The scientific basis for systemic monitoring and integrated modelling of the bioeconomy in Germany will be developed, taking into account key drivers for the transformation of the bioeconomy, the modelling of trends and their environmental and socio-economic impacts. The focus is on sustainability aspects at national and international level.

These three monitoring processes and approaches should ultimately be brought together. Regular status conferences are already taking place, at which information is provided on the respective project statuses and where an exchange of content takes place. The first pilot reports of the merged monitoring system have been released in 2020/2021.

Internationally, activities to monitor the bioeconomy exist at the level of the European Union and the FAO, among others (EC, 2018; Bogdanski, 2019). These projects are still at a comparatively early stage of development. For example, initial evaluations between European member states on socio-economic indicators show a strong relationship between per capita gross national product and the maturity of the bioeconomy (Ronzon & M'Barek, 2018).

20.5 Outlook

The depiction of the bioeconomy as a system forms the basis for its targeted development and management. The need to develop systemic monitoring has been recognised at various political levels and supported by research and development activities. The ideal of bioeconomy monitoring is associated with both descriptive and prospective informative value, which outlines the progress and impacts of decisions for action or provides the basis for management activities in this area. Similarly, the SDGs are increasingly seen as the basis for systemic monitoring of the bioeconomy. However, these can only provide the framework. Political and societal priorities and concrete visions of the future of the bioeconomy form another important basis for monitoring. They, too, still need to be further developed and negotiated (▶ Chap. 19).

In addition, it is also necessary to provide up-to-date and comprehensive data so that the monitoring of the bioeconomy is successful. Here too, the clearer the expectations of the bioeconomy are translated into monitoring systems and indicators, the more efficiently the monioring data can be provided and used.

References

Adler, P., Budzinski, M., Erdmann, G., Majer, S., Meisel, K., Schock, S., & Thrän, D. (2015). Sachstandsbericht über vorhandene Grundlagen für ein Monitoring der Bioökonomie: Nachhaltigkeit und Ressourcenbasis der Bioökonomie. Deutsches Biomasseforschungszentrum. https://www.dbfz.de/fileadmin/user_upload/Referenzen/Studien/P3310038_Sachstandsbericht_Nachhaltigkeit_und_RessRessourcenb.pdf. Accessed: 29.08.2019.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2014). Nationale Politikstrategie Bioökonomie. Nachwachsende Ressourcen und biotechnologische Verfahren als Basis für Ernährung, Industrie und Energie. https://www.bmel.de/SharedDocs/Downloads/Broschueren/BioOekonomiestrategie.pdf;jsessionid=FE433FAFDA625A9797E0CF52F1B88DA9.2_cid367?__blob=publicationFile. Accessed: 29.08.2019.

BMWi (Bundesministerium für Wirtschaft und Energie). (2018). Die Energie der Zukunft. Berichtsjahr 2016. Sechster Monitoring-Bericht zur Energiewende. https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/sechster-monitoring-bericht-zur-energiewende.pdf?__blob=publicationFile&v=37. Accessed: 2.09.2019.

Bogdanski, A. (2019). Towards sustainable bioeconomy guidelines: Monitoring & evaluation. ENRD thematic group in 'mainstreaming the bioeconmy'. FAO. https://enrd.ec.europa.eu/sites/enrd/files/tg_bioeconomy_videoconf_fao_bogdanski.pdf. Accessed: 29.08.2019.

European Commission (EC), Directorate-General for research and innovation. (2018). A sustainable bioeconomy for Europe. Updated bioeconomy strategy, S. 15, Luxembourg.

Egenolf, V., & Bringezu, S. (2018). Indikatorensystem zur Bewertung der Nachhaltigkeit der deutschen Bioökonomie. Arbeitspapier. Center for Environmental Systems Research Universität Kassel. https://symobio.de/wp-content/uploads/2018/03/Indikatorensystem-23.03.2018_final-1.pdf. Accessed: 29.08.2019.

Krüß, A. (2017). Aktueller Stand und weitere Entwicklung der bundesweiten Monitoring-Programme als Grundlage für ein umfassendes nationales Biodiversitätsmonitoring. Nationales Biodiversitätmonitoring Revisisted: Bericht zum Ne-Fo Fachgespräch am 27. Juni 2018 (S. 8–10). netzwerk-forum zur biodiversitätsforschung deutschland. http://www.biodiversity.de/sites/

default/files/products/reports/2017_fachgespraech-nationales-biodiversitaetsmonitoring_final_0.pdf. Accessed: 2.09.2019.

O'Brien, M., Wechsler, D., Bringezu, S., & Arnold, K. (2015). Sachstandsbericht über vorhandene Grundlagen und Beiträge für ein Monitoring der Bioökonomie: Systemische Betrachtung und Modellierung der Bioökonomie. Wuppertal Institut für Klima, Umwelt, Energie GmbH, Wuppertal. https://www.biosc.de/lw_resource/datapool/_items/item_644/5851_biooekonomie.pdf. Accessed: 11.12.2019.

Ronzon, T., & M'Barek, R. (2018). Socioeconomic indicators to monitor the EU's bioeconmy in transition. *Sustainability, 10*(6), 1745.

Wessler, J., & von Braun, J. (2017). Measuring the bioeconomy: Economics and policies. *Annual Review of Resource Economics, 9*, 275–298.

Zeug, W., Bezama, A., Moesenfechtel, U., Jähkel, A., & Thrän, D. (2019). Stakeholders' interests and perceptions of bioeconomy monitoring using a sustainable development goal framework. *Sustainability, 11*(6), 1511.

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Occupational Fields of the Bioeconomy

Rudolf Hausmann and Markus Pietzsch

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_21

21.1 Introduction

The bioeconomy requires a comprehensive rethinking process that leads to the sustainable use of biogenic resources for a sustainable economic system oriented towards natural material cycles. A bio-based value chain comprises the primary production of bio-based resources, their conversion into higher-value goods through processing and their marketing on the market. It thus requires not only a new basis of biogenic resources but also technological, economic and social change. Education should be strongly multi- and transdisciplinary as well as practice-oriented (Lask et al., 2018). Trained bioeconomy professionals are expected to be specialised in one field on the one hand, but on the other hand also able to understand the scientific jargon of related disciplines.

21.2 What Makes a "Bioeconomist"?

The competences of a "bioeconomy graduate" ideally result from the professional environment of the emerging bioeconomy (Lask et al., 2018). Here, "bioeconomy" is understood as a rethinking process that leads to the sustainable use of biogenic resources for a sustainable economic system oriented towards natural material cycles. However, the bioeconomy is also often used synonymously with a biobased economy. It encompasses the production of bio-based resources and their conversion into food, animal feed, bioenergy, bio-based materials, chemicals, biopharmaceuticals and also data or knowledge about bio-economic processes. A bio-based value chain includes the primary production of bio-based resources, their conversion into higher value goods through processing and marketing. It thus requires not only a new basis of biogenic resources but also technological, economic and social change. However, the bioeconomy is not a new branch of industry or a new discipline.

In the agricultural, forestry and food industries, the sustainable use of biogenic resources has already been recognised as a necessity and is being pursued in a variety of ways. This traditional sector can also be referred to as the resource-based bioeconomy. In particular, the food sector as well as the biopharmaceutical industry comprise the majority of the current bioeconomy in Germany. However, the structural change towards a sustainable economy also in all other sectors requires new technologies and the replacement of fossil carbon sources, both for material production and as energy sources. The use of biogenic resources is therefore closely linked to the use of renewable energy sources. These changes are associated with great opportunities for growth and employment for the companies and individuals active in this field, but at the same time require intensive efforts in research and innovation. To be successful in the bioeconomy therefore requires a diverse, multidisciplinary understanding and the ability to think systemically. Education should be strongly multi- and transdisciplinary as well as practice-oriented. The combination of an overarching understanding of the economic system and natural material cycles, as well as specialist skills from the fields of process engineering, agricultural and forestry sciences, food technology and chemistry, biotechnology, medicine, pharmaceuticals, materials sciences, economics or business administration, distinguish bioeconomy graduates.

21.3 How Does One Become or Train to Become a Bioeconomist?

The need for specially trained professionals with inter- and transdisciplinary competences in the bioeconomy is steadily increasing as more and more companies promote sustainable production and consumption. In contrast, most college and university curricula develop profound knowledge in one discipline, often with additional specializations offered. In contrast, the supply of degree programmes, which focus on broad, multidisciplinary education, is rather low. The bioeconomy is an excellent example of multidisciplinary education (Bioökonomie.de, 2018; Lask et al., 2018).

The majority of interdisciplinary programmes already established internationally in the field of the bioeconomy are Master's programmes. For a few years now, degree programmes specifically for the bioeconomy have been offered. Common elements of the curricula are bio-based value chains and the focus on the ecological, social and economic impacts of bioeconomic developments. The general goal is to train professionals who are able to deal with very complex interdisciplinary problems concerning the sustainable use of biogenic resources. To this end, integration and cooperation skills are important prerequisites that must be learned in practice in bioeconomy education.

As a foundation for the bioeconomy, a solid prior knowledge in the basic natural science subjects of physics, chemistry, biology and mathematics as well as in the social, economic, forestry and agricultural sciences is required. Obvious and useful specialisation subjects are organic chemistry, biochemistry, microbiology, food and biotechnology, business and economics, production and use of biogenic resources, statistics, computer science, medicine, pharmaceutics, materials science, energy technology, environmental technology, chemical, biological and thermal process engineering or methods of life cycle assessment. The bioeconomy concept can be built on the foundation of the basic subjects and the specialisation as a cross-sectional discipline. The life sciences and biotechnology play a key role in this. The targeted use of molecular biological processes marks the beginning of a potentially revolutionary development in the knowledge-based bioeconomy and has the potential to trigger a profound change in all areas of society and industry.

The aim of bioeconomy education is to teach the interrelationships between the natural material cycles of the existing economy and to enable bioeconomy graduates to shape an innovation-driven, knowledge-based and sustainable economy.

Many representatives of the bioeconomy particularly emphasise the aspect of innovation orientation. In order to substitute previous climate and environmentally harmful manufacturing processes, new products must be produced from renewable biomass or carbon dioxide. To this end, bioeconomic innovations must, on the one hand, produce resource-efficient technologies to increase productivity in agriculture, forestry and aquaculture and, on the other hand, make new biogenic products and consumer goods available. This will enable the introduction of innovative and resource-efficient production technologies and the transition to a sustainable society. This means not only using biogenic resources, but also conserving them in the sense of environmental and biodiversity protection. The ecological, economic and social dimensions of the societal rethinking process are strongly interwoven and require a complex societal problem-solving process. In order to make an important contribution with the acquired transdisciplinary competencies, bioeconomists should be able to learn how to communicate with societal stakeholders in practice at an early stage.

21.4 What Training Is Already Available?

The spectrum of possible educational paths is just as broad as the research activities on the bioeconomy. One path is classical degrees in agricultural sciences, biotechnology, chemistry, food technology, economics or social sciences. In addition, more and more universities and colleges are setting up specialised courses and degrees on the topic of the bioeconomy (Bioökonomie.de, 2018).

In Germany, transdisciplinary bioeconomy courses are offered at the Technical University of Munich (B.Sc. Bioeconomy), the University of Hohenheim (M.Sc. Bioeconomy) and the Martin Luther University Halle-Wittenberg (B.Sc. and M.Sc. Management of Natural Resources).

Across Europe, there are degree programmes focusing on the bioeconomy at the universities of Wageningen (M.Sc. Biobased Sciences) and Maastricht (M.Sc. Biobased Materials), both in the Netherlands, at the four universities of Bologna, Milan-Bicocca, Naples and Turin (M.Sc. Biocircle (Bioeconomy in the Circular Economy)) and also at the University of Edinburgh (M.Sc. Management of Bioeconomy, Innovation and Governance). In addition, the Master's programme "Biorefinery Engineering" at Graz University of Technology is a bioeconomy programme with a strong engineering focus.

All of the above-mentioned courses of study have been established in response to the growth of the global bioeconomy and the associated increasing demand for qualified specialists who have the necessary basic knowledge and skills. A few study programmes are now presented here as examples.

The B.Sc. programme "Bioeconomy" at the TU Munich teaches mathematical, scientific, environmental-economic and economic basics as well as in-depth knowledge in chemistry, physics, biology and business and economics.

The English-language international M.Sc. programme "Bioeconomy" at the University of Hohenheim has the motto "Change the system. Shape the future". The interdisciplinary M.Sc. programme looks at the entire bio-based value chain and networks. Students learn to take into account the ecological, social and economic dimensions of the bioeconomy at micro and macro level as well as the requirements for innovations and the corresponding political framework conditions. There is a strong focus on the international perspectives of the bioeconomy.

The B.Sc. and M.Sc. degree programme "Management of Natural Resources" at the Martin Luther University Halle-Wittenberg combines the subject areas "Water – Soil – Plant". In addition to the scientific process understanding of the three environmental compartments, the sustainable management of these natural resources is dealt with.

The M.Sc. "Biobased Sciences" at Wageningen University focuses on the transition from a petrochemical-based to a biobased society. The programme covers the multidisciplinary design of production chains including biomass production, bioconversion, biorefinery and societal, logistical and economic transformation processes.

The M.Sc. "Biobased Materials" at Maastricht University provides the knowledge and skills to develop, produce and apply sustainable materials from biological resources.

The M.Sc. "Biocircle", offered by the four universities of Bologna, Milan-Bicocca, Naples and Turin, provides a combination of theoretical knowledge in life sciences with a practical focus on the bioeconomy and its value chains from different perspectives.

The M.Sc. "Management of Bioeconomy", Innovation and Governance at the University of Edinburgh focuses on responsible development of sustainable innovations. The spectrum ranges from innovations in the field of life sciences to corporate strategies and politics.

In the Master's programme "Biorefinery Engineering" at Graz University of Technology, graduates acquire technical knowledge in the fields of process engineering, chemistry, biotechnology as well as energy technology and environmental engineering for the economic and sustainable use of biogenic resources.

In addition to these transdisciplinary courses, there are numerous other Bachelor's and Master's courses that have a more or less specific reference to a bioscientific subject. A presentation of these study courses, which are offered in Germany, Austria and Switzerland, would go beyond the scope of this book. Therefore, reference should be made at this point to the Conference of Biological Faculties (KBF), which represents the biological departments and faculties of German universities. For those interested in studying, it has produced a guide to Bachelor's degree courses in the biological sciences.[1] As part of a project funded by the BMBF, all relevant master's courses have also been collected.[2] The courses on offer range from A for "Agricultural and Horticultural Sciences/ Agriculture or Horticulture" (Bachelor's course at Humboldt University Berlin) to Ö for "Ecotrophology" (Bachelor's course at Kiel University) and include both natural science and engineering courses as well as teacher training courses, borderline areas to medicine (e.g. medical technology), process engineering (bioengineering) and economics (e.g. agricultural management, entrepreneurship renewable energy).

Of the 519 (788) bachelor's (master's) degree programmes listed in a life sciences subject, 44 (81) bear the designation "biotechnology". 13 Master's degree programmes in biotechnology are offered in English. Of these, six are offered by universities of applied sciences and seven by (technical) universities.

A good insight into the bioscientific professions is provided by more than 70 scientists in the book "Perspektiven – Berufsbilder von und für Biologen, Biowissenschaftler und andere Naturwissenschaftler" (VBio, 2015).

Due to the large number of bioeconomic "starting points", the bioeconomy is increasingly being systematised, i.e. attempts are being made to categorise the courses offered under different headings or in "drawers" (e.g. subdivision into courses in bioeconomy, industrial biotechnology or sustainability and resource management) (Bioökonomie.de, 2018). Since the headings are no more meaningful in themselves than the names of the study programmes, it is recommended that those interested in studying take a (time-consuming) look at the specific module handbooks.

21.5 What Does the Bioeconomist Need in Addition?

The bioeconomy's goal of achieving a sustainable society is a highly complex task. The willingness of all social groups, especially companies and consumers, to contribute to social change depends not only on the current bioeconomic framework conditions, but also on the future acceptance of modern technologies. Modern methods of gene editing in crop plants can be mentioned here as an example. The current discussion in Europe and worldwide about the legal status of gene-edited organisms clearly reveals the need for bioeconomic innovation and interface management (Lask et al., 2018). This innovation and interface management requires actors to have the ability to communicate with a wide range of disciplines and societal groups. The transdisciplinary communication skills of bioeconomists are a prerequisite for this. In some areas of the bioeconomy, remarkable progress can already be observed today. In addition, knowledge of political decision-making processes and start-up skills can be relevant for bioeconomists to drive innovation.

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[1] For more information, see ► https://www.bachelor-bio.de/.

[2] For more information, see ► https://www.master-bio.de/.

21.6 So Should There Be More "Bioeconomy" Courses?

It is to be expected that the bioeconomic sector of the economy will expand significantly in the future and thus create numerous new employment opportunities. This is suggested by various national and international studies. With a focus on high value creation and the creation of new economic activities, the knowledge-based bioeconomy will require skilled professionals. In the area of resource-based bioeconomy along biobased value chains, further decentralized employment opportunities can be expected in agriculture and forestry. Here, bioeconomists will be required for the establishment and organization of value chains. Accordingly, it can be assumed that there will be a long-term increase in the demand for bioeconomists, both nationally and internationally. Even if no empirical studies on the labour market situation of bioeconomy graduates are yet available, heuristically a rising demand for study offers and courses in the field of bioeconomy appears to be extremely reasonable.

References

Bioökonomie.de. (2018). Ausbildungswege: Bioökonomie studieren. https://biooekonomie.de/ausbildungswege-biooekonomie-studieren. Zugegriffen: 23.08.2019.

Lask, J., Maier, J., Tchouga, B., & Vargas-Carpintero, R. (2018). The bioeconomist. In I. Lewandowski (Ed.), *Bioeconomy – Shaping the transition to a sustainable, biobased economy* (pp. 343–356). Springer International Publishing.

VBio (Verband Biologie, Biowissenschaften und Biomedizin in Deutschland). (2015). *Perspektiven. Berufsbilder von und für Biologen, Biowissenschaftler und andere Naturwissenschaftler* (2nd ed.). VBio.

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Governance of the Bioeconomy Using the Example of the Timber Sector in Germany

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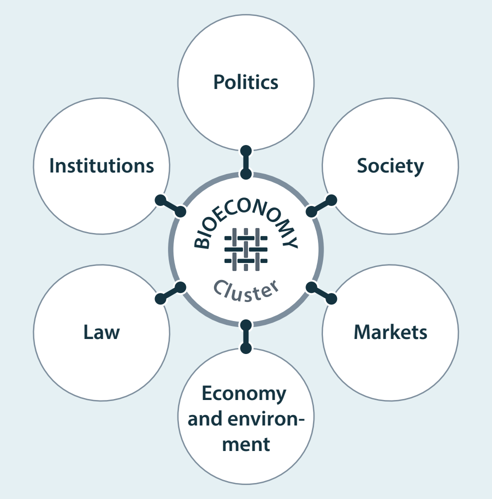
Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_22

22.1 Governance of the Bioeconomy

The term "governance" describes in general terms a system of control and regulation that includes state intervention, but also the rules governing the interaction of private actors (markets, associations, actor networks such as clusters; ◘ Fig. 22.1) (▶ Chap. 23) The wood-based bioeconomy is regarded as an important application of the economy with renewable resources. For this purpose, various forms of governance can be found in Germany that structure the interactions of the actors – in addition to direct state regulations (e.g. the Forest Act), of course, markets for primary and secondary raw materials, interest groups and company clusters, as well as negotiation processes for informal rules. Governance has two important functionsfor a sustainable bioeconomy.

- Safeguarding function: On the one hand, there is a need for explicit safeguards of economic, social and ecological sustainability through appropriate governance approaches. The bioeconomy must be more than just the management of biogenic resources. It must be a sustainable form of economy based on cycle-managed bio-based raw materials (Bioökonomierat, 2018). It can be assumed that such a sustainable, bio-based and cycle-managed form of economy will enable a more efficient and environmentally compatible use of raw materials overall than is the case today, and should therefore also be aimed for in economic terms. In order to initiate and appropriately steer this path transition, however, an effective governance framework is essential that consistently guides the political and economic actors (◘ Fig. 22.2). Bioeconomy concepts must therefore be equipped with sustainability guard rails for a comprehensive path transition from the current "throughput and sink economy" based predominantly on fossil raw materials to a circular economy oriented towards renewable resources (BMBF, 2010; Staffas et al., 2013; Richardson, 2012; BMEL, 2013; Pannicke et al., 2015).
- Enabling function: In addition to ensuring sustainability, the governance framework also has the task of ensuring fair competitive conditions for bioeconomy processes and products in the first place, thus enabling efficient decisions between alternative technologies and biogenic and non-biogenic resources on markets (enabling function of governance for the bioeconomy). The creation of incentives for innovation efforts in the area of resource use and closure of material flows is also particularly important in this context in order to limit the pressure that an expansion of the bioeconomy exerts on natural ecosystems (BMEL, 2013; Carus et al., 2014).



