The
Federal Government

National Bioeconomy Strategy

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Dear readers,

the need to live sustainably and preside over sustainable economies has become an important driving force for social, economic and political change. We are all aware that the coming years will be decisive in highlighting the way forward for sustainable development and for sustainable economic growth. To that end, the German Federal Government has introduced a wealth of innovative initiatives to overcome the challenges we will face in the future. These many and varied activities dovetail in the new National Bioeconomy Strategy. The achievement of a bio-based economy will represent a significant contribution to the attainment of the Sustainable Development Goals set out in the UN's 2030 Agenda.

The transition to a bioeconomy will generate a vast array of opportunities. Over the next few decades, the way in which we do business will change all around the world and serve to put our economies on a more sustainable footing. The individuals and companies who deliver concepts, technologies and processes that contribute to the bioeconomy will be successful in the markets of tomorrow. The development of the bioeconomy can be harnessed to strengthen rural areas, the setting in which a great deal of the added value is generated. We seek to strengthen Germany's position as an innovative country through the new National Bioeconomy Strategy and to make the country a leader in the development of pioneering approaches.

The bioeconomy harbours vast potential. It produces, harvests and uses biological resources, and avails of processes and systems that considerably reduce our dependency on fossil resources such as coal, oil and natural gas. At the same time, scientific and technological advances offer up new bioeconomy applications that extend far beyond simply replacing fossil resources with the negative implications for the environment that are inherent in their continued use. Significant groundwork for these developments was laid with the publication of the National Research Strategy 'BioEconomy 2030' (Nationale Forschungsstrategie BioÖkonomie 2030) and the National Policy Strategy on Bioeconomy (Nationale Politikstrategie zur Bioökonomie). The new National Bioeconomy Strategy builds on the successful work that was initiated under these two strategies.

The bioeconomy encompasses all sectors of the economy. It is central to global food security and supplies the renewable resources necessary for a wide range of applications. Its interdisciplinary toolbox consists not only of biotechnological processes, but also of concepts borrowed from engineering and data science. Bio-based products manufactured for industry and end consumers are set to prevail on the market. Thanks to their natural properties, such products are also ideal for integration into material cycles. The growth of the bioeconomy is, therefore, a decisive factor in the achievement of a sustainable circular economy. It is crucial for the attainment of more efficient future business practices and for the reduction of our consumption of resources.

The purpose of the National Bioeconomy Strategy is to contribute to the achievement of sustainable development as laid down in the 2030 Agenda. Around a dozen of the Sustainable Development Goals (SDGs) agreed by the international community in New York in 2015 directly address the bioeconomy. These SDGs form the main frame of reference for Germany's Bioeconomy Strategy.

Policy can set the agenda and pave the way, but the transformation to sustainable business will only be possible with extensive support from society at large. With that in mind, we will involve society early on in the implementation of the new strategy and foster dialogue amongst everyone who wishes to help shape our future bioeconomy.

Your Federal Ministry of Education and Research

Your Federal Ministry of Food and Agriculture

Summary

Sustainability and climate action are the key issues of the 21st century. Humankind has reached a point where the continued over-exploitation of our resources threatens to cause considerable damage to the biosphere. To preserve the conditions necessary for the survival of humans, animals and plant life, the consumption of natural resources must be reduced to a level that is ecologically sustainable. At the same time, it remains vitally important that we ensure economic prosperity and safeguard the right to future development of a growing global population.

The objective of the bioeconomy is to combine economy and ecology to ensure a more sustainable use of resources. The German Federal Government defines the bioeconomy as the production, exploitation and use of biological resources, processes and systems to provide products, processes and services across all economic sectors within the framework of a future-oriented economy. Innovations in the bioeconomy unite biological knowledge with technological solutions and utilise the inherent properties of biogenic raw materials such as their natural cycles, renewability and adaptability. The bioeconomy harbours the potential to provide new kinds of products and processes that protect natural resources and ensure our future prosperity.

In its National Bioeconomy Strategy, the Federal Government lays down the guidelines and objectives for its policy on the bioeconomy and lists measures for their implementation. The strategy builds on the National Research Strategy 'BioEconomy 2030' and the National Policy Strategy on Bioeconomy to weave the various political strands together in a coherent framework. The National Bioeconomy Strategy lays the foundations for Germany to strengthen its role as a bioeconomy leader and to create the technology and jobs of tomorrow. With the strategy, the German Federal Government also assumes its global responsibility in the interconnected international bioeconomy.

Two overarching guidelines support the objectives and actions set out in the National Bioeconomy Strategy. The first guideline highlights how biological knowledge and advanced technology are the pillars of a future-oriented, sustainable and climate-neutral economy. The second guideline relates to the raw materials used by industry and the need for a sustainable and circular economy based on the use of biogenic resources.