◘ **Fig. 22.1** Objects of bioeconomy governance. (Source: Own representation)

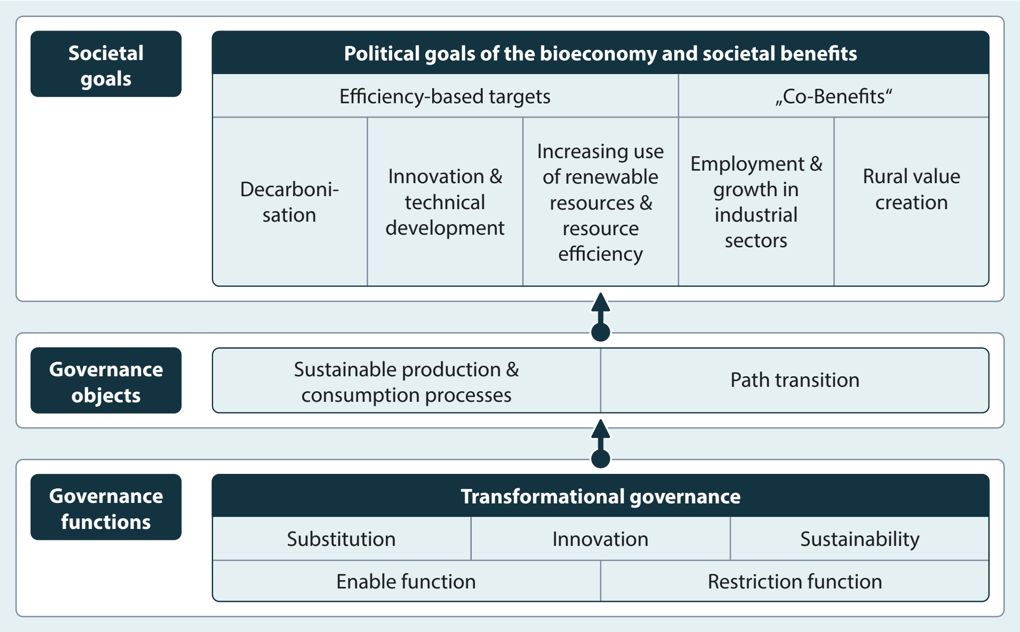


Fig. 22.2 On the role of bioeconomy governance. (Source: Gawel et al., 2016, p. 4)

22.2 The Role of Policy in Pathway Transition

The complex transition to a sustainable bioeconomy requires a wide range of technical, market and social innovations – but above all it will not succeed without appropriate state control (Hagemann et al., 2016; ► Chap. 23). This is because existing distortions of competition to the detriment of biobased products and closed-loop systems favour the persistence of markets and institutional structures in the previous fossil-based and flow-oriented economic form. In the case of fossil-based processes, for example, companies can draw on an existing infrastructure as well as experience and networks that are not yet established in the case of biobased processes. Changes in production and innovations, on the other hand, are associated with conversion costs and considerable market and legal uncertainties. In addition, the market price of fossil-based products does not reflect their full economic costs, e.g. with regard to environmental and climate damage or due to non-closed cycles (Lahl, 2014). These so-called externalities and technological and institutional path dependencies currently still favour fossil over renewable raw materials and sink economies over circular economies. Fair competition is thus not yet possible.

These distorting effects are exacerbated by a co-evolutionary development of fossil-based infrastructures and networks, interdependent industries, established consumption patterns, and existing formal and informal rules, leading to an inertia in favour of the fossil-based economy that is difficult to overcome *(carbon lock-in)*. These and other so-called market failures require the political design of an actively corrective regulatory structure that enables a shift to a bioeconomy via fair competitive conditions (Pannicke et al., 2015).

However, governmental governance interventions also face significant challenges in adequately promoting the pathway transition to a circular bioeconomy while providing effective sustainability assurance. One important reason for this is information problems arising from uncertainties about economic, environmental and social impacts of multiple and diverse bioeconomy value chains (McCormick & Kautto, 2013).

Particularly in the case of the introduction of innovations, for example, long-term and complex environmental impacts or the development of costs and technology over time can hardly be reliably estimated by political decision-makers. When selecting bioeconomy applications "worthy of support", political decision-makers thus run the risk of promoting options that in retrospect prove to be too expensive or not in line with the objectives. At the same time, it is difficult to determine an appropriate level or scope of funding, as shown, for example, by the critical debate on biofuels with comparatively high greenhouse gas abatement costs (WBGU, 2008). There is a risk here of over- and mis-subsidization.

Problems in securing the sustainability of ambitious biofuel quotas also indicate that the expansion of niche applications (the so-called scaling problem) can reveal new difficulties that were not even foreseeable when the application was on a "small scale". It is therefore all the more important to keep an eye on the costs, benefits and sustainability risks of bioeconomy promotion in policy-making, and to avoid "promotion at any price". This includes openness to alternative target achievement options, for example in the area of non-biogenic renewable resources.

In order to avoid such mismanagement, it is therefore advisable to make use, as far as possible, of decentrally available cost and benefit knowledge about resource use and its effects. This means that markets must be activated and used for resource decisions. This can be done by shaping the regulatory framework to steer the decisions of market actors in a targeted manner towards sustainability-compliant behaviour. However, this presupposes clarity about the prioritisation of political goals associated with the bioeconomy. Potential for misguidance arises in particular from unresolved conflicts of objectives, for example between the goals of environmental protection, economic growth and rural value creation pursued with the bioeconomy, which each imply completely different funding strategies. For the establishment of a sustainable bioeconomy, it is important to disclose conflicting goals and to discuss prioritisation. Different policy recommendations would result if, for example, the goal of climate protection were to be consistently prioritised, because then not all biobased material flows would be socially beneficial (see Gawel, 2011 for the example of bioenergy). From the perspective of political actors, however, this is not always expedient, for example in order not to lose certain groups of voters (Kay & Ackrill, 2012).

22.3 Governance of the Wood-Based Bioeconomy in Germany

22.3.1 Overview

In a case study on the wood-based bioeconomy in Germany (Gawel et al., 2016), the Helmholtz Centre for Environmental Research – UFZ examined current governance approaches in Germany to determine whether and to what extent they currently already fulfil the "enabling and safeguarding functions" (see ▶ Sect. 22.1 above) and can thus support the desired path transition to a sustainable wood bioeconomy in Germany.

The wood-based bioeconomy is a subsector of the bioeconomy and comprises the material and/or energetic use of lignin-containing and thus solid parts of plants (e.g. trees and shrubs) in a variety of application areas. This includes wood from forests (such as logs, pulpwood and forest residues), wood from short rotation coppices and residues from landscape management, as well as by-products, wood processing residues and recycled wood. As a case study, the wood-based bioeconomy is particularly promising because it is not in direct competition with food production, at least at the product level. In view of the tank-or-dish debate on energy crops, interest in non-food raw materials has increased significantly in recent years.

The wood-based bioeconomy is characterised by a large number of relevant actors and interests (Pannicke et al., 2015). On the producer side, both forestry and agricultural actors play a role. They align their production primarily with market criteria. As there is already a high demand for wood in the processing sector as well as in the energy sector in Germany, there is currently little incentive for them to actively support the increasing material use of wood. The processing sector as a second large group of actors includes companies such as sawmills, chemical groups, construction companies as well as the paper industry. These have so far shown no significant interest in a stringent path change (Bioökonomierat, 2015).

Consumers are also proving reluctant to demand biobased products. It is proving problematic that bio-based products usually have at best similar properties to products based on fossil raw materials, but are often more expensive (Vandermeulen et al., 2012). In addition, sustainability or functionality concerns may arise (Pfau et al., 2014).

In the political sphere, the attitude of the public (public opinion, voters) is relevant for the decisive actors. Voters generally prefer sustainability and environmental policies without high additional costs. Interest groups such as environmental associations as well as green parties could indeed support a change of path by raising public awareness and political demand for a sustainable bioeconomy. However, the associations are still in the process of positioning themselves with regard to the topic.

In the following, mainly state governance approaches are considered, which currently shape the wood-based bioeconomy in Germany. A distinction is made here (◘ Fig. 22.3):

- Rules affecting the resource base of the bioeconomy,
- rules concerning bio-based processes and products, and finally
- rules aimed at reducing the use of fossil resources as competing raw materials (indirect bioeconomy policy).

In the case of state-designed rules, the first two points correspond to a "direct" bioeconomy policy, as here either the supply of biobased resources and technologies is directly promoted (*technology-push*) or a demand for biobased processes or products is directly created (*demand-pull*). Measures that make the use of fossil-based competing options more expensive or restrict them, on the other hand, represent an "indirect" bioeconomy policy that indirectly improves the competitiveness of biobased products and processes. Here, the search for substitutes indirectly stimulates a demand pull for biobased products, but also for other options (e.g. increasing resource use efficiency).

22.3.2 Wood Production

There are currently numerous government regulations for timber production in Germany that can be assigned to the safeguarding function of bioeconomy governance. Legal regulations such as the Federal Forest Act, the forest laws of the federal states and the Timber Trade Security Act (HolzSiG) anchor sustainability as a criterion for conventional timber production. For innovative timber production in short-rotation plantations, on the other hand, agricultural law is relevant. The "Circular Economy and Safeguard the Environmentally Compatible Management of Waste Circular Economy Act" (KrWG) in turn regulates the resource flow of used wood. Overall, the legal framework for the

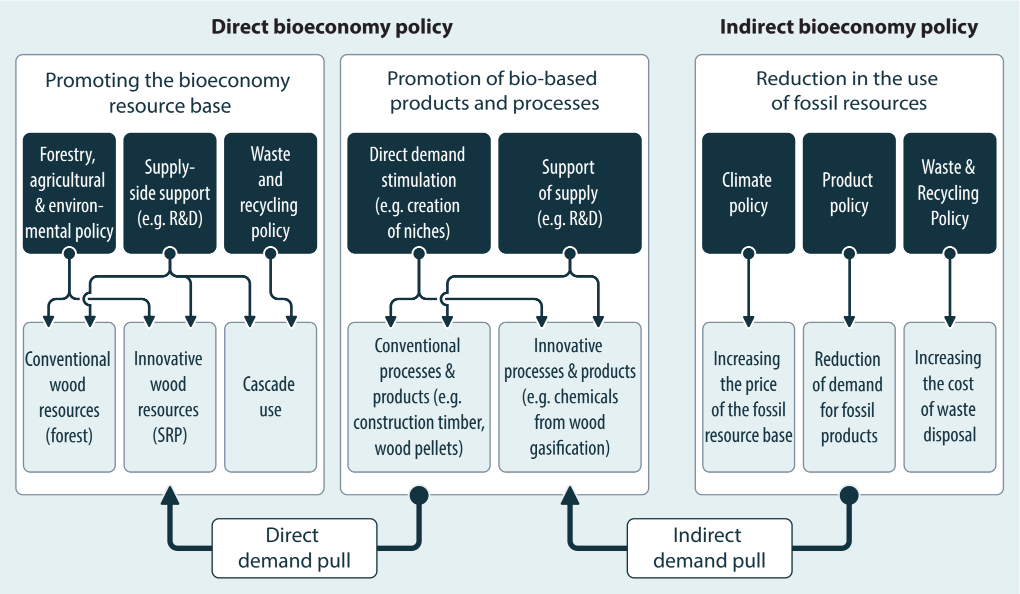


Fig. 22.3 The three pillars of wood-related bioeconomy policy. (Source: Own representation according to Pannicke et al., 2015, p. 226)

wood-based bioeconomy in Germany is highly fragmented and not yet consistently oriented towards a path change. Effective incentives for cascade use concepts are likely to require, for example, an adjustment of the current recycling regulation (Ludwig et al., 2014, 2015).

Within the barriers set by forestry and timber trade law, decisions in conventional timber production are mainly coordinated through markets. For networks such as associations of forest enterprises and forest owners, reducing production and transaction costs is a priority. Policy instruments that promote the supply of wood contribute to a path change (see explanation on "enabling function" in ► Sect. 22.1). These include financial support for short-rotation plantations or afforestation. However, such instruments only partially impose sustainability conditions. Research and development (R&D) measures in this area also directly promote supply (Purkus et al., 2018).

22.3.3 Innovative Material Products and Processes

The relevant control framework differs according to whether wood-based resources are used as inputs for material value-added purposes or are used for energy production.

In the case of material use, above all a greater willingness to pay on the part of consumers for biobased products would enable a change of path via the market mechanism. Voluntary certifications, e.g. the Blue Angel for sustainable wood products ("restriction function"), are aids to marketing these products. In addition, some international standards are used for the labelling of biobased products in the wood sector (e.g. EN 15440). The latter do not contain any comprehensive sustainability requirements, but contribute to the "enabling function" of bioeconomy governance through standardisation and the provision of information. However, demand on the consumer side has so far been low, as has the willingness to pay significant price premiums for "green" product characteristics. Internalisation of external environmental costs via the market thus only takes place for niche products.

State funding for material biobased processes and products focuses on research and development and on supporting clusters and innovation networks (e.g. the[1] BMBF's Bioeconomy Cluster of Excellence or the "Forestry and Wood" cluster initiatives of the German Länder[2]). This is supplemented by the selective promotion of niche applications. Demand for biobased products is promoted, for example, if environmental criteria such as sustainable wood management are taken into account in public procurement. In practice, however, this proves difficult due to information deficits in the administration and complex tendering procedures (Ludwig et al., 2014).

22.3.4 State Support for the Use of Wood for Energy Purposes

In the area of wood energy use, on the other hand, there are a number of government support instruments that have proven very effective in the past (Ludwig et al., 2015). These include regulations in the electricity and heating sectors that target the use of renewable energies (e.g. feed-in premiums in the electricity sector or investment grants for the installation of heating systems that use renewable energies). However, sustainability criteria for the use of wood for energy are not yet anchored here. In addition, the promotion of the use of wood for energy through renewable energy law has led to distortions in the competitive relationship with material uses. This is likely to result in a single- and multi-stage cascade use of wood that is probably too low in economic terms (Bioökonomierat, 2016; Ludwig et al., 2016a, b – see also ◘ Fig. 22.4).

22.3.5 Reducing the Use of Fossil Fuels: Environmental and Economic Cost Realism

Policy instruments that – at least in part – adequately reflect the environmental effects of the use of fossil resources in the price ("internalize") play an important role in setting incentives for a change of path. However, the existing instruments of climate policy – such as European emissions trading and taxes on electricity, energy sources and motor vehicles – have so far concentrated mainly on the energy sector and not equally on material applications. Moreover, the incentive effect of emissions trading has remained extremely limited in recent years due to the low and fluctuating prices for CO_2 certificates. At the same time, neither emissions trading nor tax regulations specify sustainability requirements for wood products, which could prove problematic if these instruments were to actually trigger increased demand for wood resources at some point (e.g. in the context of co-firing wood in coal-fired power plants).

In the area of material use, European chemicals regulation (REACH) and the German Closed Substance Cycle Waste Management Act could indirectly help to promote the development of a wood-based bioeconomy by reducing the consumption of fossil raw materials (Ludwig et al., 2014). However, chemical regulation does not put bio-based substances in a better position than those derived from fossil resources, nor does it include specific sustainability requirements. The effectiveness of the KrWG as an instrument to promote waste prevention and used wood recycling is also currently

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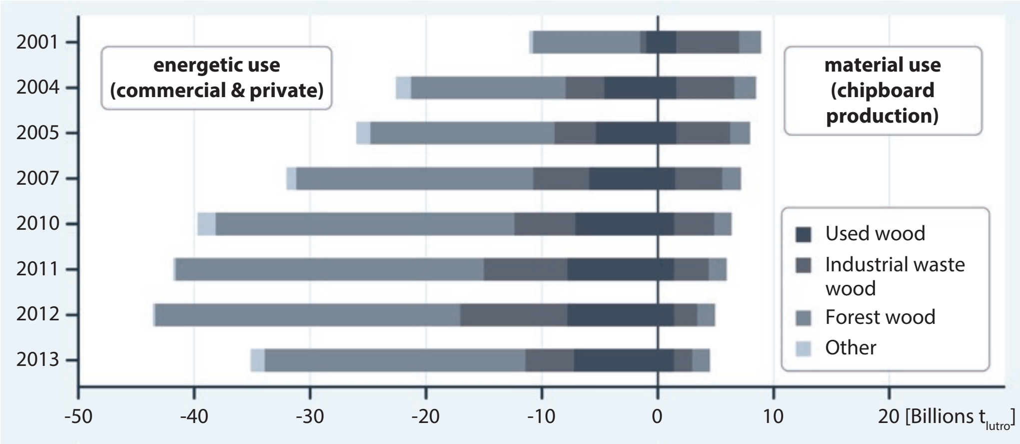
[1] See ► http://www.bioeconomy.de/.

[2] See ► https://www.forstwirtschaft-in-deutschland.de/forstwirtschaft/forstwirtschaft-in-deutschland/cluster-forst-holz/.



◘ **Fig. 22.4** Material and energy use of forest and waste wood in Germany 2001 to 2013. (Source: Own representation. Data basis: Weimar & Mantau, 2006; Mantau et al., 2007; Mantau, 2012, 2013; Weimar et al., 2012; Weimar, 2015. Individual years were partly interpolated. Forest wood includes industrial wood, forest residues, bark and landscape wood. Industrial waste wood also includes sawmill by-products and pellets. Other material recovery processes for waste wood and forest wood were not recorded)

limited, as recycling requirements are linked to "economic proportionality", which leaves considerable room for interpretation (Ludwig et al., 2015).

In the area of the ecological and economic cost truth of fossil inputs, products and processes – in the sense of an indirect bioeconomy policy – considerable steps are therefore still necessary.

22.4 Prospects for an Active Bioeconomy Policy

The case study on the wood-based bioeconomy in Germany shows that price developments on markets to date or even private governance initiatives such as voluntary sustainability certificates are not sufficient to fulfil the "enabling function" of bioeconomy governance for more than narrowly defined niche applications (Gawel et al., 2016). In order to comprehensively address environmental externalities, path dependencies and other so-called market failures that currently still distort allocation decisions to the detriment of bio-based products and processes, more far-reaching policy measures are therefore necessary. The same applies to the "constraining function" of bioeconomy governance to ensure the comprehensive sustainability of innovative processes and products.

However, the case study also makes clear that the current policy mix (◘ Fig. 22.5) and the associated legal framework (see ◘ Fig. 22.6) for the bioeconomy are still very fragmented (Ludwig et al., 2015; Pannicke et al., 2015) and are not sufficient either in terms of their approach, their strength or their overall composition to trigger a consistent pathway transition. The challenge here is to improve coordination between different areas of law and systems of actors (state, markets, associations) and to combine policy instruments geared to materials or energy into a coherent mix of instruments. In the "direct" promotion of material bioeconomy value chains, the focus to date has been on measures that increase the supply of technologies (via cluster and R&D promotion) and wood resources. Direct demand promotion, on the other hand, is only effective for energy-related

Type of policy measure		Focus of policy measures		
		Support for bioeconomy resource base	Support for bio-based processes and products	Reduction of fossil resource use
Conventional wood resources & applications	**Policy instruments with sustainability requirements**	• Forest laws, • Financial support, e.g. through GAK • Commercial law	• R&D funding • Voluntary eco-label • Public procurement law	
	Policy instruments without sustainability requirements		• EnEV • Incentives for the use of wood as an energy source in the electricity sector (EEG) & heat sector (in particular EE WärmeG)	• EU-ETS • Taxes, e.g. electricity taxes and energy taxes • Subsidies and loans for investment in energy efficiency • Energy efficiency standards and labels • KrWG
Innovative wood resources & applications	**Policy instruments with sustainability requirements**	• R&D funding • Agricultural law (for SRC) according to CAP (“greening pillar”)	• R&D funding Research networks and cluster funding • Biofuel quota: incentives e.g. for biomass to liquid (with sustainability certification)	
	Policy instruments without Sustainability requirements	• Financial support for SRC under GAK • Promotion of wood recycling (KrWG)	• Standards and norms, e.g. on bio-based ingredients • Incentives for wood gasification in the electricity sector	• Chemicals regulation (REACH)

Fig. 22.5 Policy measures in the wood-based bioeconomy. (Source: Own representation, based on Pannicke et al., 2015; Gawel et al., 2016)

wood uses. And “indirect” bioeconomy policy measures (e.g. European emissions trading, KrWG) are still far from the goal of establishing fair competitive conditions between bio-based and fossil processes and products. At the same time, there has been little demand for a comprehensive transformation policy mix in so-called “policy markets”, where the supply and demand for policy solutions meet (Pannicke et al., 2015).

In order to achieve a change of path, the impact of existing instruments should first be increased. Acute improvements are needed, for example, in policy measures that make the use of fossil resources appropriately more expensive (e.g. material, but also

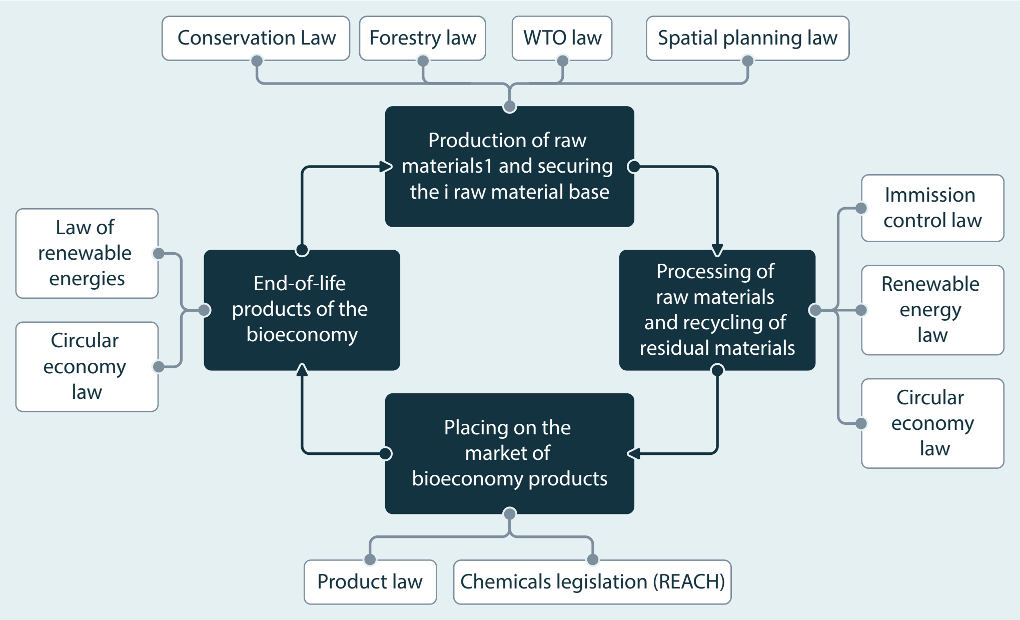


Fig. 22.6 The legal framework of the wood-based bioeconomy. (Source: Own representation)

energy-related climate policy, the "Circular Economy and Safeguard the Environmentally Compatible Management of Waste Circular Economy Act"). At the same time, politicians should communicate a clear long-term commitment to a path transition towards a sustainable bioeconomy – analogous to the "energy transition".

In addition, existing R&D funding should be combined with targeted support for niches. This includes, for example, improved "green" procurement, campaigns to improve consumer acceptance of bio-based products, as well as support for networks and knowledge transfer on the producer and consumer side. What is needed is a bioeconomy innovation system with a mix of *technology-push* and direct and indirect *demand-pull measures*.

As the example of bioenergy has shown, it is advisable to implement transformation policies only gradually in order to enable learning processes as well as corrections should problems arise with regard to sustainability assurance, among other things (Gawel et al., 2016). On the other hand, policies that create extensive demand pull for specific timber uses should be avoided. On the one hand, political decision-makers would need a high degree of information about uncertain facts and developments in order to plan such measures, and on the other hand, this could also be associated with considerable distortions of wood material flows.

The implementation of the "enabling function" of bioeconomy governance rather requires the creation of a selection environment that guides decentralized search processes towards sustainable wood resources, processes and products, e.g. supply chains based on recycled material and waste wood. Concrete proposals include, for example, scaling back the promotion of energy recovery from primary and waste wood (Ludwig et al., 2016a, b). In order to promote cascades of use for biobased raw materials, adjustments are required to the circular economy legislation, for example in the form of a revision of the Waste Wood Ordinance or the establishment of separation obligations, sorting quotas and recycling quotas (Ludwig et al., 2016a, b).

Furthermore, policy should specifically promote sustainability-enhancing innovations in waste wood use and recycling. It is also necessary to review existing forestry, agricultural, environmental and trade policies in terms of their ability to ensure sustainability even in the event of a sharp increase in biomass demand. Over time, these first steps of "constraining" and "enabling" bioeconomy governance can help build a "coalition of proponents" that supports a more comprehensive transformation policy mix.

- In the long term, the aim should be a self-sustaining transformation process that sees the advantages of a sustainable bioeconomy rewarded on the market itself and meets with sufficient "political" and economic demand. Substantial steps towards a change of path from a fossil-based economy to a sustainable, bio-based circular economy require a number of important governance conditions:
- The state creates stable long-term framework conditions for the development of a wood-based bioeconomy. These include both the direct promotion of innovative applications and technologies and the consistent increase in the price of fossil competition. In this context, coordination with global economic developments is just as necessary as securing lasting political approval for the sustainability transformation.
- A learning bioeconomy policy is being pursued that specifically takes into account the uncertainties of increased demand for biomass for energy and material uses and attaches great importance to ensuring the sustainability of biobased economic activity (no funding "at any price").
- To this end, a clearly contoured, genuine policy field of the bioeconomy and a consistently developed, corresponding bioeconomy law are emerging.
- Consumers recognise social added value in sustainable bio-based products, articulate an increased willingness to pay for corresponding products and are open to innovations. A consistent sustainability-related pricing policy, but also communication and information on the part of politicians and companies active in the bioeconomy can contribute to this.
- Companies seek long-term development opportunities, are innovation- and quality-oriented, and form political coalitions that confront the advocates of maintaining "fossil development paths" in the political arena as well (and not only in markets). In doing so, they focus on economic added values that "offer" something to society as a "sustainability service" rather than "demand" something from it. Companies integrate value chains, in particular by linking material and energy uses, for example through the cascade principle, and pursue a consistently transparent and active communication of both risks and consumer benefits.

References

Bioökonomierat. (2015). Die deutsche Chemieindustrie – Wettbewerbsfähigkeit und Bioökonomie. BÖRMEMO 02. http://biooekonomierat.de/fileadmin/Publikationen/berichte/BOERMEMO_Chemie_final.pdf. Accessed: 05.12.2018.

Bioökonomierat. (2016). Holz in der Bioökonomie – Chancen und Grenzen. BÖRMEMO 05. http://biooekonomierat.de/fileadmin/Publikationen/empfehlungen/BOER_Memo_Holz.pdf. Accessed: 05.12.2018.

Bioökonomierat. (2018). Thesen zur Gestaltung der Bioökonomiepolitik 2018. http://biooekonomierat.de/fileadmin/Publikationen/empfehlungen/BO___Thesenpapier_final.pdf. Accessed: 05.12.2018.

BMBF (Bundesministerium für Bildung und Forschung). (2010). Nationale Forschungsstrategie BioÖkonomie 2030. Unser Weg zu einer bio-basierten Wirtschaft.

https://www.bmbf.de/pub/Nationale_Forschungsstrategie_Biooekonomie_2030.pdf. Accessed: 05.12. 2018.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2013). Nationale Politikstrategie Bioökonomie. Nachwachsende Ressourcen und biotechnologische Verfahren als Basis für Ernährung, Industrie und Energie. https://www.bmbf.de/files/BioOekonomiestrategie.pdf. Accessed: 05.12.2018.

Carus, M., Raschka, A., Fehrenbach, H., Rettenmaier, N., Dammer, L., Köppen, S., Thöne, M., Dobroschke, S., Diekmann, L., Hermann, A., Hennenberg, K., Essel, R., Piotrowski, S., Detzel, A., Keller, H., Kauertz, B., Gärtner, S., & Reinhardt, J. (2014). Ökologische Innovationspolitik – Mehr Ressourceneffizienz und Klimaschutz durch nachhaltige stoffliche Nutzungen von Biomasse. Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_01_2014_druckfassung_uba_stofflich_abschlussbericht_lang_20_2_2014_2.pdf. Accessed: 05.12.2018.

Gawel, E. (2011). Stoffstromanalyse und Stoffstromsteuerung im Bereich der Bioenergie. In F. Beckenbach & A. I. Urban (Eds.), *Methoden der Stoffstromanalyse. Konzepte, agentenbasierte Modellierung und Ökobilanz* (pp. 255–283). Metropolis.

Gawel, E., Purkus, A., Pannicke, N., & Hagemann, N. (2016). Die Governance der Bioökonomie – Herausforderungen einer Nachhaltigkeitstransformation am Beispiel der holzbasierten Bioökonomie in Deutschland. UFZ Discussion Papers 02/2016, Helmholtz-Zentrum für Umweltforschung – UFZ, Leipzig. https://www.econstor.eu/bitstream/10419/142760/1/861932153.pdf. Accessed: 05.12.2018.

Hagemann, N., Gawel, E., Purkus, A., Pannicke, N., & Hauck, J. (2016). Possible futures towards a wood-based bioeconomy – A scenario analysis for Germany. *Sustainability*. https://doi.org/10.3390/su8010098

Kay, A., & Ackrill, R. (2012). Governing the transition to a biofuels economy in the US and EU: Accommodating value conflicts, implementing uncertainty. *Policy and Society*. https://doi.org/10.1016/j.polsoc.2012.10.001

Lahl, U. (2014). Bioökonomie für den Klima- und Ressourcenschutz – Regulative Handlungskorridore. BZL Kommunikation und Projektsteuerung/NABU (Naturschutzbund Deutschland e.V.). https://www.nabu.de/imperia/md/content/nabude/gentechnik/studien/140821-nabu-biooekonomie-studie_2014.pdf. Accessed: 05.12.2018.

Ludwig, G., Tronicke, C., Köck, W., & Gawel, E. (2014). Rechtsrahmen der Bioökonomie in Mitteldeutschland. Bestandsaufnahme und Bewertung. UFZ Discussion Papers 22/2014. Helmholtz Centre for Environmental Research – UFZ, Leipzig. https://www.econstor.eu/bitstream/10419/103565/1/802930913.pdf. Accessed: 10.12.2018.

Ludwig, G., Tronicke, C., Köck, W., & Gawel, E. (2015). Der Rechtsrahmen für die Bioökonomie in Deutschland. *Die Öffentliche Verwaltung, 68*(2), 41–53.

Ludwig, G., Gawel, E., & Pannicke, N. (2016a). Altholz in der Kaskadennutzung – eine Bestandsaufnahme für Deutschland. *Wasser und Abfall, 18*(11), 52–56.

Ludwig, G., Gawel, E., & Pannicke, N. (2016b). Kreislaufwirtschaft im Bereich Holz – Rechtliche Bestandsaufnahme und Reformvorschläge für Kaskadennutzung. *Zeitschrift für das Recht der Abfallwirtschaft, 15*(4), 170–178.

Mantau, U. (2012). Holzrohstoffbilanz Deutschland: Entwicklungen und Szenarien des Holzaufkommens und der Holzverwendung von 1987 bis 2015. Zentrum für Holzwirtschaft, Arbeitsbereich Ökonomie der Holz- und Forstwirtschaft. University of Hamburg. https://www.dhwr.de/docs/dyn/5842/00_holzrohstoffbilanz_2012.pdf. Accessed: 10.12.2018.

Mantau, U. (2013). Umsatzentwicklung energetischer Holzverwendung in Deutschland 2000 bis 2012: Abschlussbericht. Im Auftrag des Zentrum für Sonnenenergie- und Wasserstoff-Forschung. https://literatur.thuenen.de/digbib_extern/dn053145.pdf. Accessed: 10.12.2018.

Mantau, U., Sörgel, C., & Weimar, H. (2007). *Holzrohstoffbilanz Deutschland: Bestandsaufnahme 1987 bis 2005. Zentrum für Holzwirtschaft, Arbeitsbereich Ökonomie der Holz- und Forstwirtschaft*. University of Hamburg.

McCormick, K., & Kautto, N. (2013). The bioeconomy in Europe: An overview. *Sustainability*. https://doi.org/10.3390/su5062589

Pannicke, N., Gawel, E., Hagemann, N., Purkus, A., & Strunz, S. (2015). The political economy of fostering a wood-based bioeconomy in Germany. *German Journal of Agricultural Economics*. http://www.gjae-online.de/news/pdfstamps/freeoutputs/GJAE-817_2015.pdf. Accessed: 10.12.2018.

Pfau, S., Hagens, J., Dankbaar, B., & Smits, A. (2014). Visions of sustainability in bioeconomy research. *Sustainability*. https://doi.org/10.3390/su6031222

Purkus, A., Hagemann, N., Bedtke, N., & Gawel, E. (2018). Towards a sustainable innovation system for the German wood-based bioeconomy: Implications for policy design. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2017.04.146

Richardson, B. (2012). *From a fossil-fuel to a bio-based economy: The politics of industrial biotechnology*. Environment and Planning C: Politics and Space. https://doi.org/10.1068/c10209

Staffas, L., Gustavsson, M., & McCormick, K. (2013). Strategies and policies for the bioeconomy and bio-based economy: An analysis of official national approaches. *Sustainability*. https://doi.org/10.3390/su5062751

Vandermeulen, V., Van der Steen, M., Stevens, C. V., & Van Huylenbroeck, G. (2012). Industry expectations regarding the transition towards a bio-based economy. *Biofuels, Bioproducts and Biorefining*. https://doi.org/10.1002/bbb.1333

WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen). (2008). Welt im Wandel: Zukunftsfähige Bioenergie und nachhaltige Landnutzung. https://www.wbgu.de/fileadmin/user_upload/wbgu.de/templates/dateien/veroeffentlichungen/hauptgutachten/jg2008/wbgu_jg2008.pdf. Accessed: 10.12.2018.

Weimar, H. (2015). Altholz- und Holzaufkommen und -verwendung in Europa (und Deutschland), Präsentation auf dem Altholztag des BAV – Bundesverband der Altholzaufbereiter und -verwerter e. V., Speyer. (unpublished).

Weimar, H., & Mantau, U. (2006). Standorte der Holzwirtschaft: Einsatz von Holz in Biomasse- und Holzfeuerungsanlagen: Abschlussbericht. Zentrum für Holzwirtschaft, Arbeitsbereich Ökonomie der Holz- und Forstwirtschaft. Universität Hamburg. https://literatur.thuenen.de/digbib_extern/dn051277.pdf. Accessed: 19.12.2019.

Weimar, H., Döring, P., & Mantau, U. (2012). Einsatz von Holz in Biomasse-Großfeuerungsanlagen 2011. Zentrum für Holzwirtschaft, Arbeitsbereich Ökonomie der Holz- und Forstwirtschaft. Universität Hamburg. https://literatur.thuenen.de/digbib_extern/dn051277.pdf. Accessed: 10.12.2018.

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Governance of the Bioeconomy in Global Comparison

Thomas Dietz, Jan Börner, Jan Janosch Förster, and Joachim von Braun

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_23

23.1 Introduction

The bioeconomy is based on the idea of applying biological principles and processes in all sectors of the economy and to increasingly replace fossil-based raw materials in the economy with bio-based resources and principles. An innovative and sustainable use of bio-based resources in different sectors of the economy (i.e., a bio-based transformation) provides opportunities for achieving a number of different Sustainable Development Goals (SDGs), which have been designed to improve social, economic, and ecological living conditions. Particularly, this applies to sustainable solutions to current climate change risks (De Besi & McCormick, 2015). However, recent studies emphasize the dependence of a sustainable bioeconomy on technical, economic, and social prerequisites that the bioeconomy itself cannot create (Pfau et al., 2014). Experts, therefore, increasingly demand the development of a comprehensive governance framework for the bioeconomy to ensure the emergence of sustainable bio-based transformations (Von Braun & Birner, 2016; El-Chickakli et al., 2017; ▶ Chap. 22).

Previous research on this topic is mostly organized around case studies, which focus on the governance of selected segments of the bioeconomy in individual countries or in small samples of countries (Bosman & Rotmans, 2016; Purkus et al., 2015). The detailed contribution by Pannicke et al. on the governance of the German wood industry may serve as an example (Pannicke et al., 2015; ▶ Chap. 22). However, a broader perspective that provides a comparative global overview about national bioeconomy politics is still missing.Overall, we found 41 states worldwide that currently pursue explicit political strategies to expand and promote their bioeconomies. In this chapter, a systematic overview of 41 of these national bioeconomy strategies in existence at the time of this research is provided. What types of bioeconomies are individual states striving for? Why does the development of a sustainable bioeconomy require an effective governance framework?

Which political means are available to states to promote transformations towards sustainable bioeconomies, and how do individual states design their national bioeconomy strategies in order to meet this demand for a sustainable governance framework? In the following sections, we will address these research questions. In doing so, we aim to not only develop an overview of national bioeconomy policies, but also to develop an information tool that enables national and international policy makers to learn from other countries' bioeconomic strategies. Our considerations rest on a comprehensive understanding of the bioeconomy. We distinguish between four bio-based transformation paths:

1. substitution of fossil fuels with bio-based raw materials,
2. productivity increase in bio-based primary sectors,
3. increasing efficiency in biomass utilization and
4. value creation and addition through the application of biological principles and processes separate from large-scale biomass production.

Whether or not the bioeconomic development along these four pathways will have a positive impact on the achievement of SDGs is uncertain. One key challenge is that bio-based transformations may involve high conversion costs (Bröring et al., 2017). Path dependencies and economic incentive systems that stem from the fossil fuel era and pre-biotechnological production processes might hamper investments in a progressive bioeconomy. The question of how politics can support the rise of the bioeconomy through appropriate political means (enabling governance), therefore, presents the first key challenge for the development of a sustainable bioeconomy. In principle, states have a wide range of different mechanisms at their disposal to promote their bioeconomies. These mechanisms may include a bio-based research and development strategy, enhancing the competitiveness of bio-based products through subsidies, or implementing awareness-raising campaigns to increase societal participation in bio-based transformation including more responsible and sustainable consumption.

However, technical progress rarely offers only positive opportunities, but usually also leads to new risks. This is also the case for the bioeconomy. Scholars interested in studying the bioeconomy point to goal conflicts between SDGs that can result from bio-based transformations. Today, the discussion about conflicting goals goes far beyond the original "food versus fuel" debate in the field of bioenergy development and includes issues such as global equity concerns, water scarcity, land degradation and land use change. The identification and effective political management of conflicting goals, therefore, represents the second major challenge for the development of a sustainable governance framework for the bioeconomy. To address this, a number of different public and private governance tools exist that states can use to minimize tradeoffs and promote synergies in bio-based transformation processes (constraining governance).

However, how do individual states really react to these two fundamental governance challenges, and which means do they concretely employ to make their bioeconomies sustainable? Our results suggest the following: today a great number of states have set the goal of developing and expanding their bioeconomies. Further, states are willing to provide comprehensive political support to their bioeconomies to achieve this goal. Currently, states are highly active in addressing the first abovementioned governance challenge (enabling governance). On the other hand, our results show that the political management of conflicting goals has not yet reached the same level of attention. Only a minority of national bioeconomy strategies even mention the potentially negative consequences of bio-based transformations for sustainable development, and those states that are pursuing a more sustainable strategy mostly opt for soft political approaches to manage these conflicts. Overall, states address the second fundamental challenge of developing a sustainable bioeconomy (constraining governance) to a considerably lesser degree than the first challenge (enabling governance).

The chapter consists of two sections: the first section lays out the conceptual foundations for our empirical study. We begin with a brief note on the concept of governance. Subsequently, we characterize the four different transformation paths along which bio-based transformations are likely to proceed. We then discuss the two key governance challenges for a sustainable bio-based transformation and present a set of key governance mechanisms that governments can use to support the development of a sustainable bioeconomy. Based on this theoretical framework, the second section presents our empirical analysis of a total of 41 national bioeconomy strategies. Here, we show which bio-based transformation path (or which combination of transformation paths) the states follow strategically, which of the governance mechanisms specified in the first section the states apply to promote their bioeconomies, which goal conflicts they identify, and how they attempt to regulate them. Finally, we summarize the results of the study and present perspectives for further research.

23.2 Coneptual Foundations

23.2.1 A Short Note on the Concept of Governance

Governance can be understood as the process by which societies adapt their rules to new challenges (Stone-Sweet, 1999). Governance has a substantial dimension (what are the rules?), a procedural dimension (how are the rules developed?) and, finally, a structural dimension (the procedural rules and institutions that determine rule-making, how the rules are implemented and enforced, and how conflicts over rules are resolved). Societal adaption of rules to new challenges can be spontaneous and informal at the level of social relationships and networks. However, modern societies also delegate governance functions to specialized institutions, which set and enforce the rules in formally organized procedures. Such institutions first and foremost include the state at local, regional, and national level, but may also include inter- and supranational organizations, as well as private standard setters, which together build an interacting and overlapping governance system of plural authorities. In this sense, the UN Commission has defined the term governance as

> […] the sum of the many ways individuals and institutions, public and private, manage their common affairs. It is a continuing process through which conflicting or diverse interests may be accommodated and co- operative action may be taken. It includes formal institutions and regimes empowered to enforce compliance, as well as informal arrangements that people and institutions either have agreed to or perceive to be in their interest […] (Commission on Global Governance, 1995).