The Federal Government's National Bioeconomy Strategy addresses a broad spectrum of objectives targeting different levels of society across all economic sectors. It can be summarised in six common strategic goals:

1) Develop bioeconomy solutions for the 2030 Agenda for Sustainable Development
2) Recognise and harness the potential of the bioeconomy within ecological boundaries
3) Enhance and apply biological knowledge
4) Establish a sustainable raw material base for industry
5) Promote Germany as the leading location for innovation in the bioeconomy
6) Involve society and strengthen national and international collaboration

For each of these strategic goals, specific implementation objectives have been formulated in the context of research funding, the pertinent framework conditions and cross-cutting instruments.

Research is the key to recognising and harnessing the opportunities offered by the bioeconomy. Future research funding will focus on the following building blocks: biological knowledge as the key to the bioeconomy; converging technologies and transdisciplinary cooperation; boundaries and potentials; translation to real-life application; bioeconomy and society; and international research collaboration.

The strategy describes policy areas, in which the Federal Government will implement specific actions over the coming years, in order to improve the framework conditions for the bioeconomy. These are as follows: reducing pressure on land use; ensuring the sustainable production and supply of biogenic raw materials; expanding and developing the supply chains and networks of the bioeconomy; designing instruments to establish and bring bio-based products, processes and services to the market; ensuring policy coherence; making use of the opportunities offered by the bioeconomy for the development of rural areas; and taking advantage of digital technology for the bioeconomy.

To do justice to the concept of the bioeconomy as an all-embracing approach, the Federal Government applies cross-cutting instruments to implement its strategy. This involves the establishment of an advisory committee, co-operation between the Federal and Länder levels of government and at European and international level, measures to foster communication and open dialogue with various groups in society, initiatives to promote training and development of skills, and the establishment of a bioeconomy monitoring system.

The German National Bioeconomy Strategy

Policy guidelines and goals

Guideline 1

Harnessing biological knowledge and responsible innovation for sustainable, climate-neutral development

Guideline 2

Using biogenic raw materials for a sustainable, circular economy

Common strategic goals for research funding and a policy framework

1. Develop bioeconomy solutions for the 2030 Agenda for Sustainable Development
2. Recognise and harness the potential of the bioeconomy within ecological boundaries
3. Enhance and apply biological knowledge
4. Establish a sustainable raw material base for industry
5. Promote Germany as the leading location for innovation in the bioeconomy
6. Involve society in the bioeconomy and strengthen national and international collaboration

Implementation

- Research funding
- Framework conditions
- Cross-cutting instruments

Preface

The German Federal Government supports the transition from an economy largely based on fossil raw materials to a more resource-efficient and circular economy based on renewable resources. As early as 2010, Germany committed itself in its the National Research Strategy 'Bioeconomy 2030'[1] to the vision of creating a sustainable, bio-based economy founded on natural material cycles. The concomitant National Policy Strategy on the Bioeconomy[2] , introduced in 2013, defined goals and measures intended to support this structural transition, including actions seeking to adapt the prevailing framework conditions.

The German Federal Government remains committed to this vision. It is intensifying its efforts to implement a sustainable bioeconomy by pooling the measures taken so far and by taking into consideration other relevant policy strategies and merging them into the new National Bioeconomy Strategy. This involves harmonising the various sub-goals and linking the corresponding measures more closely with one another. With its new National Bioeconomy Strategy, the Federal Government aims to formulate the tasks that policy makers and researchers will need to undertake in the coming years, while also identifying the challenges that businesses and society will face along the way towards the achievement of a bioeconomy. Building on the steps taken since 2010, and taking into account new knowledge and current developments, the German Federal Government is committed to expanding the bio-based economy and is establishing new priorities in order to tap the rich potential of the bioeconomy for sustainable development, while avoiding undesirable developments.

The new Bioeconomy Strategy is the result of a comprehensive agenda process that incorporated numerous inputs. These included the progress report on the National Policy Strategy on the Bioeconomy[3], the evaluation of the previous national research strategy[4], recommendations from the Bioeconomy Council of the Federal Government of Germany[5] , which sat until 2019, and experiences gleaned from the implementation of other bioeconomy strategies at the European and international level. The process included conferences, workshops and consultations with representatives from business, research, politics and civil society. This participatory approach is to be maintained in order to promote a varied and broad range of opinions and perspectives when implementing the strategy. For this purpose, the German Federal Government will appoint an independent and thematically diverse advisory body that, with the involvement of all relevant stakeholder groups, will draw up a roadmap of practical implementation steps. This roadmap will be continuously updated.

1

Bioeconomy for a sustainable future

The bioeconomy aims to help solve major challenges of the 21st century by providing new solutions. The definition and objectives of the bioeconomy are explained on the following pages.