23.2.2 The Concept of Four Bio-Based Transformation Paths

The course and effects of bioeconomic transformation processes depend, among other aspects, on the development level, resources and political system of a given state (see ◘ Fig. 23.1).

Transformation processes can be triggered by the interaction of driving forces, such as population growth and technological innovation, or by political or social action. Depending on the country context and its interaction with other economies, for example in the form of trade and knowledge transfer, bioeconomic transformation can proceed along one or more of the four paths depicted in ◘ Fig. 23.1 with different possible effects.

▪ Transformation Path 1 (TP1)

In the past, this rather intensely researched TP has often been triggered by temporarily increased oil prices, subsidies, and environmental policies. For example, biofuel policies in the EU and US have led to increased demand for bioenergy, with direct and indirect effects on land use worldwide depending on land availability and the effectiveness of environmental and economic governance systems (Ceddia et al., 2013, 2014; Searchinger et al., 2015).

▪ Transformation Path 2 (TP2)

If technological innovation increases productivity in agriculture, forestry, or even fishing, it can release transformative forces that open up new production methods or locations. In the past, and globally, according to the so-called Borlaug hypothesis, this has repeatedly led to an easing in food markets despite increasing population growth (Lobell et al., 2013). However, regional and local boosts in agricultural productivity have also been shown to increase demand

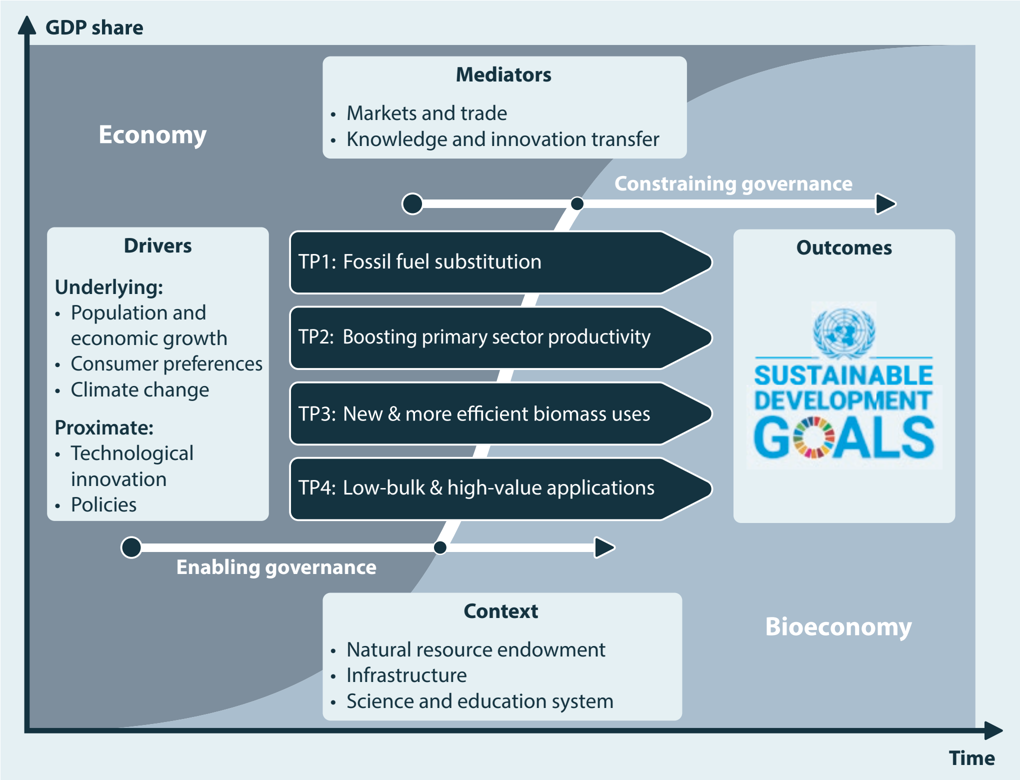


Fig. 23.1 Conceptual diagram of transformative pathways in the bioeconomy (developed by the authors)

for land in ecological sensitive biomes, leading to losses in globally valued ecosystem services (Ceddia et al., 2014; Angelsen & Kaimowitz, 2001).

Transformation Pathway 3 (TP3)

Innovation in downstream sectors often aims to increase the efficiency of biomass use and waste stream recycling. Such innovation can be associated with "rebound effects", i.e., increased demand due to improved provision. In the long term, however, the impact depends on supply dynamics, consumer behavior and the regulatory environment (Herring & Roy, 2007; Smeets et al., 2014).

Transformation Pathway 4 (TP4)

Biological principles and processes can be used largely independently of biomass streams' industrial applications, such as in the case of enzymatic synthesis and "biomimicry". Many countries with bioeconomic ambitions have high expectations for this knowledge and technology-intensive TP (see ► Sect. 23.2). Corresponding transformative processes result, inter alia, from providing cheaper and more environmentally friendly production methods or completely new products.

The above-mentioned transformation pathways can be driven by both production (supply) and consumption (demand) dynamics. We focus primarily on supply side dynamics in this chapter. However, it is noteworthy that promoting sustainable consumption through regulations and incentive systems is one among many of the governance challenges of the sustainable bioeconomy.

23.3 Governing the Bioeconomy: Theoretical Framework

23.3.1 Governance to Promote Sustainable Bioeconomic Dynamics

The four paths of bio-based transformation presented in the last section offer opportunities as well as risks for a sustainable transformation of our existing economic and social systems. As shown above, one of the major opportunities of a comprehensive bio-based transformation is the possibility of promoting sustainable growth across economic sectors. However, a sustainable bio-based transformation cannot be taken for granted.

Current literature on bioeconomy repeatedly emphasizes the great potential of the bioeconomy for sustainable developments towards SDG achievement, but simultaneously points out that the realization of these potentials is facing considerable hurdles. Some researchers argue that the path dependence of economic and political development is the root cause of the problem (Gawel et al., 2016). This means that previous decisions in politics, economics, and society—taken before the bio-based transformation paradigm emerged—have shaped the economic system in a way that today hampers the development of a bio-based economy even though it may bring about significant sustainability gains.

First, problems of path dependencies may arise from a lack of adaptation of existing institutional frameworks to the specific needs of the bioeconomy. Indeed, the political and legal institutions (such as intellectual property rights, consumer protection, environmental rights), which govern our current economic systems, have developed over long periods, during which the technological possibilities of the current bioeconomy were unknown. Given this, the chances are high that existing institutions are poorly aligned to the institutional demands of a rapidly developing and innovative bioeconomy. Institutional path dependencies might thus lead to a situation in which the bioeconomy faces high regulatory and transaction costs, which, in turn, may prevent the transformative dynamics of the bioeconomy from unfolding.

Further, problems of path dependency occur at the level of industrial organization and production. Many existing value chains are specialized in an efficient use of fossil-based resources and pre-biotechnological production processes. The same applies to existing infrastructure (transport systems), on which these economic activities are based. Naturally, this leads to lock-in effects (Unruh 2002a, b). Even if bio-based transformations promise long-term sustainability gains for both individual companies and society as a whole, companies currently avoid incurring the costs of changing their organizational structures and methods of production towards bio-based processes, since under the given conditions such changes would still compromise their competiveness. To conclude, it seems that current economic systems that have been shaped through the utilization of fossil-based resources and pre-bioeconomy production techniques are not yet able to provide the necessary incentives to leverage comprehensive bio-based transformations.

Both points have in common that they conceptualize path dependency problems as problems of economic incentives that ill-inform individual economic decisions. From these rational choice-based approaches, a structural approach can be distinguished. From a sociological perspective, both our identity and knowledge about the world is defined by culture, social norms, and ideology and, ultimately, these social structures also determine our economic conduct (Finnemore, 1996).

Obviously, normative and cognitive structures that incrementally manifest in a given society are even harder to change than economic incentives. At the level of social structures, path-dependency problems limiting bioeconomic dynamics may, therefore, be even stronger than at the level of economic institutions, organizations and production techniques. Misinformation, including limited knowledge, about the properties of bio-based products or a conceptual reduction of the bioeconomy to risk technologies can undermine consumer confidence (a phenomenon well known from the debate around genetically modified organisms). The bioeconomy has an influence on almost all areas of social life. It changes what we eat, how we live, how we move, how we dress, and much more. Consumption patterns in all these areas are deeply rooted in the cultural habits of societies and, therefore, extremely difficult to change (Bröring et al., 2017).

In conclusion, it can be said that not only the economic institutions, organizations, and production techniques that evolved in the era of fossil resource utilization but also the societal structures that developed during this period may hamper the emergence of a dynamic bioeconomy. Against this background, it is not surprising that scholars interested in bioeconomy research currently regard the creation of an appropriate governance framework that is capable of overcoming the various path-dependency problems as one of the most pressing political challenges in the development of a sustainable bioeconomy.

However, which specific governance mechanisms can governments use to address this challenge? One governance tool, often discussed in this context, presents the implementation of a comprehensive research and development strategy to promote investments in technological innovations whose costs and risks private actors are not willing to incur under the given conditions (Bosman & Rotmans, 2016). Further, political support measures can aim at increasing the competitiveness of bio-based products through subsidies, thereby creating markets for the bio-economy that do not independently develop in the economy (Dabbert et al., 2017). Industrial location policies may have similar effects (Cooke, 2007). Political support measures such as the creation of favorable legal frameworks, state-supported training of the labor force or the promotion of industry clusters are all intended to make it more attractive for companies to invest in the bioeconomy. This form of political support for the bioeconomy also includes measures for strategic international research collaborations and foreign direct investment. Finally, states can promote bio-based transformation at a societal level through deliberate political campaigns to increase the legitimacy and acceptance of the bioeconomy (Bröring et al., 2017).

► Box 23.1 provides an overview of such governance mechanisms that states can use to promote bio-based transformative processes. In the following empirical section of this chapter, this serves as a typology for the policy instruments that states actually intend to use to promote their respective bioeconomies.

Box 23.1 Overview of the means for enabling governance

(I) Promoting research and development for a bio-based transformation
  - Funding of research projects
  - Establishment of specific research facilities
  - Promotion of research networks and strategic partnerships
  - Promotion of knowledge and technology transfer (science-praxis-nexus)

(II) Improving the competitiveness of the bioeconomy through subsidies
  - Quotas for the bioeconomy
  - Promotion of bio-based public procurement
  - Promotion of sustainable consumption behavior

  - Tax benefits
  - Specific credit programs
- (III) Industrial location policies for bio-based industries
  - Promotion of industry clusters in the field of bioeconomy
  - Promotion of knowledge and technology transfer between research and industry
  - Promotion of labor education in the field
  - Creation of appropriate intellectual property rights
  - Promotion of foreign direct investment (FDI) in the field
- (IV) Political support for bio-based social change
  - Promote public dialogues to increase understanding of the functioning of the bioeconomy
  - Promote public dialogues on technological risks in the field of bio-economics

23.3.2 Governance of Risks and Goal Conflicts

The creation of a favorable political framework within which the bioeconomy can thrive presents one major governance challenge. However, political support measures alone will not suffice to ensure the development of a sustainable bioeconomy. The problem is that, as much as the bioeconomy can contribute to the achievement of a range of different SDGs, it can also undermine the achievement of SDGs (Kleinschmit et al., 2017; Fritsche & Rösch, 2017). An effective political regulation of these conflicting objectives presents the second major challenge for a sustainable governance of the bioeconomy.

The concept of bioeconomy rests on the idea of applying biological principles and processes in all sectors of the economy and to increasingly replace fossil-based raw materials in the economy with biogenic resources. However, the question whether or not bioeconomic transformations will either lead to more sustainability or produce new sustainability risks remains debated. The following table (▣ Fig. 23.2) provides an overview of some common aspects of this debate.

Both the above-mentioned optimistic and critical views on the impact of bioeconomic transformation on SDGs achievements (▣ Fig. 23.2) depend strongly on assumptions about how and in which contexts new bio-based technologies and principles will be used. We illustrate this point in the following examples.

Sustainability Dimension (SDG)	Opportunities	Risks
Food security (SDG 2)	Increase via higher yields and new production methods	Reduction due to food price increases
Poverty/inequality (SDG 1, 10)	Reduce via transfer of technology and leapfrogging	Increase via exclusion from technical progress
Natural resources (SDG 7, 14, 15)	Conserve by improving production methods	Degrade/loss through inefficient production and overuse
Health (SDG 3)	Improve through new and retined torms of therapy	Risk/damage through improver use of risky technologies
Climate change (SDG 13)	Mitigate through emissions reductions	Exacerbate through direct and indirect land use change

▣ **Fig. 23.2** Frequently mentioned opportunities and risks of bioeconomic transformation

► Example 1

The EU promotes biofuels with the aim of reducing emissions (SDG 13). This can lead to a global loss of tropical forests through direct and indirect land use change, but also to the spread of environmentally hazardous and health-threatening production methods (which conflicts with SDGs 3, 14, 15). Both technological innovation (e.g., improving production of biomass at marginal sites with higher yields) and governance mechanisms (e.g., implementing existing legislation to prevent illegal deforestation or misuse of agrochemicals or incentive systems for sustainable production) can help alleviate this conflict. ◄

► Example 2

Developed countries promote bio-based applications in chemical or pharmaceutical sectors (SDG 3). Due to restrictive patent rights and often lengthy and costly licensing procedures, the associated benefits accrue only to the affluent segment of the world's population. This might create a conflict with SDG 10. This conflict could be mitigated by innovation transfer, more efficient administrative structures and a more inclusive patent system.

These two examples show how narratives of the bioeconomy that highlight the potentially associated risks often assume that regulations constraining the bioeconomy are ineffective, or that existing technologies and processes that might be able to increase the efficiency of the bioeconomy remain inaccessible. On the other hand, perspectives that highlight the opportunities inherent in bioeconomic developments assume that efficient biotechnologies will evolve and diffuse and that appropriate governance frameworks can be set up to regulate the remaining potentially negative effects of the bioeconomy.

The political support measures that enable the evolution and diffusion of efficient biotechnologies have been discussed above (enabling governance). In the following, we focus on the question of what states can do to constrain economic activities related to the bioeconomy where necessary (constraining governance). Looking into this issue of regulating the bioeconomy, it strikes us that various governments and non-government actors have already developed a variety of rules to govern bioeconomic activities in different areas of the bioeconomy. For example, multistakeholder initiatives such as the Global Bioenergy Partnership or the United Nations Voluntary Guidelines on the Responsible Governance of Tenure, Land, Fisheries, and Forests in the Context of National Food Security both aim to ensure the priority of the right to food in the bioeconomy to prevent land grabbing. Other examples include the International Draft Standard DIN EN ISO 14046: 2015–11, which sets out guidelines for determining the water footprint of products based on a life cycle assessment, or the United Nations Convention on Biological Diversity, which aims to connect the bioeconomy to conservation initiatives.

Given this relatively well-developed normative basis, the central challenges in developing an effective regulatory framework for the bioeconomy clearly emerge in the later stages of the governance cycle, i.e., in the implementation and enforcement of the existing rules (Förster et al., 2017). The adoption of regulations into state legislation is one possibility, but it presupposes the existence of functioning state enforcement mechanisms, which do not exist in many emerging and developing countries. In addition, state regulations operate only within the territory of a state, but they have no reach to regulate cross-border economic processes, and they have less influence again on global economic dynamics, both of which are becoming increasingly important in the global bioeconomy. An expansion of international law might provide a solution, but is itself subject to major compliance problems due to the absence of an authority beyond the individual states that could enforce compliance with international law (Dietz, 2014). Of course, states can refrain from a pure legal enforcement logic and create positive incentives to regulate a global bioeconomy (e.g., payment for ecosystem services (Börner et al., 2017)), and support softer instruments, such as private standards and certification systems along global value chains (Auld et al., 2009).

Ultimately, an effective form of regulation for the bioeconomy can only be created through the use of a combination of different public and private mechanisms. We summarize the individual regulatory approaches that states may support to achieve this goal in ► Box 23.2 below. ◄

Box 23.2 Overview of regulatory mechanisms

(I) State regulation of the bioeconomy
(II) Governmental development of positive incentives (e.g., payments for environmental services)
(III) Government support for private standards and certifications
(IV) International cooperation (through international organizations and regimes)

23.4 Methods

We conducted a qualitative document analysis (Mayring, 1991) of national bioeconomy strategy documents using ATLAS.TI software. We provide an overview of the countries and documents analyzed in Appendix A at the end of this article. The tables above (► Boxes 23.1 and 23.2; ◘ Figs. 23.1 and 23.2) served as a codebook guiding the systematic coding of the strategy documents. We have used ► Box 23.1 as providing the themes to analyze the enabling governance means for achieving national development goals as well as contributing to addressing selected global sustainability goals contained in ◘ Fig. 23.2. ► Box 23.2 serves as a heuristic conceptual overview of possible regulatory mechanisms grouped into four (I–IV) dimensions. The methods used draw mainly upon techniques of qualitative content analysis (Labuschagne, 2003). The analytic procedure entailed selecting and appraising passages contained within the policy documents with regard to the themes of the codebook and connecting them to other lines, quotations about political means chosen to address a certain issue. This, for example, is related to the finding of anticipated negative impacts of implementing the bioeconomy policy on land and water resources and the governance means chosen to address them. Such document analysis yielded data in the form of excerpts, quotations, or entire passages chosen according to the major themes and categories from the codebook (Wild et al., 2009).

23.5 Results

Having laid out our preferred indicators to distinguish and classify national strategies, in this section we now discuss our findings from the empirical analysis of national bioeconomy strategies. Specifically, our empirical analysis of 41 different national bioeconomy strategies aims to contribute to answering the following three questions:

1. Type of bioeconomy: Which of the four bio-based transformation pathways or combinations of transformation paths are individual countries pursuing in their strategies?
2. Enabling governance: Which means of governance do countries employ in their political strategies to overcome problems of path dependencies in the development of a sustainable bioeconomy?
3. Constraining governance: Which goal conflicts in the development of a sustainable bioeconomy have the individual countries identified in their strategies, and which political means have the individual strategies used to regulate these goal conflicts and reduce resulting risks?

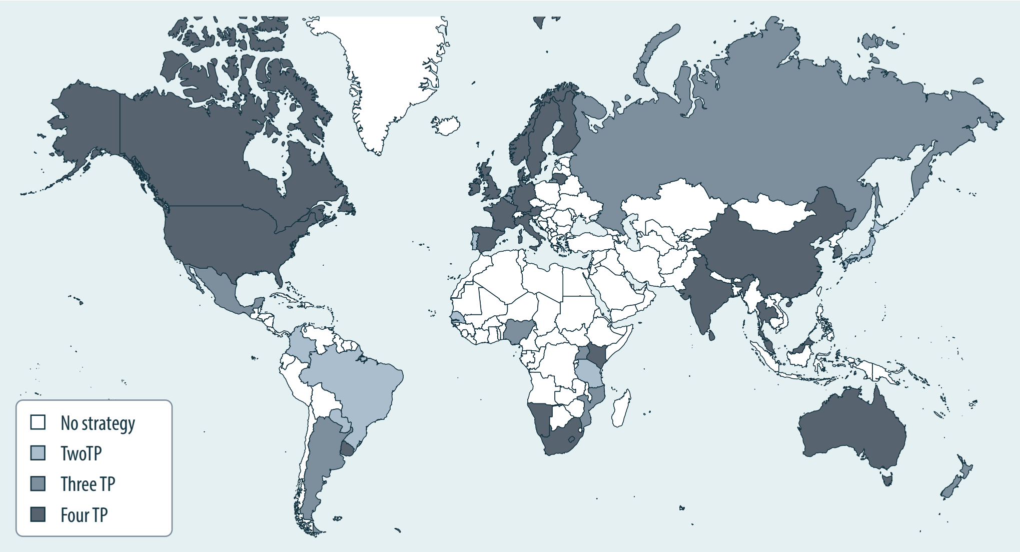


Fig. 23.3 Transformative pathways by country

23.5.1 Type of Bioeconomy

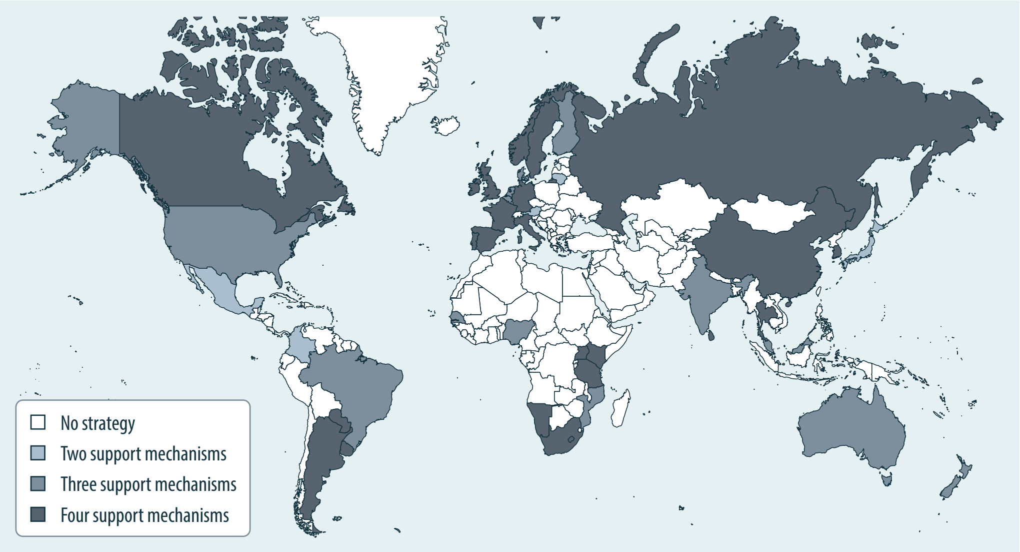
Practically all countries with explicit bioeconomy strategies aim to foster transformation processes along at least two of the pathways outlined in Fig. 23.3. In countries that explicitly envision only two transformation pathways, particular emphasis is often placed on the efficient provision of biomass for TP1, both domestically and for trading partners, as in the case of Brazil.