According to the definition adopted by the German Federal Government, 'bioeconomy' refers to the production, exploitation and use of biological resources, processes and systems to provide products, processes and services in all economic sectors within the framework of a sustainable economic system. The bioeconomy aims to provide solutions to the great challenges of the 21st century. It addresses the basic questions that face the world of tomorrow:

- How can we ensure the security of food and resources for an increasing global population while at the same time protecting the climate, the environment and biological diversity?
- How can we successfully link ecology and the economy while ensuring an equitable distribution of the associated opportunities and challenges?
- How can we transform our current economic system into a sustainable system that will also safeguard future prosperity?
- What must we do to make sure that the bioeconomy can contribute as quickly and as effectively as possible to the international climate protection goals outlined in the Paris Agreement?

An expansion of the bioeconomy will bring about a sustainable alignment of the resource base of the economy and a replacement of fossil raw materials. Replacing these limited raw materials, the very use of which damages our climate, can be a step towards greater sustainability provided the substitute biomass is used efficiently and produced in accordance with ecological and ethical criteria. Biological knowledge and advanced technologies make it possible to develop new, resource-saving processes and products, thereby expanding and linking various supply chains. Bioeconomic innovations combine biological knowledge with technological solutions and harness the natural properties of biogenic raw materials (recyclability, renewability, CO_2 balance and adaptability) for the benefit of a sustainable economy.

The benchmark for the benefits and added value associated with bio-based products and processes is their contribution to a sustainable and climate-neutral economy. Given the fact that we have exceeded planetary boundaries – with corresponding negative impacts on biodiversity, climate, the nitrogen cycle and soil fertility – the advancement of the bioeconomy is expected to contribute to a transition towards sustainable development.

The modern debate over the concept of sustainability, ongoing since the 1980s, has shown that the three dimensions of sustainability – economic, ecological and social – cannot be set against one another, but rather that they are interdependent. A form of economy that relies on natural material cycles and simultaneously uses and protects the services of ecosystems must at the same time be competitive and provide jobs. The bioeconomy represents one contribution to the ongoing discussion about the specific nature and design of sustainable development and encompasses the Sustainable Development Goals of the United Nations' 'Agenda 2030 for Sustainable Development'. This link is explored in more detail below (section 2.3). The cornerstone of a sustainable bioeconomy is the responsible production, harvesting and use of biogenic raw materials and residues. Securing a global supply of food is and has always been a priority, and ethical principles and socially recognised goals such as environmental protection, landscape conservation and animal welfare must be accorded similarly high valuation.

The decision as to whether a product, a process or a service is aligned with the bioeconomy depends on the biological resources used. The bioeconomy uses raw materials that are produced in agriculture, forestry and marine settings, in fisheries and aquaculture, or in microbial production. Biogenic residues and waste materials are also building blocks of the bioeconomy. In addition to the materials used, the resources of the bioeconomy include knowledge of biological processes and systems for new applications, as well as the development of raw material sources through biological processes.

Sustainable economy

Climate-neutral and circular

2

The Bioeconomy Strategy of the German Federal Government

With its new Bioeconomy Strategy, the German Federal Government is committed to the sustainable production and use of biological resources, and to the promotion of environment- and nature-friendly production processes in all economic sectors. This chapter describes the guidelines, strategic goals and implementation targets of the strategy.

A sustainable, bio-based economy is an essential foundation for the future of our society. With its Bioeconomy Strategy, the German Federal Government is committed to the sustainable production and use of biological resources, and to the promotion of environment- and nature-friendly production processes in all economic sectors. Sustainable management demands the responsible use of our natural resources. This is the only way to preserve the foundations of life vital for the wellbeing of future generations. The challenges of the 21st century are immense. By the end of this century, the limited available farmland will be required to produce sufficient healthy food to feed a predicted population of around 11 billion people. The first step towards combating climate change is to achieve a rapid and significant reduction in greenhouse gas emissions; the second is to achieve greenhouse gas neutrality by 2050. The ongoing loss of natural spaces, forests and suitable agricultural land, and the global decline in both soil fertility and biodiversity necessitate countermeasures. These issues are exacerbated by the finite nature of fossil raw materials, the increase in the demand for raw materials and political uncertainties affecting the market.

Although these factors are driving forces towards greater sustainability, the corresponding development of a bioeconomy enjoying widespread public acceptance cannot simply be taken for granted. Research, suitable economic and legal framework conditions, dialogue with and the participation of various social groups, and cooperation with international partners will all play an important role in making the bioeconomy a reality.

The new Bioeconomy Strategy highlights measures and means to meet future challenges and identifies the priorities that must be set. Any additional expenditure that may result from the implementation of the Bioeconomy Strategy is offset by a prioritisation of the use of existing funds foreseen in the relevant budgetary sections and which can be implemented without any added financial burden.