By contrast, the majority of industrial nations, as well as some emerging economies, envisage or currently implement more diversified strategies along all four TPs. In the majority of cases, the selection of and focus on individual TPs in the examined strategies reflects three aspects: the respective resource availability of the countries (e.g., availability or scarcity of agricultural area); historically developed pioneering roles in special technology and research areas (e.g., biotechnology); or country-specific development deficits to be overcome. For example, the German bioeconomy strategy specifically focuses on applications in the field of recycling waste streams and the more efficient or cascading use of biomass (TP2). In turn, China's bioeconomy strategy relies strongly on bio-based substitution of fuels and materials (TP1).

23.5.2 Strategies to Enable the Bioeconomy

How do the individual states intend to promote their bioeconomies politically, and what concrete political means do they use to do so? In this context, Fig. 23.4 below shows the intentions of the individual states to provide political support to their bioeconomies. In Fig. 23.2 of our conceptual framework, we distinguished between four political support measures that states can draw upon in promoting their bioeconomies. Our analysis of these national strategies is based on those categories, and reveals that the individual states are indeed intensively using all these means to strategically promote the development of their bioeconomies.

It becomes clear that almost all states with an explicit bioeconomy strategy rely on



▪ **Fig. 23.4** Enabling policy means in national bioeconomy strategies

at least three of the political support measures identified, and the majority of states even deploy all four measures mentioned above. In other words, they pursue a targeted research and development strategy for bio-based transformation and want to improve the competitiveness of their bioeconomy through subsidies. In addition, many countries pursue active industry location policies aimed at improving the overall conditions for bio-based industries, and plan to improve the acceptance of the bioeconomy through education and other capacity-building and awareness-raising campaigns. Thus far, we can state that many countries with bioeconomic ambitions declare comprehensive bioeconomies as a strategic political goal (see ▪ Fig. 23.2) and are prepared to intensively promote this development politically (see ▪ Fig. 23.3). Overall, this suggests that the bio-based transformation may gain momentum in the coming years.

23.5.3 How Do States Regulate Their Bioeconomies?

The complex task of creating expedient regulatory measures for managing conflicting interests throughout the development of a bioeconomy is the second governance challenge. ▪ Figure 23.5 shows the extent to which national bioeconomy strategies give political answers to the risks and potentially related goal conflicts mentioned in ▪ Fig. 23.2 above.

Most national strategies pay little or no attention to risks and goal conflicts (26 out of 41 states). This includes countries with potentially large bioeconomies, such as the USA, Russia, Brazil, and Argentina. In contrast, China and a few African states explicitly recognize the need to manage risks as a crucial political challenge in shaping a sustainable bioeconomy. Overall, European states show the highest political sensitivity to potential risks and goal conflicts.

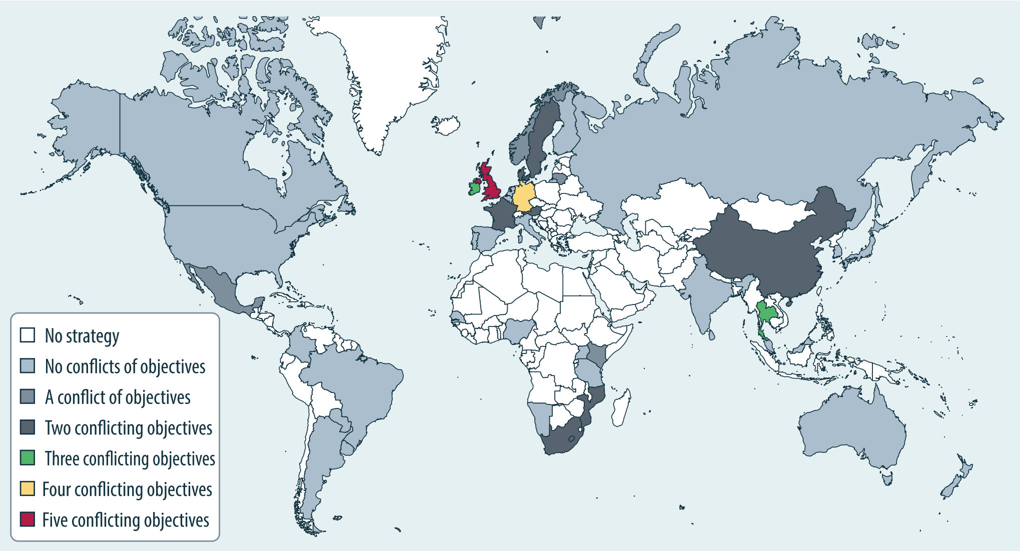


Fig. 23.5 Anticipated risks in national strategy documents of 41 countries

Country	Nutrition	Poverty/Inequality	Nat. Res. (Air)	Nat. Res. (Forests)	Nat. Res. (Land)	Nat. Res. (Water)	Health	Climate
Austria	●				●			
Denmark	●				●			
France	●			●	●			
Germany	●	●		●	●			●
Ireland	●				●		●	
Kenya				●	●	●		
Lithuania					●			
Mexico				●	●	●		
Mozambique	●				●			
Norway						●		
South Africa	●		●		●	●		
Sweden	●				●			
Thailand	●			●	●			●
United Kingdom	●	●	●	●	●	●	●	●
China	●				●	●		
Total	12	2	2	6	15	7	2	3

Fig. 23.6 Overview of conflicting goals and associated risks identified in national bioeconomy strategies

Figure 23.6 compares the identification of conflicting goals in national strategies. It shows that states are particularly concerned with negative impacts of the bioeconomy on land and water resources, as well as on global food security. This reflects the discourses about the sustainability risks associated with the first generation of biofuels. Other negative effects potentially associated with the bioeconomy, such as inequality and poverty, climate, or health risks, have only played a minor role in national strategies so far.

Our content analysis also shows that states rely heavily on soft regulatory means, such as self-regulation of global value chains through private standards and certification regimes, to manage bioeconomy-related risks. In addition, most states advocating more comprehensive regulation to avoid conflicting goals (as in the case of Germany) aim to intensify international cooperation in this field. Despite this, the need to react to bioeconomic conflicts of interest by means of concrete legislative amendments was not a central focus of the national bioeconomy strategies examined. Our analysis also does not reveal a broad willingness of countries with bioeconomy strategies to safeguard the protection of natural resources through the development of positive incentives, such as the widely discussed instrument of payments for ecosystem services (Labuschagne, 2003).

23.5.4 Regional Developments

The last sections have provided a global overview of national bioeconomy strategies. In the following, we complement this view by a short regional assessment. In doing so, it becomes clear from the various figures and maps presented above, that European states have developed the most advanced sustainable bioeconomy strategies, notably the UK and Germany. These results reflect the role of the European Union as an active partner in promoting bioeconomic transformations. It strikes us that most Eastern European Countries are, so far, absent from these developments. Despite the fact that compared to other regions European countries have developed the most advanced bioeconomy strategies, in Europe a substantial governance gap still exists between promoting and regulating the bioeconomy.

The Western Hemisphere presents a further world region in which most individual states are currently advancing comprehensive bioeconomy strategies. Different from the European bioeconomy strategies, which have at least partly integrated some measures to regulate the bioeconomy, regulatory aspects that deal with potential sustainability risks associated with the rise of the bioeconomy are almost completely absent in the strategies drafted by countries located in the Western Hemisphere. The gap between promoting and regulating the bioeconomy is, therefore, even greater here than in Europe. Overall, our results make clear that both North and South American countries are currently undertaking significant efforts to enhance their bioeconomic sectors.

Again, a different picture emerges in Asia and Australia. In this region, we find many states—especially major states such as China, India, Russia, and Australia—that have adopted advanced bioeconomy strategies. However, we also find a significant number of states without explicit bioeconomy strategies. Different from the states located in the Western Hemisphere, among the Asian states at least two states (China and Thailand) pay some attention to the sustainability risks associated with a rise of the bioeconomy.

In Africa, we find the smallest share of countries with bioeconomy strategies. Nevertheless, the countries located in the southern parts of Africa show with their strategies that they see very large potential in the bioeconomy to foster their economic developments in a sustainable way. Among these countries, South Africa and Mozambique stand out in having developed the most advanced bioeconomy strategies. They also include some regulatory aspects. Overall, there is still very large potential for African states to develop more explicit bioeconomy strategies.

23.6 Perspectives

Summarizing the results of our analysis, it is evident that many countries seek to develop and expand their bioeconomies. In order to achieve this, states are willing to support their bioeconomies through comprehensive political means. It is also clear that countries around the world have embraced the first major governance challenge of enabling bio-based transformation. However, the second challenge of deploying political means to address the potential risks and goal conflicts of bio-based transformation does not appear to be wholeheartedly addressed. Only a minority of states even mentioned the potentially negative implications of bio-based transformation for sustainable development. Those states pursuing comprehensive strategies rely largely on soft political means of risk mitigation and conflict management.

The notion of governance includes the process of how societies adapt their rules to new challenges (Stone-Sweet, 1999). In this article, we explored the question of how nation-states globally aim to adapt their rule systems to the governance challenges associated with an emerging bioeconomy. This raises further questions: why are the respective national strategies different? How effectively do individual states implement their strategies? What are the real impacts on SDG achievement that follow when states implement their bioeconomy strategies? In conclusion, it can be said that national governments widely regard the development of a modern bioeconomy as a central strategy to promote their economies and to ensure sustainable development worldwide. However, to achieve these goals, national bioeconomies need an effective and globally coordinated governance framework. Future research should contribute to identifying key ingredients of such a framework and support their effective implementation, for example by documenting implementation processes and outcomes in all relevant sustainability dimensions.

A prerequisite for creating effective governance arrangements is the development of comprehensive approaches for measuring and assessing the bioeconomy (Wesseler & von Braun, 2017). Inadequate monitoring and a lack of impact assessment could otherwise lead to over- or under-regulation of the bioeconomy. The risks associated with the business-as-usual scenario of a fossil-fuel-based future global economy must be confronted with the bioeconomy-specific risks in order to comprehensively assess risks and conflicting goals (Wild et al., 2009). This exceeds the scope of this chapter, but we strongly emphasize the need to investigate these issues in future research.

References

Angelsen, A., Kaimowitz, D., editor (2001). *Agricultural technologies and tropical deforestation*; CABI Publishing in Association with Center for International Forestry Research (CIFOR): New York, NY, USA. ISBN 0851994512.

Auld, G., Balboa, C., Bernstein, S., & Cashore, B. (2009). The Emergence of Non-State Market Driven (NSMD) global environmental governance: A cross sectoral assessment. In M. A. Delmas & O. R. Young (Eds.), *Governance for the environment. Perspectives* (pp. 183–218). Cambridge University Press, Cambridge, UK. https://doi.org/10.1017/CBO9780511627170.009

Börner, J., Baylis, K., Corbera, E., Ezzine-de-Blas, D., Honey-Rosés, J., Persson, U. M., & Wunder, S. (2017). The effectiveness of payments for environmental services. *World Development, 96*, 359–374. https://doi.org/10.1016/j.worlddev.2017.03.020

Bosman, R., Rotmans, J. (2016). Transition governance towards a bioeconomy: A comparison of Finland and the Netherlands. Sustainability, 8. https://doi.org/10.3390/su8101017.

Bröring, S., Baum, C. M., Butkowski, O., & Kircher, M. (2017). Kriterien für den Erfolg der Bioökonomie. In J. Pietszch (Ed.), *Bioökonomie für Einsteiger* (pp. 161–177). Springer Spektrum. ISBN 9783662537626.

Ceddia, M. G., Sedlacek, S., Bardsley, N. O., & Gomez-y-Paloma, S. (2013). Sustainable agricultural intensification or Jevons paradox? The role of public governance in tropical South America. *Global Environmental Change, 23*, 1052–1063. https://doi.org/10.1016/j.gloenvcha.2013.07.005

Ceddia, M. G., Bardsley, N. O., Gomez-y-Paloma, S., & Sedlacek, S. (2014). Governance, agricultural intensification, and land sparing in tropical South America. *Proceedings of the National Academy of Sciences, USA, 110*, 7242–7247. https://doi.org/10.1073/pnas.1317967111

Commission on Global Governance. A New World. (1995). In *Our Global Neighborhood*. Oxford University Press, Chapter 1. http://www.gdrc.org/u-gov/global-neighbourhood/chap1.htm. Accessed:13.6.2018.

Cooke, P. (2007). *Growth cultures: The global bioeconomy and its bioregions*. Routledge, ISBN 978-0-415-39223-5.

Dabbert, S., Lewandowski, I., Weiss, J., & Pyka, A. (Eds.). (2017). *Knowledge-driven developments in the bioeconomy: Technological and economic perspectives*. Springer. https://doi.org/10.1007/978-3-319-58374-7

De Besi, M., & McCormick, K. (2015). Towards a bioeconomy in Europe: National, regional and industrial strategies. *Sustainability, 7*, 10461–10478. https://doi.org/10.3390/su70810461

Dietz, T. (2014). *Global order beyond law–how information and communication technologies facilitate relational contracting in international trade*. Hart Publishing. ISBN 9781849465403.

El-Chickakli, B., von Braun, J., Barben, D., & Philp, J. (2017). Policy: Five cornerstones of a global bioeconomy. *Nature, 535*, 221–223. https://doi.org/10.1038/535221a

Finnemore, M. (1996). *National interests in international society*. Cornell University Press.

Förster, J. J., Downsborough, L., & Chomba, M. J. (2017). When policy hits reality: Structure, agency and power in South African water governance. *Social and Natural Resources, 30*, 521–536. https://doi.org/10.1080/08941920.2016.1268658

Fritsche, U., & Rösch, C. (2017). Die Bedingungen einer nachhaltigen Bioökonomie. In J. Pietszch (Ed.), *Bioökonomie für Einsteiger* (pp. 177–203). Springer Spektrum. ISBN 366253763X.

Gawel, E., Purkus, A., Pannicke, N., Hagemann, N. (2016). Die Governance der Bioökonomie–Herausforderungen einer Nachhaltigkeitstransformation am Beispiel der holzbasierten Bioökonomie in Deutschland. http://nbn-resolving.de/urn:nbn:de:0168-ssoar-47319-9. Accessed: 13.06.2018.

Herring, H., & Roy, R. (2007). Technological innovation, energy efficient design and the rebound effect. *Technovation, 27*, 194–203. https://doi.org/10.1016/j.technovation.2006.11.004

Kleinschmit, D., Arts, B., Giurca, A., Mustalahti, I., Sergent, A., & Pülzl, H. (2017). Environmental concerns in political bioeconomy discourses. *International Forestry Review, 19*, 41–55. https://doi.org/10.1505/146554817822407420

Labuschagne, A. (2003). Qualitative research: Airy fairy or fundamental? The Qualitative Report. https://nsuworks.nova.edu/tqr/vol8/iss1/7/. Accessed: 03.12.2018.

Lobell, D. B., Baldos, U. L. C., & Hertel, T. W. (2013). Climate adaptation as mitigation. The case of agricultural investments. *Environmental Research Letters, 8*, 1–12. https://doi.org/10.1088/1748-9326/8/1/015012

Mayring, P. (1991). Qualitative inhaltsanalyse. In U. Flick, E. von Kardoff, L. von Rosenstiel, & S. Wolff (Eds.), *Handbuch Qualitative Forschung: Grundlagen, Konzepte, Methoden und Anwendungen* (pp. 209–2013). Beltz–Psychologie Verl. Union. ISBN 9783621280747.

Pannicke, N., Gawel, 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*, 224–243.

Pfau, S., Hagens, J., Dankbaar, B., & Smits, A. (2014). Visions of sustainability in bioeconomy research. *Sustainability, 6*, 1222–1249. https://doi.org/10.3390/su6031222

Purkus, A., Röder, M., Gawel, E., Thrän, D., & Thornley, P. (2015). Handling uncertainty in bioenergy policy design – A case study analysis of UK and German bioelectricity policy instruments. *Biomass and Bioenergy, 79*, 54–79. https://doi.org/10.1016/j.biombioe.2015.03.029

Searchinger, T., Edwards, R., Mulligan, D., Heimlich, R., & Plevin, R. (2015). Do biofuel policies seek to cut emissions by cutting food? *Science, 347*, 1420–1422. https://doi.org/10.1126/science.1261221

Smeets, E., Tabeau, A., van Berkum, S., Moorad, J., van Meijl, H., & Woltjer, G. (2014). The impact of the rebound effect of the use of first generation biofuels in the EU on greenhouse gas emissions: A critical review. *Renewable & Sustainable Energy Reviews, 38*, 393–403. https://doi.org/10.1016/j.rser.2014.05.035

Stone-Sweet, A. (1999). Judicialization and the construction of governance. *Comparative Political Studies, 32*, 147–184. https://doi.org/10.1093/0199256489.003.0002

Unruh, G. C. (2002a). Escaping carbon lock-in. *Energy Policy, 30*, 317–3259. https://doi.org/10.1016/S0301-4215(01)00098-2

Unruh, G. C. (2002b). Understanding carbon lock-in. *Energy Policy, 28*, 817–830. https://doi.org/10.1016/S0301-4215(00)00070-7

Von Braun, J., Birner, R. (2016). Designing global governance for agricultural development and food and nutrition security. Review of Develpopment Economics, 21. https://doi.org/10.1111/rode.12261.

Wesseler, J., & von Braun, J. (2017). Measuring the bioeconomy: Economics and policies. *Annual Review of Resource Economics, 9*, 275–298. https://doi.org/10.1146/annurev-resource-100516-053701

Wild, P. J., McMahon, C., Darlington, M., Liu, S., & Culley, S. (2009). A diary study of information needs and document usage in the engineering domain. *Design Studies, 31*(1), 46–73. https://doi.org/10.1016/j.destud.2009.06.002

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Sustainability and Bioeconomy

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Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_24

24.1 Introduction

With the publication of the study "The Limits to Growth" (Meadows et al., 1972) by the Club of Rome in 1972, the finiteness of fossil and other non-renewable resources was brought to public attention. The study played a major role in the strengthening of the environmental movement in Germany and worldwide. The discussion about the finiteness of resources was taken up in the 1980s in the so-called Brundtland Report of the UN Commission on Environment and Development, which impressively formulated the goal of sustainable development (WCED, 1987): The possibilities of future generations to satisfy their needs must not be restricted by the present generation. At the 1992 UN Conference in Rio, sustainability was recognised as a political goal by almost all the countries of the world, and at the follow-up conference Rio+20 it was underpinned by concrete sustainability goals, the Sustainable Development Goals (SDGs). An economy based essentially on fossil raw materials and other non-renewable resources – as is currently still the case worldwide – is not sustainable because there is no guarantee that future generations will have sufficient resources at their disposal.

The vision of the bioeconomy is to transform the economy, which up to now has been based to a large extent on fossil raw materials, into a market economy in which fossil resources are replaced by renewable raw materials. Other non-renewable resources are also to give way to renewable resources as far as possible. In this respect, a bioeconomy is the necessary prerequisite and basis for any economy oriented towards the goal of sustainability (▶ Chap. 1) or, to put it bluntly: a sustainable economy is forced to become a bioeconomy. At the same time, there is a risk that biomass cultivation in its practical implementation will have negative side-effects, for example with regard to ecology or the food security of the population.