2.1 Guidelines of the Bioeconomy Strategy

The goal of tapping the potential of the bioeconomy and using it to achieve sustainability and climate goals is supported by two overarching guidelines that serve as the foundation for all of the implementation measures contained within the new Bioeconomy Strategy.

Guideline 1:
Harnessing biological knowledge and responsible innovation for sustainable, climate-neutral development

The constant expansion of our knowledge of biology offers up new opportunities for innovation and sustainable solutions, and is the driving force behind the transition towards a bio-based economy. The range of new bio-based technologies and products is constantly increasing, and the corresponding demand will continue to rise in the future, both from industry and from other consumers. Technological advances achieved through, for example, digitisation and new process technologies, make it possible to deepen our biological knowledge even further and to use it for innovation. Biology and technology can merge in a new, sustainable form of production.

To convert these auspicious prospects into tangible components of sustainable development, our knowledge of biology must be linked with research into the social and ecological systems in which the bioeconomy is embedded. Socio-economic processes, such as competition for scarce resources, population growth and changing values, lifestyles and consumption patterns, have consequences for the transition to a bioeconomy. At the same time, the very transition to a bioeconomy in turn exerts an influence over these processes. Such interactions have to be considered while performing research and in designing the policies underlying the transformation process. This applies particularly to questions concerning ethical principles and social values; for instance, when it comes to the use of new technologies, access to resources, a just global distribution and the value of nature. It is, therefore, important to encourage an open debate with broad social participation, examining and discussing possible development pathways for the bioeconomy and weighing up opportunities and challenges when determining the order of priorities.

Bioeconomic innovations can make a significant contribution to a sustainable future. However, merely promoting the development of bio-based products and processes will not be enough. It is crucial that the bioeconomy provides services that are desired by society. This includes resource- and environmentally-friendly solutions stimulating more sustainable consumption.

Guideline 2:
Using biogenic raw materials for a sustainable, circular economy

Biogenic raw materials possess properties that render them particularly valuable and convenient. In contrast to fossil raw materials, they are renewable. However, they also face limitations arising from the limited availability of the space required for biomass production. Due to their chemical-physical nature, biogenic raw materials are particularly suitable for use in cascades or cycles. This includes both material use and composting. At the very end of a chain of applications, biomass can finally also be used to provide energy. In principle, when using biogenic raw materials no more carbon dioxide is released than was removed from the atmosphere during the growth phase, although an exact balance calculation must also take into consideration the energy used in conversion and transportation. Biogenic resources and bio-based products can, therefore, represent a climate- and resource-saving alternative to fossil raw materials and fossil-based products. Biogenic materials, such as construction materials and new materials used in durable industrial goods, also extract and bind CO_2 from the atmosphere for long periods of time. Germany's Federal Government supports corresponding product and process developments through its funding programmes as a means to contribute to a more sustainable, efficient and climate-neutral use of resources.

The bioeconomy not only replaces fossil raw materials with renewable raw materials, it also facilitates the development of new products and processes in very different sectors. Unlocking the full potential of the bioeconomy means opening and expanding traditional supply chains and, where necessary, replacing them. Following the guiding principles of cascade and cyclical use, supply chains should be linked to create new and efficient value creation networks. The option to undertake initial steps in the processing of these materials at the site of production provides a future-oriented development perspective, especially for rural areas.

For the bioeconomy to achieve these positive effects on the climate, biodiversity, the environment and welfare, it is essential that the underlying biogenic resources be generated sustainably. Given the limited space available for cultivation, the scale of production of biomass cannot simply be expanded at will. Any increase in yield must be achieved sustainably on the existing land. It is also necessary to encourage the most efficient and responsible possible uses of the raw materials produced. New production systems must be taken into consideration, whereby biomass is generated, for example, in a technological setting or on degraded land. Where there are competing uses, food security is always the priority. At the same time, it is essential that we protect biodiversity and strengthen the ecosystem service function of forests as a sink for greenhouse gases.

The Algae Science Centre at the Forschungszentrum Jülich.

Goals of the National Bioeconomy Strategy

Common strategic goals and implementation objectives for research funding and the development of a policy framework

1 Develop bioeconomy solutions for the 2030 Agenda for Sustainable Development

- Align the bioeconomy with the Sustainable Development Goals (SDGs) of the United Nations' 2030 Agenda

- Guarantee food security for a growing world population
- Use climate-neutral production to achieve the 1.5 °C goal
- Protect, maintain and use biodiversity

2 Recognise and harness the potential of the bioeconomy within ecological boundaries

- Understand production systems in an ecosystem context
- Research conflicting objectives and interactions
- Integrate economy and ecology in holistic approaches
- Establish a comprehensive monitoring system, measure and analyse biomass flows and implement comparative sustainability assessments

3 Enhance and apply biological knowledge

- Understand and model biological systems
- Develop novel production organisms for agricultural systems and industry
- Develop and establish innovative process engineering concepts for bio-based production systems
- Use converging technologies such as digitisation, artificial intelligence, nanotechnology, miniaturisation, robotics, and automation for the bioeconomy
- Strengthen interdisciplinary collaboration
- Expand the infrastructure available for research and technology transfer

4 Establish a sustainable raw material base for industry

- Produce and supply sustainable biogenic raw materials
- Conserve agricultural land and maintain soil fertility
- Use biogenic raw materials and byproducts
- Reduce dependency on fossil raw materials
- Use the potential of the bioeconomy for the development of rural areas
- Develop novel cycles for the production, processing and recycling of biogenic resources, for instance in urban areas

5 Promote Germany as the leading location for innovation in the bioeconomy

- Strengthen research transfer and take advantage of the opportunities offered by the bioeconomy for business models, job creation and increased revenue across all economic sectors
- Accelerate the launch of bioeconomy products, processes and services on the market
- Establish novel supply chains
- Support start-ups and small and medium-sized enterprises
- Promote clusters und model regions

6 Involve society in the bioeconomy and strengthen national and international collaboration

- Set up an advisory committee featuring a wide array of expertise
- Promote dialogue with interested groups in society
- Strengthen the social sciences in research for the bioeconomy
- Expand European and international collaboration

2.2 Goals and implementation of the Bioeconomy Strategy

Flanked by the two guidelines, the Federal Government's Bioeconomy Strategy addresses a broad spectrum of goals adopted at different social levels and applying across all economic sectors. The objectives are set out within the overall context in the remaining sections of this chapter and explained in more detail in the following chapters on research funding and the prevailing framework conditions. The overview on page 16 summarises the common strategic goals and the corresponding implementation goals.

2.3 Bioeconomy as a contribution to sustainability

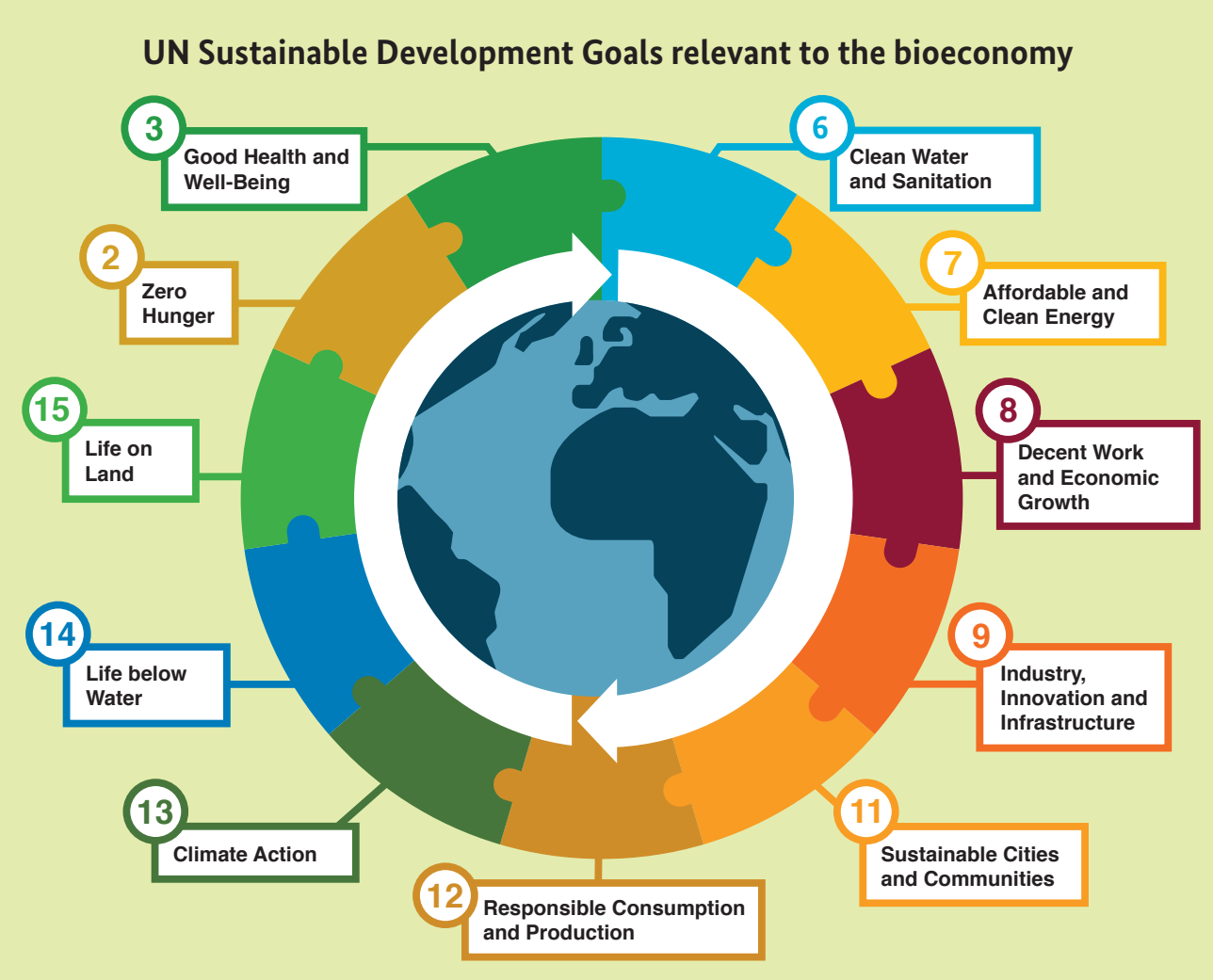
The overarching goal of sustainability is an objective that the bioeconomy shares with various other initiatives, each of which addresses specific aspects along the path towards greater sustainability. In recent years, the German Federal Government has launched numerous measures to anchor sustainability as a cross-cutting issue applying across all policy areas and economic sectors. With the 'German Sustainability Strategy'[6], the Federal Government committed to promoting sustainable development as a fundamental goal and establishing it as a benchmark for all government action. The government has set clear and comprehensive goals for the political implementation of the United Nations' sustainability agenda. Important aspects are also addressed in the government's own programmes; for example, on climate protection, resource efficiency[7] and circular economy[8], sustainability research[9] and biological diversity[10]. The 'High-Tech Strategy 2025'[11], an overarching innovation strategy, sets out a specific sphere of activity and defines various missions addressing the issue of sustainability. The Federal Government's National Bioeconomy Strategy is in line with these initiatives and promotes the strengthening of a bio-based economy as an essential pillar of its sustainability policy.