In view of the promises, but also the practical difficulties and problems of a bioeconomy, this chapter takes a closer look at the relationship between sustainability and the bioeconomy. To this end, the often inadequately specified concept of sustainability is first explained in more detail (▶ Sect. 24.2). The idea of sustainability is then placed in relation to the concept of the bioeconomy and core ideas of sustainable management using biogenic resources are outlined (▶ Sect. 24.3). Selected UN Sustainable Development Goals are then used to highlight key points of contact between the bioeconomy and the concept of sustainability (▶ Sect. 24.4) and, on this basis, to outline key challenges for a sustainable bioeconomy (▶ Sect. 24.5). The chapter concludes with a brief outlook on the necessary steps towards a transformation to a bioeconomy and the roles of the various relevant actors (▶ Sect. 24.6).

24.2 What Is Meant by Sustainability?

The concept of sustainability originally comes from forestry. In 1713, Hans-Carl von Carlowitz formulated the principle of sustainability for the first time in his book "Sylvicultura oeconomica – Anweisung zur wilden Baumzucht" ("Sylvicultura oeconomica – Instructions for wild tree cultivation"), stating that no more of a renewable resource may be harvested than will grow back in order to be able to use it in the long term (Grober, 2012). This principle of Carlowitz can be transferred to the entire biomass production. The basic idea is immediately obvious and can be substantiated by resource economic considerations and models (e.g. Fisher, 1981).

The principle is generally accepted. If it is taken into account, renewable resources can be used indefinitely. This is why it is stated in the Federal Government's sustainability strategy under the heading "Preserving the natural foundations of life" (Bundesregierung, 2018, p. 51):

> Non-renewable natural resources (such as mineral resources or fossil fuels) shall be used as sparingly as possible. Renewable resources shall replace the use of non-renewable resources to the extent that this reduces the environmental impact and this use is also sustainable in all aspects.

This could be understood as a programme for a bioeconomy. However, it also suggests that there are probably other aspects of sustainability that also need to be taken into account.In fact, in the current discussion the term sustainability is used in a much broader meaning compared to Carlowitz's formulation. In the aforementioned final report of the World Commission for Environment and Development (WCED) (WCED, 1987), sustainability – or as it is called there "sustainable development" – is formulated as a principle of justice (WCED, 1987, p. 43):

> Sustainable development is development that meets the needs of the present without risking that future generations will not be able to meet their own needs. Two key concepts are important: – the notion of 'needs', especially the basic needs of the world's poorest, which should have the overwhelming priority; and – the notion of the constraint that the state of technology and social organisation places on the ability of the environment to meet present and future needs.

There are many other attempts to clarify and define the concept of sustainability, which we will not go into here (but cf. Klauer, 1999). They certainly differ in detail, but agree on some central aspects (Klauer et al., 2017). These include in particular

1. the understanding of sustainability that our way of doing business must not be at the expense of future generations and at the expense of the global South (sustainability as a principle of "intra- and inter-generational justice") and
2. the conviction that sustainability requires us to take a long-term perspective and to include effects of our current actions that will only have an impact far into the future.

24.3 Bioeconomy as a Building Block for Sustainability

Every economy is based on resources: with the help of labour and capital, raw materials are transformed into goods that serve to satisfy people's needs. How can we manage to operate today in such a way that future generations also have the opportunity to satisfy their needs, as called for in the Brundtland Report's definition of sustainability? Three answers: First, nature and the environment must not be destroyed. Second, the productive forces must be preserved. And thirdly, resources – mineral resources and natural capital – must be used in such a way that it is possible to continue doing so in the long term. The demand for a sustainable bioeconomy focuses on this third demand without, of course, ignoring the other two.

An obvious, promising and yet at the same time utopian idea is to reuse the materials in the economy again and again, to lead them in a circle. Raw materials become goods that become waste after use, but can then be reused after processing if necessary. Such an ideal circular economy needs no new raw materials and produces no waste. It is driven solely by the energy of the sun and the ideas of people.

In the practice of a circular economy, however, numerous problems and difficulties arise. Waste can hardly be 100% recycled. In fact, goods wear out and materials mix inseparably. 100% recycling is often not only economically challenging, but also technically unfeasible in many cases. Non-renewable resources such as some minerals, metals or rare earths etc. must – at least at present – be added to our economic system, even with the most advanced technology.

If new resources are always needed – to a certain extent – a sustainable economic system is only possible if the resources used are renewable. This idea can be seen as the starting point of the bioeconomy concept. In contrast to the circular economy, the bioeconomy focuses on a comparatively simple, manageable aspect – although this too involves a radical transformation of the existing economic system: the replacement of non-renewable resources, and in particular fossil resources, with biomass. Biomass is a renewable resource because it can be constantly recreated with solar energy through photosynthesis. It serves as a resource in many ways – on the one hand as a supplier of energy, where combustion produces as much CO_2 as was bound from the atmosphere when it was created, and on the other hand as a diverse supplier of raw materials in the form of food, wood and other fibrous materials, basic material for the chemical industry, to name just a few of the most important uses.

24.4 Key Sustainability Dimension of the Bioeconomy

It is certainly true for a sustainable bioeconomy that Carlowitz's principle of sustainability must be observed, namely that no more biomass may be consumed than will grow back again. However, this alone does not guarantee a sustainable bioeconomy. It is true that a bioeconomy understood in this way could, under certain circumstances, trigger positive distribution effects globally (and thus contribute to intragenerational justice; Foust et al., 2015) and create a resource base that would not be limited by the finite nature of fossil resources. However, this would ignore ecological and social risks associated with biomass production and desires to use ecosystems that do not make substantial contributions to the bioeconomy but nevertheless provide important ecosystem services.

In order to get a comprehensive idea of the various intersections of the concepts of bioeconomy and sustainability, a rough sorting of these reference points along the UN Sustainable Development Goals is helpful (El-Chichakli et al., 2016; Issa et al., 2019; Zeug et al., 2019). These goals can be understood as a concretisation of the aforementioned abstract sustainability definition of the Brundtland Report, which were elaborated and adopted by the international community in the context of the Rio Conference on Environment and Development in 1992 and the subsequent process that continues to this day. According to Zeug et al. (2019), the following SDGs in particular refer to relevant sustainability dimensions of the bioeconomy:

- **SDG 2 – Food security:** In the context of the "food vs. fuel" debate, there is controversy about the extent to which the increased cultivation of biomass for (among other things) the production of bio-based fuels is causing a shortage of land for food production. The resulting increases in food prices could pose an existential threat to low-income households. On the other hand, opportunities arise for improving food security in developing countries, among other things because rising agricultural prices enable income growth for agricultural producers, or because the development and distribution of modern bioenergy technologies open up possibilities for cooling food or improving irrigation (Lynd & Woods, 2011; Foust et al., 2015). Biotechnological processes can also help to substantially increase the efficiency of crop growth and thus provide additional food without increasing land use (South et al., 2019). The *trade-off* addressed here is complicated by the fact that positive impacts on food security observed on a global average (Bureau & Swinnen, 2018) do not preclude serious local deteriorations in this regard. This is particularly the case in urban contexts, where people face rising food prices but at the same time do not experience income improvements if they do not produce and sell food themselves (Osseweijer et al., 2015).

- **SDG 3 – Healthy Living:** The expansion of bioenergy sources and technologies is associated with the hope of replacing traditional forms of biomass use, which are associated with significant indoor pollution and consequent ill health (burning wood, coal or dung in open fires) (Pratiti et al., 2020). Significant health opportunities are also attributed to increasing opportunities for parental care of infants and young children when the requirement for time-consuming collection of traditional fuels is eliminated (Foust et al., 2015). In addition, health opportunities from the development of new medicines and therapies based on biotechnological processes are highlighted as potentials of the bioeconomy (Larroche et al., 2016). The spread of multi-resistant bacteria, for example, can be contained much more effectively than in the past with the aid of genome sequencing (Marks, 2017).
- **SDG 7 – Energy for all:** The substitution of traditional forms of bioenergy use is also a goal in itself if it can improve the security of supply and affordability of energy. The achievement of this goal in turn has a positive impact on other sustainability goals. For example, the reduced need to collect traditional bioenergy sources can expand educational opportunities and increase the security of children and young women who often carry this responsibility (Sudhakara Reddy & Nathan, 2013). Also mentioned earlier are potential improvements in food security through energy-based food refrigeration or expanded irrigation opportunities.
- **SDG 8/9 – Growth, industry, innovation:** In addition to the circular economy and green economy approaches, the bioeconomy is equally understood as a conceptual framework for an economic system that is not limited to ecological sustainability through sufficiency (D'Amato et al., 2017). To the extent that biological innovations not only enable more resource-efficient economic activities but also generate additional income, they also tend to have a positive impact on a range of social sustainability aspects (health/life expectancy, education) (e.g. Ulas & Keskin, 2017; Bechtel, 2018). Biological innovations can also be an important component in shaping a sustainable industry that is resource-efficient as well as based on renewable resources and provides high-quality employment opportunities (e.g. Pätäri et al., 2016; Pyka, 2017).
- **SDG 13 – Climate change:** From an environmental perspective, the substitution of fossil energy sources is particularly relevant with regard to the associated opportunities for reducing greenhouse gas emissions. In the petrochemical industry, for example, a substantial reduction in energy consumption is possible through the substitution of fossil oil with biological raw materials, because on this basis certain chemical conversion processes are easier to manage, and further processing often requires lower temperatures and pressures (Burk & van Dien, 2016). In addition to conserving fossil greenhouse gas sinks, the cultivation of biomass in combination with CCS technologies can contribute to the reduction of greenhouse gases in the atmosphere (Fridahl & Lehtveer, 2018). On the other hand, expanding biomass production to areas with high GHG stocks (e.g. peatlands or forests) comes

with the risk of increasing emissions, at least in the short and medium term (Searchinger et al., 2018; Norton et al., 2019). The use of energy-intensive mineral fertilisers for the cultivation of bioenergy crops can also affect the greenhouse gas balance of bioenergy.

- **SDG 14, 15 – Aquatic and terrestrial ecosystems:** Increased cultivation of biomass in the form of intensive agriculture – i.e. using monocultures, heavy machinery, mineral fertilisers, pesticides – threatens to increase the associated risks to soils and water bodies. These include soil degradation including compaction, erosion, reduction of biodiversity, local aggravations of water scarcity, among others, through further pollution of ground, surface, coastal and marine waters (Karp et al., 2017; Kluts et al., 2017). On the other hand, extensive land management with selected bioenergy crops (e.g. permanent grass) enables qualitative improvements of ecosystems, for example by absorbing salts and heavy metals from degraded soils (Osseweijer et al., 2015). In addition, biotechnological innovations can help to reduce the need for synthetic fertilisers and pesticides, which contributes to the reduction of fugitive emissions into water bodies. For example, plants can be modified to absorb more nitrogen from the air, which can reduce the application of additional fertilisers (Oldroyd & Dixon, 2014).

Beyond the sustainability dimensions of the bioeconomy presented here in rudimentary form, broader sustainability references can be made (Issa et al., 2019; Zeug et al., 2019). Given the fundamental importance of the concept for the transformation of the economic system, this is not surprising. Assessing the relationship between the bioeconomy and sustainability thus poses a multi-layered challenge and implies an analysis based on a variety of social, economic and environmental criteria that go far beyond the principle of limiting biomass consumption to the renewable potential.

24.5 Discourses and Challenges for a Sustainable Bioeconomy

The complex relationships between the concept of the bioeconomy and sustainable development described above are probably one reason why there are competing discourses on the sustainability contribution of “the” bioeconomy (Pfau et al., 2014; Bugge et al., 2016; Hausknost et al., 2017; Ramcilovic-Suominen & Pülzl, 2018). An extreme point here is the view that a bioeconomy is per se *more* sustainable than a *business-as-usual scenario* due to the substitution of non-renewable resources. This perspective primarily focuses on the lack of intergenerational equity of the overuse of fossil energy sources, including the associated climate impacts. At the other extreme is the position that the bioeconomy merely serves as an ecological façade for the conventional logic of growth and competition, and also promotes unsustainable lifestyles and consumption patterns by exacerbating the overexploitation of nature. It is often assumed here that a massive expansion of biomass production comes at the expense of species- and carbon-rich land and forest areas.

A mediating perspective on the bioeconomy is provided by approaches that grant the concept extensive opportunities in terms of a more resource-efficient way of doing business, but address the associated risks and then attempt to minimise them. In this context, the bioeconomy has no fixed contours, but rather takes shape through the process of balancing opportunities and risks.

What a sustainable bioeconomy looks like in concrete terms is therefore not easy to answer. The high complexity of the subject matter and the aforementioned interactions between the various dimensions of sustainability pose a major challenge in the selection and design of concrete measures. The fact that the bioeconomy has an impact on numerous different sustainability dimensions entails the risk of conflicting goals. In other words, it is possible that progress in one sustainability dimension is bought by shifting (unsustainable) resource use to another sustainability dimension (Purkus, 2016). A prominent example of this is the potential climate change mitigation contribution from fossil fuel substitution, which, however, comes at the risk of consuming other types of non-renewable resources, such as the reduction of biodiversity due to increased land use by energy crops (Immerzeel et al., 2014; Hof et al., 2018).

Secondly, the design of a sustainable bioeconomy is confronted with the challenge that sustainability-related conflicts of objectives often occur at different scales and, moreover, affect non-substitutable goods. For example, it is difficult to answer the question which greenhouse gas savings from the increased cultivation of biomass outweigh a certain loss of biodiversity.

Thirdly, bioeconomy policies face the challenge of high uncertainties with regard to the consequences of the chosen measures. In many cases, it is not possible to determine with sufficient certainty or at reasonable cost, let alone predict, what effects an increased demand for biogenic resources will have on food prices or indirect land use, for example.

24.6 Outlook

As a building block of sustainability transformation, a bioeconomy policy should therefore first identify and implement *no-* and *low-regret measures* whose consequences are manageable and justifiable. These include, in particular, the use of biological waste and residues and the exploitation of efficiency potentials in the economic sectors concerned. If the use of biomass for materials or energy is to be expanded beyond this, cross-sectoral and, if necessary, cross-national ecological and social guard rails are required to ensure positive contributions to sustainability (Gawel et al., 2019). Due to the uncertainties mentioned, a step-by-step approach is recommended, in which the consequences of policy actions are regularly reviewed and the corresponding regulations are readjusted if necessary (Purkus, 2016).

The key actors for establishing a sustainable bioeconomy are companies, politics and civil society: companies must expand their research and development efforts in order to make cost-effective biobased substitutes available and to close resource cycles (use of production waste or recyclates). This applies in particular to resource-intensive sectors such as energy production, construction, chemicals, transport and agriculture. It is the task of policy-makers to ensure that bio-based products also reflect the environmental and social costs of their production. The same applies, of course, to fossil-based alternatives, as otherwise bio-based products will be even less competitive in the markets than they have been to date. In addition, politicians – together with NGOs – are called upon to embed the concept of the bioeconomy more firmly in society and to promote acceptance of the transformation. Finally, civil society has the task of developing and expressing “demand” for a sustainable bioeconomy policy and for ecologically and socially “true prices”. Changing consumer behaviour alone, on the other hand, will have only limited effect, since in the absence of comprehensive social and ecological product standards the choice of sustainable products is hampered by the complexity of environmental and social impacts. At the same time, the additional costs of such individual consumption behaviour would burden the part of society that participates voluntarily, whereas the remaining consumers would be spared (free-rider problem). Overall, therefore, there is a need for comprehensive participation and cooperation between a large number of social actors. Approaches to formulating joint positions in the form of the European Bioeconomy Stakeholders Manifesto therefore point in the right direction.

From a structural point of view, it should be noted that contributions of the bioeconomy to sustainability – just like other economically relevant sustainability efforts – require an efficient and internationally coordinated approach. Inefficient transformation strategies, particularly on the basis of regulatory measures such as quotas for bio-based raw materials or products, can significantly increase the costs of bioeconomy policy and thus jeopardise the acceptance of potential sustainability contributions in society. Instead, there is a need for efficient control with the aid of directly price-controlling instruments (tradable usage rights, levies) that ensure a cost-minimising adaptation path. Ensuring acceptance also requires the international competitiveness of the economy to be taken into account. An internationally coordinated approach offers, among other things, opportunities for a broader and thus more rapid innovation process, through which the costs of the transformation towards a sustainable bioeconomy can be reduced.

Finally, with regard to the relationship between the bioeconomy and sustainability, it should also be noted that certain technologies or principles of the bioeconomy (genetic engineering, synthetic biology) raise ethical questions that may refer to sustainability aspects beyond the SDGs. For example, one can ask to what extent the implementation of the SDGs constitute progress in terms of sustainability (or guarantee sustainability) if it is not foreseeable whether fundamental risks to the preservation of human life arise from the methods used in the process (Hoffmann, 2019). A frequently cited example of this is the possible lowering of the threshold for producing biological weapons (Bennett et al., 2009; DiEuliis & Giordano, 2018). Furthermore, it can be debated whether a world in which the boundary between nature and technology is increasingly blurred and humans emerge as ‘creators’ is equally worth living in (Carroll & Charo, 2015; Wang & Zhang, 2019). Together with the aforementioned potentially contradictory impacts of a bioeconomy within and between different sustainability dimensions, this results in a highly complex web of relationships between the two concepts. A holistic consideration and evaluation of measures to shape a sustainable bioeconomy therefore represents a considerable challenge that requires further research beyond disciplinary boundaries and, if necessary, a new (scientific) ethical foundation.

References

Bechtel, G. (2018). The human development index as isoelastic GDP. Evidence from China and Pakistan. *Economies, 6*(2), 32–40.

Bennett, G., Gilman, N., Stavrianakis, A., & Rabinow, P. (2009). From synthetic biology to biohacking. Are we prepared? *Nature Biotechnology, 27*(12), 1109–1111.

Bugge, M., Hansen, T., & Klitkou, A. (2016). What is the bioeconomy? A review of the literature. *Sustainability, 8*(7), 691–713.

Bundesregierung. (2018). Deutsche Nachhaltigkeitsstrategie – Aktualisierung 2018. https://www.bundesregierung.de/resource/blob/975274/1546450/65089964ed4a2ab07ca8a4919e09e0af/2018-11-07-aktualisierung-dns-2018-data.pdf?download=1. Accessed: 11.06.2019.

Bureau, J.-C., & Swinnen, J. F. M. (2018). EU policies and global food security. *Global Food Security, 16*, 106–115.

Burk, M. J., & van Dien, S. (2016). Biotechnology for chemical production. Challenges and opportunities. *Trends in Biotechnology, 34*(3), 187–190.

Carroll, D., & Charo, R. A. (2015). The societal opportunities and challenges of genome editing. *Genome Biology, 16*, 242–251.

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.

DiEuliis, D., & Giordano, J. (2018). Gene editing using CRISPR/Cas9. Implications for dual-use and biosecurity. *Protein & Cell, 9*(3), 239–240.

El-Chichakli, B., von Braun, J., Lang, C., Barben, D., & Philp, J. (2016). Five cornerstones of a global bioeconomy. *Nature, 535*(7611), 221–223.

Fisher, A. C. (1981). *Resource and environmental economics*. Cambridge University Press.

Foust, T. D., Arent, D., de Carvalho Macedo, I., Goldemberg, J., Hoysala, C., Maciel Filho, R., Nigro, F. E. B., Richard, T. L., Saddler, J., Samseth, J., & Somerville, C. R. (2015). Energy security. In G. M. Souza, V. R. L. Victoria, & C. A. Joly (Eds.), *Bioenergy & sustainability. Bridging the gaps* (pp. 61–89). SCOPE.

Fridahl, M., & Lehtveer, M. (2018). Bioenergy with carbon capture and storage (BECCS): Global potential, investment preferences, and deployment barriers. *Energy Research & Social Science*. https://doi.org/10.1016/j.erss.2018.03.019

Gawel, E., Pannicke, N., & Hagemann, N. (2019). A path transition towards a bioeconomy – The crucial role of sustainability. *Sustainability, 11*(11), 3005–3027.

Grober, U. (2012). *Sustainability: A Cultural History*. Green Books.

Hausknost, D., Schriefl, E., Lauk, C., & Kalt, G. (2017). A transition to which bioeconomy? An exploration of diverging techno-political choices. *Sustainability, 9*(4), 669–691.

Hof, C., Voskamp, A., Biber, M. F., Böhning-Gaese, K., Engelhardt, E. K., Niamir, A., Willis, S. G., & Hickler, T. (2018). Bioenergy cropland expansion may offset positive effects of climate change mitigation for global vertebrate diversity. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1807745115

Hoffmann, A. F. (2019). The precautionary principle: Origin, ethical implications, and theological outlook. In C. Dürnberger, S. Pfeilmeier, & S. Schleissing (Eds.), *Genome editing in agriculture. Between precaution and responsibility* (pp. 251–258). Nomos.

Immerzeel, D. J., Verweij, P. A., van der Hilst, F., & Faaij, A. P. C. (2014). Biodiversity impacts of bioenergy crop production: A state-of-the-art review. *Global Change Biology Bioenergy*. https://doi.org/10.1111/gcbb.12067

Issa, I., Delbrück, S., Hamm, U., & Sarangi, P. K. (2019). Bioeconomy from experts' perspectives – Results of a global expert survey. *PLoS One, 14*(5), 1–22.