The issue of sustainability continues to grow in importance at an international level. There is an increased global effort to harmonise and coordinate policies. With the adoption of the 'Agenda 2030 for Sustainable Development'[12] in 2015, the international community acting under the auspices of the United Nations set out 17 Sustainable Development Goals (SDGs) with 169 accompanying targets. The bioeconomy is in a position to addresses numerous aspects of these comprehensive development goals. Of particular note are the potential contributions to SDG 2 ' No Hunger', SDG 3 'Health and Wellbeing', SDG 6 'Clean Water and Sanitation', SDG 7 'Affordable and Clean Energy', SDG 8 'Decent Work and Economic Growth', SDG 9 'Industry, Innovation and Infrastructure', SDG 11 'Sustainable Cities and Communities', SDG 12 'Sustainable Consumption and Production', SDG 13 'Measures for Climate Protection', SDG 14 'Life under Water' and SDG 15 'Life on Land'.

The considerable role that the bioeconomy can play in the achievement of the Sustainable Development Goals is generally recognised. This is reflected, among other things, in the numerous political initiatives that have been undertaken lately. A number of the 16 federal states that make up Germany have developed their own bioeconomy strategies in recent years, and in 2012 the European Union introduced its own bioeconomy strategy. This strategy was revised in 2018[13] , with a stronger emphasis placed on sustainability and viability, the definition of new priorities, and the reaffirmation of the five goals of the original strategy, namely to secure the supply of food, manage natural resources sustainably, reduce dependence on unsustainable raw materials, combat and adapt to climate change, increase competitiveness, and secure and create jobs. The German National Bioeconomy Strategy embraces these objectives.

The growing importance of the bioeconomy is not limited to Germany and Europe. Approximately fifty countries around the world have developed bioeconomy strategies of their own. Their programmes differ in accordance with the available biogenic resources and prevailing national political, social and technological framework. These strategies illustrate the wide scope encompassed by the bioeconomy. The trend reveals that a growing number of countries are placing great hope in the potential inherent in bioeconomic solutions. However, it is also clear that the develop-

ment of the bioeconomy depends on international cooperation, which is essential if the overarching goals are to be achieved. This opens up many opportunities for exchange, to link best practices and even to coordinate the entire implementation process. In the coming years, the German Federal Government will intensify cooperation, both within Germany and in the European Union, and with other international partners.



2.4 Global challenges, holistic solutions

The way we currently produce and consume at a global level is fast approaching, and in some cases already exceeding, the limits of our planet's ability to provide. It will not be possible to satisfy the consumption habits of a growing and increasingly demanding world population in the long term without destroying our livelihoods, if there is not a fundamental change in our behaviour. This is all the more true now that the consequences of climate change and the overuse of the planet's resources are becoming more and more visible and increasingly placing limitations on the opportunities that will be available to future generations. Our economic system must be sustainable and future-oriented.

Our ability to come up with solutions to the major societal challenges we face and to establish a more sustainable economy requires the adoption of a holistic perspective. What we need are sustainable solutions that provide alternatives to established forms of production and consumption patterns by taking into account systemic relationships. This means that we take into consideration the

interactions between biological systems and their environment and the role played by abiotic sources of raw materials and energy. It is vital that different perspectives be combined and that interactions at all levels be considered, ranging from organisms through ecosystems to the planetary climate balance.

As part of this holistic approach, it is particularly important that we take into account not only the social and economic outcomes but also the ecological effects associated with all measures undertaken. This includes posing questions about the future of our economic system in general, but particularly also more specific questions about the consequences of digitisation and demographic development for the labour market and future employment. Given the complexity of the challenges we face, and the multitude of corresponding aims, it is inevitable that some goals will conflict. The adoption of systemic thinking and holistic approaches will help to identify such conflicts ahead of time and permit us to use the best available scientific knowledge to reduce their impact. Under the best of circumstances, the creation of synergies will result in win–win situations.

This applies not just to the central core of the bioeconomy. Bioeconomic solutions and technologies only begin to unfold their full potential when implemented in conjunction with other future technologies. Driven by digitisation and advances in technological disciplines such as microelectronics, nanotechnology and materials and process engineering, completely new applications are emerging, the full potential of which cannot yet even be estimated. At the same time, the broad horizon of the bioeconomy and its orientation towards current social issues also provide numerous points of contact to other branches of policy and research. The bioeconomy addresses questions that are also of importance for the health and life sciences, environmental ethics, climate research, ecosystem sciences, materials research, resource efficiency, renewable energies and Industry 4.0.

2.5 Bioeconomy as a development strategy

The bioeconomy is a cross-sectoral economic concept that has become increasingly important in recent years. This development can be observed in the increasing proportion of bio-based products and processes employed in manufacturing. It is also evident in the many bio-based innovations that are currently being conceived, developed and tested, or which in a number of cases are already in common use – innovations often exhibiting improved properties compared to their conventional fossil-based counterparts. These bio-based innovations have many possible applications; for instance, in open-technology breeding research, biopolymer research, in the enzymatic breakdown of plant raw materials, in the development of high-quality ingredients based on microalgae, in organic and conventional agriculture, in the production of platform chemicals, in lightweight construction using bio-based composite materials, in housebuilding using innovative construction and insulation materials made from renewable ingredients, in the use of bio-based geotextiles for erosion prevention, in medical technology and biopharmaceutical and drug research, right up to the direct use of CO_2 from industrial processes as a source of carbon.

As renewable raw materials are predominantly sourced from rural areas, the bioeconomy is also suitable as a model for the sustainable development of the countryside and of structurally weak regions. If we can implement the subsequent stages in the processing of the biogenic raw materials that are required as part of an innovative bioeconomy concept directly at the site of raw material production, or in the immediate catchment area, this will have a positive effect in terms of value and job creation in rural areas. Resultant residues and waste materials could then, as part of a circular economy, be returned to the agricultural production process without additional transport effort and, whenever possible, reused as raw materials in other processes. Renewable raw materials can be used to underpin the energy supply in some regions, for example, in remote rural areas, provided other renewable sources of energy cannot be used to meet the demand safely and securely. This also applies in the case of decentralised systems for the provision of energy.

Due to the great innovation potential inherent in a large number of possible uses of biogenic raw materials, and in conjunction with the application of biotechnological processes, the advancement of the bioeconomy will present great opportunities for Germany to position itself internationally as a pioneer and innovation hub for the economic sectors and jobs of tomorrow.

3

Research funding for a sustainable bioeconomy

Research and development are important drivers of the identification, development and exploitation of the contribution that the bioeconomy can make to the achievement of a sustainable economy. In this chapter the research funding activities planned as part of the new National Bioeconomy Strategy are summarised.

Research is an important force for the identification, development and exploitation of the potential of the bioeconomy. Research into the bioeconomy covers the production, harvesting and use of biological resources, and the corresponding processes and systems. The aim is to create the scientific and technical prerequisites necessary to provide sustainable products, processes and services across all economic sectors and within the framework of a sustainable economic system. Biological resources, as we understand them in bioeconomy context, comprise not only the basic biogenic raw materials such as plants, algae, fungi, insects, microorganisms and biomolecules, but importantly also include our knowledge of biological and ecological processes and systems. It is vital that we are able to assess the limits to the performance and the capacities of these systems. The objective behind bioeconomy research approaches is to unlock the potential inherent within the bioeconomy. The basis for the development of innovative products and processes is a deep understanding of biological systems. In order for these systems to work within the framework of the sustainability agenda, the overarching relationships must be understood and the associated opportunities and risks must be considered, both in the production of biogenic raw materials and in the use of biotechnological processes.