Karp, A., Artaxo Netto, P. E., Berndes, G., Cantarella, H., El-Lakany, H., Moellwald Duque Estrada, T. E., Faaij, A., Fincher, G. B., Huntley, B. J., Ravindranath, N. H., Van Sluys, M.-A., Verdade, L. M., & Youngs, H. (2017). Environmental and climate security. In G. M. Souza, V. R. L. Victoria, & C. A. Joly (Eds.), *Bioenergy & sustainability. Bridging the gaps* (pp. 139–183). SCOPE.

Klauer, B. (1999). Defining and achieving sustainable development. *The International Journal of Sustainable Development and World Ecology, 6*(2), 114–121.

Klauer, B., Manstetten, R., Petersen, T., & Schiller, J. (2017). *Sustainability and the Art of Long-Term Thinking*. Routledge.

Klauer, B., Manstetten, R., Petersen, T., & Schiller, J. (2013). *Die Kunst langfristig zu denken. Wege zur Nachhaltigkeit*. Nomos.

Kluts, I., Wicke, B., Leemans, R., & Faaij, A. (2017). Sustainability constraints in determining European bioenergy potential: A review of existing studies and steps forward. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2016.11.036

Larroche, C., Sanromán Ángeles, M., Du, G., & Pandey, A. (Eds.). (2016). *Current developments in biotechnology and bioengineering. Bioprocesses, bioreactors and controls*. Elsevier.

Lynd, L. R., & Woods, J. (2011). Perspective: A new hope for Africa. *Nature, 474*(7352), 20–21.

Marks, L. (2017). Introduction: Biotechnology – An ever expanding toolbox for medicine. In L. Marks (Ed.), *Engineering health. How biotechnology changed medicine* (pp. 1–26). Royal Society of Chemistry.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W., III. (1972). *The limits to growth – A report for the Club of Rome's project on the predicament of mankind*. Universe Books.

Norton, M., Baldi, A., Buda, V., Carli, B., Cudlin, P., Jones, M. B., Korhola, A., Michalski, R., Novo, F., Oszlányi, J., Duarte Santos, F., Schink, B., Shepherd, J., Vet, L., Walloe, L., & Wijkman, A. (2019). Serious mismatches continue between science and policy in forest bioenergy. *Global Change Biology. Bioenergy, 11*, 1256–1263.

Oldroyd, G. E. D., & Dixon, R. (2014). Biotechnological solutions to the nitrogen problem. *Current Opinion in Biotechnology, 26*, 19–24.

Osseweijer, P., Watson, H. K., Johnson, F. X., Batistella, M., Cortez, L. A. B., Lynd, L. R., Kaffka, S. R., Long, S. P., van Meijl, H., Nassar, A. M., & Woods, J. (2015). Bioenergy and food security. In G. M. Souza, V. R. L. Victoria, & C. A. Joly (Eds.), *Bioenergy & sustainability. Bridging the gaps* (pp. 91–137). SCOPE.

Pätäri, S., Tuppura, A., Toppinen, A., & Korhonen, J. (2016). Global sustainability megaforces in shaping the future of the European pulp and paper industry towards a bioeconomy. *Forest Policy and Economics, 66*, 38–46.

Pfau, S., Hagens, J., Dankbaar, B., & Smits, A. (2014). Visions of sustainability in bioeconomy research. *Sustainability, 6*(3), 1222–1249.

Pratiti, R., Vadala, D., Kalynych, Z., & Sud, P. (2020). Health effects of household air pollution related to biomass cook stoves in resource limited countries and its mitigation by improved cookstoves. *Environmental Research, 186*, 109574. https://doi.org/10.1016/j.envres.2020.109574

Purkus, A. (2016). *Concepts and instruments for a rational bioenergy policy. A new institutional economics approach*. Springer.

Pyka, A. (2017). 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), 385–397.

Ramcilovic-Suominen, S., & Pülzl, H. (2018). Sustainable development – A ‚selling point' of the emerging EU bioeconomy policy framework? *Journal of Cleaner Production, 172*, 4170–4180.

Searchinger, T. D., Beringer, T., Holtsmark, B., Kammen, D. M., Lambin, E. F., Lucht, W., Raven, P., & van Ypersele, J.-P. (2018). Europe's renewable energy directive poised to harm global forests. *Nature Communications*. https://doi.org/10.1038/s41467-018-06175-4.

South, P. F., Cavanagh, A. P., Liu, H. W., & Ort, D. R. (2019). Synthetic glycolate metabolism pathways stimulate crop growth and productivity in the field. *Science, 363*(6422), 1–11.

Sudhakara Reddy, B., & Nathan, H. S. K. (2013). Energy in the development strategy of Indian households – The missing half. *Renewable and Sustainable Energy Reviews, 18*, 203–210.

Ulas, E., & Keskin, B. (2017). Is there a relation between HDI and economic performances? In D. Procházka (Ed.), *New trends in finance and accounting* (pp. 61–70). Springer.

Wang, F., & Zhang, W. (2019). Synthetic biology: Recent progress, biosafety and biosecurity concerns, and possible solutions. *Journal of Biosafety and Biosecurity, 1*(1), 22–30.

Zeug, W., Bezema, A., Moesenfechtel, U., Jähkel, A., & Thrän, D. (2019). Stakeholder's interests and perceptions of 2 bioeconomy monitoring – Using an 3 SDGs-framework. *Sustainability, 11*, 1511–1534.

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25

Assessment of the Bioeconomy System in Germany

Daniela Thrän and Urs Moesenfechtel

Contents

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7_25

25.1 Introduction

In this book, we have described the bioeconomy in Germany on the basis of a systems perspective. To this end, the bioeconomy has been subdivided into subsectors for a better representation of the overall system. This subdivision was based on the respective resources that are primarily used. Admittedly, this division is not entirely clear-cut, since, for example, "trees" (wood-based bioeconomy) are of course also plants, or the process technologies in the bioeconomy of plants and microorganisms and fungi overlap. However, because these resource-based views of the bioeconomy are often considered specifically and negotiated independently in business, academia, politics and civil society, they provide key insights into the bioeconomy system. In addition to the resource-based sub-areas, concrete actors within their networking structures were also presented, as well as the framework for action in which the bioeconomy in Germany (and Europe) can be shaped and developed.

Despite the differences in the subsystems and partial views, which will be discussed in more detail below, there is a broad common understanding of the bioeconomy as an opportunity to transform the economy and society. This can be seen in the general spirit of optimism and the accompanying inventiveness that characterises the subsystems and also the fields of action – even 15 years after their initial beginnings – in Germany and Europe. The actors not only see themselves as belonging to the system on a discursive meta-level, they also form real cooperation structures among themselves and thus invest in the future of a larger bioeconomy picture. They also describe similar conflicting goals and name identical hopes and desires in their visions, which can only be achieved through greater integration of their own respective aspirations with those of other bioeconomy actors.

In the following, individual central points of these conflicting goals and visions of the bioeconomy system in Germany are brought together, and a classification in the international and future developments and an outlook on the bioeconomy system in Germany are made.

25.2 Resources for Tomorrow's Bioeconomy

Whether in Germany or globally, biomass has always been used to meet different needs for food, housing, mobility, information, etc. The "bioeconomy" is therefore "*per se*" not an invention of the modern era. What is new, however, is that the bioeconomy is developing new methods, products and processes that are intended to make this use more ecological and economical – and above all to open up new possibilities for use. However, how different subsystems of the bioeconomy define the (future) potential uses of biomass and what conflicts of interest they see in this context is diverse.

Thus, the plant-based bioeconomy understands its fundamental objective to be to produce as much biomass as possible and as sustainably as possible (above all, while preserving biodiversity) in order both to secure food and to be able to replace a fossil-based economy with a biobased economy. It also highlights the potential of its research, products and processes to increase or improve the quality of the resource base. However, it is confronted with social controversy with regard to certain processes and products, so that the possible potentials have not yet been fully exploited; this applies primarily to genome editing and synthetic biology processes.

The wood-based bioeconomy focuses primarily on the forestry resource base in Germany and describes this as stable, provided that the climate adaptation measures already initiated are continued. However, future wood use should not only meet the known raw material requirements, but also supply new products and, at the same time, invest more in forest maintenance and forest conversion. The expectation is that only a demand for high-quality products by appropriate processing companies will ensure a durable, sustainably maintained and productive forest.

The animal-based bioeconomy particularly highlights the challenges of global world nutrition, resource scarcity and upcoming competitions for plant-based biomass. In conclusion, the innovation understanding of the animal-based bioeconomy lies in a comprehensive interplay of efficiency improvements in the field of plants, microorganisms, fungi and animals. In particular, the ability of monogastric livestock to utilise non-edible biomass is to be reactivated, and for this purpose improvements in plant breeding, cultivation techniques, and harvesting and preservation methods are to be made to preserve the feed value of the mostly perishable biomass. At the same time, by-products resulting from the processing of plants into food, feed and materials must be consistently returned to the feed cycle, thereby reducing the demand for cultivated feed.

The marine bioeconomy also addresses the resource issue and sees itself as a way of reducing the pressure of use, especially on agricultural land. For example, food production should be brought closer to cities again, thus avoiding long transport routes. Aquaponics systems, for example, are described as a possible solution to relieve the pressure on agricultural land.

Similarly, the microbial bioeconomy sees itself as having a duty to keep the demand for renewable raw materials and the associated land-use change in check. It wants to concentrate microbial processes on those product areas that depend on carbon. These are organic chemical products (including food and feed additives and pharmaceutical products) and sub-sectors of the fuel market (heavy duty, marine and aviation). Great innovation potential is seen in the diversity of applications of microorganisms, ranging from new processes and products to mechanical and plant engineering and process organisation. Process innovations concern all process steps, starting, for example, with the enzymatic digestion of wood, the development and optimisation of microbial strains and enzymes, microbial and enzymatic conversion processes and processing and product purification.

The waste-based bioeconomy shows that, on the one hand, there is already considerable use of biogenic residues and waste materials, but on the other hand, there is still a need to develop unused residue flows in order to further reduce the pressure on land use. To this end, the waste-based bioeconomy calls for the further development of existing plant and waste legislation towards a comprehensive circular economy.

The digital bioeconomy shows the opportunities that can arise, for example, through the use of Big Data to conserve resources in all other subsectors. The resource base of the digital bioeconomy is the operation of data systems which need eectricity, but on the other hand also in new data stroage systems. It is the sub-sector that is still at an early stage – the players are still poorly networked, the material and energy flows are not clearly outlined.

It can be seen that there is an awareness that a transformation of the economy and society can only succeed if there is a prudent and healthy use of limited resources and that this guides action in all subsystems – not only in Germany, but worldwide. However, the expectation of limited biomass resources and the extensive replacement of fossil-based products (at least at the current level of consumption) are not postulated in any subsystem. Nonetheless, the bioeconomy wants to and can replace the fossil-based economy at least in some areas of application – with a particular focus on high-value products. This is to be achieved by realising a wide range of potentials for better use of biomass as a raw material: by making existing biomass material flows more sustainable or by developing new material flows. In particular, unused resources are mentioned; the expectation of increasing biomass imports plays a subordinate role.

In summary, three main elements can be identified as to how the actors would like to realise a sustainable, efficient use of biomass, or already implicitly assume this in their own processes. Basically, the actors expect to be able to increase their already used resource base through these measures. However, this is also associated with challenges:

1. **Access to new resources outside established land uses**

Relevant for	Sub-areas of marine bioeconomy, plant-based bioeconomy and microbial bioeconomy
Challenges	The potential resources outside established land use can only be estimated with great uncertainty. In addition, land-based systems of the marine bioeconomy (aquaponics systems) may lead to further land-use conflicts or a higher use of energy or other inputs (such as nutrients), as is the case with *vertical farming* (see also point 2).

2. **Increasing yields through better information and new manufacturing technologies**

Relevant for	All sub-sectors of the bioeconomy
Challenges	Better information and production processes are generally associated with additional energy expenditure. However, the provision of energy is not described as a limited production element in any sub-sector of the bioeconomy – with the exception of the low added value of the high emissions from the direct use of wood for energy. Accordingly, the challenges and environmental effects of an increased energy demand of an innovative bioeconomy are not problematised.

3. **Extension of the value chain through multi-stage usage cascades**

Relevant for	In particular the sub-areas of wood-based bioeconomy, microorganism bioeconomy and waste-based bioeconomy
Challenges	The focus of combined and cascade use is on the provision of high-quality products. However, this requires the merging of material flows across the individual sub-sectors, which is currently hampered by a variety of restrictions. One fundamental problem, for example, is the inadequate cooperation between the actors in the sectors, which leads to information deficits. Also, requirements for cascades are differently well established: While energy use can make use of a wide range of materials, material recycling is often difficult. Designing for recycling would increase recycling opportunities, but corresponding concepts are not yet an integral part of the bioeconomy.

There are contradictory expectations as to whether the more efficient and more cascaded use of raw materials will also have an impact on the size and location of production structures: The marine bioeconomy, for example, points to the possibilities of significantly reducing food transport distances through aquaponics systems close to cities. The microorganism bioeconomy addresses the impact of a broad shift to microbial processes on local industrial centres. It is expected that previous, traditional (agricultural, forestry and marine-based) biomass production sites will disappear or agglomerate as they are replaced by new, industrial forms of biomass production, or move entirely to other parts of the world where the necessary infrastructures already exist or are established more rapidly. This may lead to a complete reorganisation of regional, supraregional and international supply chains for biobased raw materials, the concrete form of which, however, is not yet foreseeable.

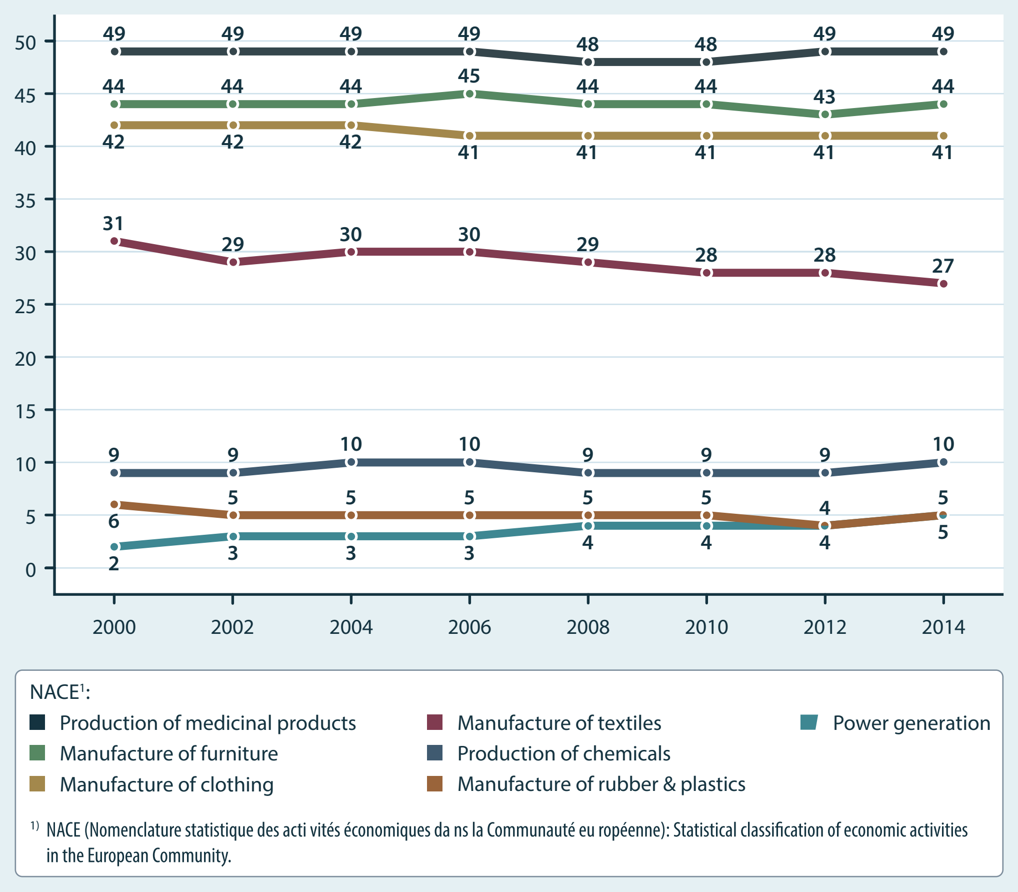
Common to all sub-areas and actors is that they mention biodiversity as an important action concept in the context of their own sustainability claims. Specifically, biodiversity conservation is mentioned as a goal for action in the areas of wood-based, plant-based and marine bioeconomy. In the case of the marine bioeconomy, the claim to combine ecology and economy is given concrete form. However, biodiversity is expected as a framework for action rather than being shaped in the subsystems themselves: How exactly "biodiversity" is preserved, protected or increased by bioeconomy has not yet been elaborated (in detail). Unlike the considerations on resource efficiency, the question of biodiversity thus remains programmatic.

25.3 Innovation Expectations and Target Images

Many actors, especially the regions with a bioeconomy focus, want to accelerate innovation through networking. In doing so, they proceed in different ways. The German bioeconomy regions and clusters described here have in common that they focus on specific sectors and/or product areas. Such specifications can also be found in the other German bioeconomy networks (which, however, are not listed in this book). Different forms of organisation are used to improve the exchange between the actors and to build up more comprehensive value chains. In this context, the current status of these efforts can be understood as an investment: networking structures are being created in order to develop cross-sectoral products and innovations. According to all actors, these networking activities involve a considerable investment of time.

The return on these investments in innovation has yet to be seen: So far, the new products are mainly niche applications. Production figures and bioeconomy shares are developing only slowly in Germany as well as in Europe. ◘ Figure 25.1 shows the estimated bioeconomy shares in different sectors, based on the quantities used in Europe. Even though innovative products with low volume requirements are not shown in this representation, it can be seen that at least the demand for non-bioeconomic volumes in the different sectors could not be reduced by these innovations (M'Barek et al., 2018). Only in the energy sector – as a result of strong promotion – have higher shares been achieved in the meantime, including an increasing use of fuel wood, liquid biofuels and biogas.

The target vision of the bioeconomy is formulated more and more comprehensively by all sub-areas and sub-views. Thus, an increasingly common understanding of the bioeconomy is developing in Germany. For example, all stakeholders emphasise that the bioeconomy is necessary due to dwindling (fossil) resources, demographic change and the resulting threat to global food security, the loss of biodiversity, land use conflicts, etc. It is also emphasised that only through more sustainable, economic and socially responsible development can the bioeconomy be realised. Likewise, it is jointly emphasised that only through more sustainable, economically and ecologically advantageous products and processes is it possible to compete with previous, established and simultaneously existing economic methods. All sub-subsectors accordingly point to approaches to solutions through which a transformation of the economy and society could be realised. The comprehensive systemic understanding of the bioeconomy set out in the German government's bioeconomy strategy of 2014 has thus been taken up by the actors and sub-sectors in recent years.



[1] NACE (Nomenclature statistique des activités économiques dans la Communauté européenne): Statistical classification of economic activities in the European Community.

Fig. 25.1 Development of sectoral biobased shares in the EU (2008–2015). The evolution of sectoral bio-based shares 2008–2015 is shown in this Fig. at the EU-28 level. The developments may differ at Member State level. (Source: Own representation according to M'Barek et al., 2018, p. 9)

25.4 Actors as a Starting Point for the Formation of a Bioeconomy System

The networking of the actors with each other essentially takes place along the respective resource use focal points and their value chains (with the sub-areas of provision, processing, distribution, use and disposal). It takes place primarily in clusters, platforms and networks. These associations are united by the challenge of bringing together different disciplines and research cultures and establishing a common understanding of the respective challenges and opportunities. In addition, there are actors who critically accompany the bioeconomy, whether in the context of NGO activities or in the media. All sub-sectors of the bioeconomy, as described in this book, see themselves as belonging to an "overall bioeconomy system". In this context, the actors (described in this book) pursue a middle course between the affirmative and the pragmatic approach (see Sects. 17.3.1 and 17.3.2). Apart from this "meta-narrative of the bioeconomy", however, the focus is primarily on one's own sub-sector, as is evident, for example, from the only weakly developed merging of material flows between these sub-sectors. Although the goal of closing cycles is formulated, it has so far been pursued mainly in the individual field of action. Similarly, the interlinking of material and energy use of biomass has only been partially realised. Further improvement of the cascade use of wood products in Germany could, for example, lead to considerable greenhouse gas emission reductions. For a future bioeconomy, it is important to identify unused potential by thinking more strongly about individual sub-sectors.

The activities of bioeconomy actors can be divided into two main lines of action: One focuses on how to produce more and better usable biomass. The others are interested in making better use of biomass and producing smarter, more sustainable products. The future of the bioeconomy will depend on the extent to which these two groups of actors cooperate, as this is the only way to overcome foreseeable competing uses.

25.5 How Much Bioeconomy Can We Afford?

In principle, the influence of a German bioeconomy on a global economic system is limited. Germany is only one piece of the puzzle in the world. Currently, Germany's contribution to global development comprises 1.0% of the world's population, 1.4% of wood production, 2.2% of bioenergy use, 2.4% of anthropogenic climate gas emissions and 2.5% of meat production. This includes 0.3% of global forest land and 0.8% of global cropland. Those about 1–3% percent of the different indicators, Germany appears to be a small building block in a global bioeconomy. Similarly, the development potential of a German bioeconomy is limited – at least if it were to be based solely on domestic resources. Nevertheless, a transformation of our national economy and society – if existing consumption patterns are not changed – would lead to impacts not only on resources from Germany, but on the whole world.

The decision on how many of these resources – whether national or international – should be used for the bioeconomy must ultimately be negotiated within the society. The bioeconomy discourse to date in Germany and Europe, and worldwide, reflects this negotiation process: different target images lead to very diverse assessments of "how much bioeconomy" we can and should afford as a society and global community. This assessment depends on whether the bioeconomy is conceived as a continuation and, if necessary, an increase in the same, previous non-sustainable economic practices (but now on the basis of biogenic resources), as a substitution or as a complete change (not only of the raw material base, but also of all material flows, production processes and consumption patterns). What opportunities and challenges exist here can only be discussed in a global context.

25.6 Outlook on Global Material Flows

An examination of the five decisive product groups of human demand shows that the associated global material flows contain different starting points for shaping a bioeconomy:

Meat is currently the most important source of protein within the human diet. In many countries of the world, meat consumption is directly linked to personal prosperity. However, protein intake through meat is characterised by low conversion efficiencies and a large ecological effort or high follow-up costs. In addition, health experts consider meat consumption in many countries of the world to be significantly too high and harmful to health: the average meat consumption worldwide is 42.5 kg per year and person (Ritchie & Roser, 2017). In contrast, German nutritionists, for example, recommend a maximum of 300–600 g of meat per week (DGE, 2017), which corresponds to 16–32 kg of meat per year and person. Ergo, global meat production could or should be halved, if only for health reasons. Such a halving would be accompanied by a reduction in the need for 660 kg of feed per year and per inhabitant of the Earth, or – to put it another way – about 1760 m^2 of agricultural land, which could then be used for other purposes.[1] Freeing up this land use potential would have a massive impact on the development opportunities of the bioeconomy.

Wood burning in open fireplaces is the dominant way of providing household heat for food preparation in many regions of the world. Around 3 billion people worldwide depend wholly or partly on firewood as main energy source (Nijuis, 2017). These fireplaces use only a small fraction of the energy bound up in firewood, with over 80% usually going unused (Thrän, 2015). Open fireplaces in huts and houses that produce soot and dust are a major health hazard for those present – mostly women and children. If the wood were used in modern stoves and ovens, the energy yield would be at least three times higher and thus the same energy would be possible with less than a third of the amount of wood (Adria & Bethge, 2013). Over 20 EJ of wood fuel could be saved each year. That is 1.5 billion m^3 of wood each year that could be available for other products – or also one and a half times the total annual energy use in Germany, which was 13.7 EJ in 2017 (BMWi, 2018).[2] This is also where the bioeconomy can come in with new innovations in the use of biomass for energy.

Chemical products made from renewable raw materials can replace a wide range of products made from fossil raw materials. The current and expected innovations are extensive and are seen in all sub-sectors of the bioeconomy. The carbon compounds that nature synthesises form high quality substitutes for today's fossil carbon compounds in plastics, active ingredients, lubricants, etc. They save alternative expenditures that would be necessary to harness the carbon from the CO_2 in the air and that researchers at RWTH Aachen University put at an increase in global electricity demand from the current 26 to over 44 PWh (Le Page, 2019). And this electricity demand would have to be provided from renewable sources, because otherwise fossil feedstocks will be replaced by fossil fuels. However, even for renewable resources, the current importance of chemical products is still very low: of the 350 million or so plastics currently produced (Statista, 2019), just under 5 million are bioplastics (Recyclingportal, 2016), i.e. plastics made from renewable resources, but most of which are not degradable. And the market is growing only slowly – between 5% and 10% was the increase in product qualities in recent years (ibid.). Even if the current production capacity (5 million tonnes) were to be increased every year from tomorrow, the share of bioplastics would only be 12% in 2030.

Building materials must become significantly more renewable, as cement production currently causes 8% of anthropogenic climate gases due to the high energy demand and process-related emissions (Rodgers, 2018). If the construction sector in Europe consistently switches to renewable raw materials, then the use of construction timber could double from a maximum of 15–30 million m^3 in the period between 2015 and 2030 (Hildebrandt et al., 2017). The additional demand would correspond to approximately 5% of[3] current European wood fuel use. As fuel, these building materials only

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[1] Own calculations based on Ritchie and Roser (2017) and Campogeno (2016). Assumed halving of current pig, poultry and beef production.

[2] The following conversion factors: 13 GJ per solid cubic metre.

[3] Own account.

become available once they have reached their material service life.

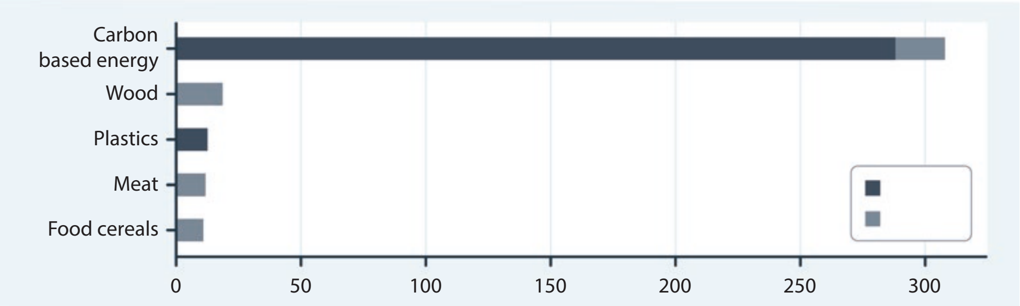
Renewable energy supply is a lion's task that goes far beyond the possibilities of the bioeconomy. Bioeconomy thus needs other renewable energies for the transition to climate-neutral resources. In the bioeconomy, bioenergy is therefore not a basic energy source, but a premium energy for those areas where alternatives from other renewable energies would be significantly more expensive, such as in aviation or heat for industry. If it were dispensed with, the climate gas savings would only be realisable more slowly, the demand for renewable electricity would increase significantly once again and the costs for climate gas avoidance would also be significantly higher (Thrän et al., 2019).

Energy as a key issue If the material flows of biogenic and fossil products are placed in relation to each other on the basis of their energy content, it becomes apparent what relevance the products have and what savings they bring (see ◘ Fig. 25.2). They show that, in terms of energy content, the global use of food grains, meat and plastics is of a comparable order of magnitude, while the energy use based on carbon compounds exceeds the energy content of the product groups mentioned by a factor of 6. Energy provision is thus the key issue for a sustainable bioeconomy.

25.7 "New Players" Beyond the Material Flows

In addition to the major material flows, there are a number of innovations and innovation expectations that hold out the prospect of smart services and products beyond the major material flows, but there are also other unknowns that will comprehensively influence the system in the coming years and decades. Important examples include:

New uses for the available resources are seen in all subsystems. For example, there are fundamentally new ways of using wood if it is possible to generate high-quality individual fractions such as lignin and, in parallel, to provide cost-effective products that animals and humans can metabolise. These, but also other raw materials, could then provide a wide range of foodstuffs in the future (such as synthetic meat), and thus fundamentally reduce the need for animal feed, for example. This is only one example; a reduced demand for resources is formulated in many innovation pictures. However, it is not specified what energy requirements are associated with this. A similar picture emerges for the use of CO_2 as a raw material for future carbon-based products: CO_2 is produced as a by-product in various production processes, but these quantities are rather small compared to the demand for future



◘ **Fig. 25.2** Comparison of energy content of the largest five product groups; scope of major carbon-based products for 2017/2018 in energy units (EJ/year), KB stands for carbon-based; nuclear and renewable energy are not included. (Source: Own presentation based on FAO, 2009; Kaltschmitt et al., 2009; Proplanta, 2018; REN 21, 2019) products (Billig et al., 2019). If atmospheric CO_2 is used to produce plastics, for example, the biogenic raw material base is considerably relieved, but the energy requirement is considerable: if plastics were to be produced from CO_2 in the future, for example, this would be accompanied – according to calculations by RWTH Aachen University – by an increase in global electricity demand from 26 to 44 PWh (Plasticker, 2019).

New systems The crucial new player, however, is the digital bioeconomy – the use of knowledge from information technology in biotechnology and vice versa. The common technology approaches are available and are being pursued much more vigorously outside Europe. We know from the past that such fundamental innovations have often been associated with fundamental social changes: For example, historians associate the printing press with the Reformation and the steam engine with the development of the communist idea. Fundamental social changes brought about by the fusion of biotechnology and information technology are therefore not unlikely. However, they have been discussed only sporadically so far (Harari, 2018). And they can perhaps only be assessed to a limited extent even with our empirical knowledge. Processes and institutions that socially tame these fundamental innovations are currently being wrestled with in various forums (Rechtsdepesche, 2017; BfR, 2019; BÖR, 2018). What can be inferred in broad terms, however, are the effects of the innovations on energy demand: there is clear evidence that the energy demand of such a technology merger is likely to be substantial. Experts at TUM estimate the current energy demand of Bitcoin's computers to be around 45.8 trillion Wh in 2018, which is roughly equivalent to the electricity consumption of Bangladesh (BUND, 2019). According to the study, this leads to annual emissions of 22–22.9 million t CO_2. However, comparable estimates of the effects of the convergence of the bioeconomy and digitalisation are not currently being discussed.

Climate change is another unknown in the bioeconomy system. If international climate protection measures are not intensified, the global average temperature increase could reach 2 °C shortly after 2060. While the sub-sectors of the bioeconomy have described ideas on how bioeconomic innovations can contribute to slowing and mitigating climate change, the effects of climate change on the bioeconomy are far less clear: for ecosystems (and their biodiversity) around the world, as well as for agriculture, global warming above 2 °C will have devastating consequences: increasingly frequent, extreme weather events and increasing precipitation, as well as increased extreme heat waves and droughts. Significant crop losses, the spread of disease and damage to infrastructure would be (and already are) expected. The sectors most affected will be agriculture, forestry, energy and tourism, for which certain temperature and precipitation levels are particularly important (IPCC, 2019).

The global rate of biodiversity loss is already at least ten to one hundred times higher than the average over the last 10 million years – and is continuing to increase: largely due to human influence, around 25% of species in most animal and plant groups, i.e. up to 1 million species, are already threatened with extinction. Like extinction itself, the potential threat is accelerating: the risk of extinction in the best-studied groups of organisms has been greatest over the last 40 years. This risk will affect many species within the next few decades – unless action is taken to reduce the intensity of the drivers responsible for biodiversity loss (IPBES, 2019). Biodiversity loss has direct consequences for people. Biodiversity and intact habitats are an indispensable foundation for healthy, functioning ecosystems. If their function is severely restricted or no longer given due to a loss of biodiversity, this has a negative impact, for example, on water and air quality, food security, a secure energy supply and ultimately on human health and thus our livelihoods (ibid.). Whether the bioeconomy can help to further exacerbate or mitigate a progressive global loss of species is not yet foreseeable. An impact assessment of the loss of biodiversity on the bioeconomy and studies on the influences of the bioeconomy on biodiversity are still pending.

The new players bring great uncertainties. Currently, they are only insufficiently considered. Among other things, an additional energy demand is to be expected. However, the bioeconomy system is comprehensively dependent not only on this but also on the other new influencing factors. The understanding of the system should be expanded to include these aspects. There is a need for research to be able to describe the new influencing factors in their range and thus to estimate their effects.

25.8 Prospects for the Bioeconomy System in Germany

The systemic view of the bioeconomy has matured in Germany in recent years at various levels: the subsystems of the bioeconomy have set up informal and formal “bioeconomy circles”, the actors are investing in regional and intersectoral networking to enable new innovations, and the supporting systems have put the shaping of the bioeconomy on the agenda.

The promise of innovation to increase efficiency and improve products is concrete. Specific resource and climate gas savings can be expected in all sub-sectors of the bioeconomy. The current market does not adequately support these ideas: low prices for fossil raw materials, a regulatory framework that is in many cases not adapted to bioeconomy products and services, and diffuse consumer demand have so far concentrated innovations in niche applications with low product volumes (e.g. in the areas of pharmaceuticals, food and feed additives, and skin care products). The bioeconomy thus does not yet have a major impact on the intended raw material change. Not only research and development, but also adapted financing and market mechanisms are needed to increase the competitiveness of bioeconomic products and to realise the associated resource relief in products and services.

Beyond the subsystems, however, the prospect of conserving natural resources is programmatic: the contributions to climate protection and species conservation are described as central, but are to be achieved primarily through “more from the same base”. If the competitiveness of bioeconomy products changes in the face of the need to save climate gases, this is likely to result in a central conflict of goals that goes far beyond the German bioeconomy system: climate protection requires the rapid and comprehensive closing of carbon cycles. And: the carbon that is not provided from biobased sources will have to be extracted in future using energy-intensive processes. Under these premises, there are no concrete ideas on how the sub-sectors can grow together.

Images of the future of the bioeconomy are therefore difficult, but urgently needed to help the bioeconomy out of the current “transition phase”. The grown system understanding of the actors in the sub-areas of the bioeconomy and the framing systems forms a good basis for a necessary societal debate on a required transformation of the economy and society, from which a common target picture can be formulated. In this context, the following elements will have to be given central consideration, which lie beyond our experience to date but will determine how sustainable the bioeconomy system is: on the one hand, the convergence of information technology and biotechnology will have the potential to bring about fundamental upheavals, and on the other hand, there is no alternative to a fast and substantial reduction of consumption in may sectors of our daily life.

And so, behind all the considerations of a bioeconomy system, there may be the fundamental, hitherto little considered question: is modesty a sufficiently strong biological principle that it can drive a bioeconomy?

References

Adria, O., & Bethge, J. (2013). The overall worldwide saving potential from domestic cooking stoves and ovens. bigEE. http://www.bigee.net/media/filer_public/2014/03/17/appliance__residential_cookingstoves__worldwide_potential__20140220__8.pdf. Accessed: 11.10.2019.

BfR (Bundesinstitut für Risikobewertung). (2019). BfR-Verbraucherkonferenz Genome Editing. https://www.bfr.bund.de/de/verbraucherkonferenz_genome_editing.html. Accessed: 20.01.2020.

Billig, E., Decker, M., Benzinger, W., Ketelsen, F., Pfeifer, P., Peters, R., Stolten, D., & Thrän, D. (2019). Non-fossil CO_2 recycling – The technical potential for the present and future utilization for fuels in Germany. *Journal of CO_2 Utilization*. https://doi.org/10.1016/j.jcou.2019.01.012.

BMWi (Bundesministerium für Wirtschaft und Energie). (2018). Primärenergieverbrauch in Deutschland 2017. https://www.bmwi.de/Redaktion/DE/Infografiken/Energie/Energiedaten/Energiegewinnung-und-Energieverbrauch/energiedaten-energiegewinnung-verbrauch-03.html. Accessed: 11.10.2019.

BÖR (Bioökonomierat). (2018). Genome editing: Call for new EU legislation. Germany and EU should help to shape bio-innovations. https://biooekonomierat.de/en/news/genome-editing/. Accessed: 20.01.2020.

BUND Regionalverband Südlicher Oberrhein. (2019). Bitcoin Kritik! Energieverbrauch, Stromverbrauch, Umweltzerstörung, Klimawandel, Betrug, Verluste & Gier. http://www.bund-rvso.de/bitcoin-strom-energie-verbrauch-umwelt-gier.html. Accessed: 11.10.2019.

DGE (Deutsche Gesellschaft für Ernährung). (2017). Vollwertig essen und trinken nach den 10 Regeln der DGE. https://www.dge.de/fileadmin/public/doc/fm/10-Regeln-der-DGE.pdf. Accessed: 11.10.2019.

FAO (Food and Agriculture Organization of the United Nations). (2009). Global demand for wood products. State of the World's Forests. http://www.fao.org/3/i0350e/i0350e02a.pdf. Accessed: 11.10.2019.

Harari, Y. N. (2018). *21 Lektionen für das 21. Jahrhundert*. Beck.

Hildebrandt, J., Hagemann, N., & Thrän, D. (2017). The contribution of wood-based construction materials for leveraging a low carbon building sector in europe. *Sustainable Cities and Societies*. https://doi.org/10.1016/j.scs.2017.06.013.

IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services). (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://www.ipbes.net/sites/default/files/downloads/spm_unedited_advance_for_posting_htn.pdf. Accessed: 11.10.2019.

IPCC (Intergovernmental Panel on Climate Change). (2019). Summary for policymakers. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield, editor. *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (pp. 3–24). https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf. Accessed: 11.10.2019.

Kaltschmitt, M., Hartmann, M., & Hofbauer, H. (Eds.). (2009). *Energie aus Biomasse: Grundlagen, Techniken und Verfahren*. Springer.

Le Page, M. (2019). Greening the chemical industry requires massive amount of renewables. NewScientist. https://www.newscientist.com/article/2202691-greening-the-chemical-industry-requires-massive-amount-of-renewables/. Accessed: 11.10.2019.

M'Barek, R., Calikowski, T., Lier, M., Kovacs, B., Ronzon, T., Martti, A., Iost, S., Kwant, K., Lansac, R., Dollet, E., Jurga, P., Parisi, C., & Spekreijse, J. (2018). Getting (some) numbers right – Derived economic indicators for the bioeconomy. European Commission. https://doi.org/10.2760/2037.

Nijuis, M. (2017). Three billion people cook over open fires – With deadly consequences. National Geographic. https://www.nationalgeographic.com/photography/proof/2017/07/guatemala-cook-stoves/. Accessed: 11.10.2019.

Plasticker. (2019). RWTH Aachen: Ist CO_2 das neue Erdöl? – Studie zu einem geschlossenen Kohlenstoffkreislauf für die chemische Industrie. https://plasticker.de/Kunststoff_News_34981_RWTH_Aachen_Ist_CO2_das_neue_Erdoel___Studie_zu_einem_geschlossenen_Kohlenstoffkreislauf_fuer_die_chemische_Industrie. Accessed: 11.10.2019.

Proplanta. (2018). Größter Teil der Getreideernte geht in den Futtertrog. https://www.proplanta.de/Agrar-Nachrichten/Pflanze/Groesster-Teil-der-Getreideernte-geht-in-den-Futtertrog_article1514903567.html. Accessed: 11.10.2019.

Rechtsdepesche. (2017). Debatte zu Genome-Editing. https://www.rechtsdepesche.de/ethikrat-fordert-debatte-zu-genome-editing/. Accessed: 20.01.2020.

Recyclingportal. (2016). Produktionskapazitäten für Biokunststoffe steigen global trotz niedrigem Ölpreis. https://recyclingportal.eu/Archive/28041. Accessed: 11.10.2019.

REN 21. (2019). Renewable 2019. Global Status Report. https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf. Accessed: 11.10.2019.

Ritchie, H., & Roser, M. (2017). Meat and dairy production. Our World in Data. https://ourworldindata.org/meat-production. Accessed: 11.10.2019.

Rodgers, L. (2018). Climate change: The massive CO_2 emitter you may not know about. https://www.bbc.com/news/science-environment-46455844. Accessed: 11.10.2019.

Statista. (2019). Weltweite und europäische Produktionsmenge von Kunststoff in den Jahren von 1950 bis 2017 (in Millionen Tonnen). https://de.statista.com/statistik/daten/studie/167099/umfrage/weltproduktion-von-kunststoff-seit-1950/. Accessed: 11.10.2019.

Thrän, D. (2015). Introduction. In D. Thrän (Ed.), *Smart bioenergy: Technologies and concepts for a more flexible bioenergy provision in future energy systems* (pp. 1–9). Springer.

Thrän, D., Lauer, M., Dotzauer, M., Kalcher, J., Oehmichen, K., Majer, S., Millinger, M., Jordan, M. (2019). Technoökonomische Analyse und Transformationspfade des energetischen Biomassepotentials (TATBIO). Endbericht. Deutsches Biomasseforschungszentrum. https://www.ufz.de/export/data/2/231891_technooekonomische-analyse-und-transformationspfade-des-energetischen-biomassepotentials(1).pdf. Accessed: 11.10.2019.

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Supplementary Information

D. Thrän, U. Moesenfechtel (eds.), *The bioeconomy system*,
https://doi.org/10.1007/978-3-662-64415-7

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