The German National Research Strategy 'BioEconomy 2030' has made significant steps towards this goal since its introduction in 2010. The research programme underpinning the new National Bioeconomy Strategy builds upon these successes and on the knowledge gained.

This amassing of knowledge is made possible, among other things, by linking existing processes and traditional knowledge with the use and further development of cutting-edge technologies (smart technology and high-tech). In order to create completely new future technologies and breakthrough innovations, science must be granted the freedom to tread unfamiliar paths. The German Federal Government supports excellent and open research, without giving preference to certain technologies over others. The Federal Government has created incentives and the scope for the adoption of holistic approaches and intelligent innovation processes. It has also set a framework for responsible implementation that adheres to the precautionary principle.

Our ability to tap the potential of the bioeconomy to the fullest extent possible will require the constant expansion of our knowledge and of technical, social and systemic innovations. The key to success is not only the replacement of fossil raw materials, but also advancing the development of new bio-based products and processes, thereby reducing our overall raw material and energy requirements. The development of tailor-made bioeconomic innovations with high added value and novel properties and functions will lead to new business segments in growing and, in some cases, entirely new markets. The new National Bioeconomy Strategy forms an important pillar of the Federal Government's 'From Biology to Innovation' agenda.

Research will help to drive the necessary transformation process towards a sustainable economic system. This will have an impact on the way production and operations are conducted within a sector. Understanding this social change, with all of its attendant consequences, is an important component of bioeconomy research. It is essential that research funding be transparent and that it include different forms of participation, especially when it comes to defining problems and gaps in our knowledge, but also to develop proposals for actions and measures. Research creates the prerequisites necessary to shape the current transition towards a bioeconomy so that it is in line with the demands of society and with sustainability objectives.

Overview of the bioeconomy research landscape in Germany

3.1 Focus of the research funding

Research funding for the bioeconomy follows the guidelines outlined above. It is targeted towards achieving the strategic goals of the National Bioeconomy Strategy.

Expanding biological knowledge through research

The foundation of the bioeconomy is knowledge of biological principles, systems and processes. In recognition of this, the Federal Government intends to consistently push research and development onwards and to further strengthen the continuous gains being made in our knowledge in relation to the life sciences.

This applies to all levels of biological systems, from molecules through single and multicellular organisms to their interactions in ecosystems and within the wider environment. For a comprehensive understanding of biological systems, however, it is not sufficient to look at the different stages individually. It is only through the interaction of different elements and levels that new systemic properties develop. To advance our understanding of these complex relationships, the exchange between the life sciences and converging areas of science and technology must be intensified.

Using biological knowledge to create bio-based innovations

The expansion, intelligent use and meshing of biological knowledge are the root of invention and innovation in the bioeconomy. It is only through a deeper understanding of the basic mechanisms of life that the enormous poten-

tial that our knowledge of biology holds in terms of bioeconomic innovations can be revealed. To attain this deeper knowledge, research must be intensified, from the fundamentals through applied approaches to pilot plants and demonstrators covering all conceivable technologies. Creative and courageous ideas should be encouraged.

Advances in, for example, nanotechnology, information technology and cognitive, material and engineering sciences lead to new fields of application in the bioeconomy, while new biological knowledge inspires these branches of science and technology in turn. The resulting synergies have the potential to engender sustainable competitive innovation and the development of key new future and emerging technologies of high economic value. Some examples of bioeconomic innovations are: precisely tailored biological processes in industrial and agricultural production, innovative products with new, smart functions, and largely closed material cycles.

Digitisation also plays a key role in the generation of bio-based innovations and is crucially important for the entire innovation process. It makes it possible to capture enormous amounts of data pertaining to biological systems. It also allows us to network the data intelligently and so to exploit the innovative power of integrated systems.

Conserving natural resources through bio-based innovations

When transitioning to bio-based innovations, it is essential that due consideration be given to the availability of natural resources within ecological limits. The protection, sustainable and responsible use of ecosystems and the services they provide to society are crucial. These essential services include the preservation of biodiversity, the provision of clean water and healthy soils, and climate regulation.

The ultimate aim of research funded under the strategy is to bring about a significant reduction in the high current levels of consumption of non-renewable resources such as fossil fuels and mineral raw materials. Biogenic resources must be produced and used efficiently and sustainably, always bearing in mind potential conflicts between competing objectives; for example, in the area of land and resource use. This applies to bioeconomic innovations in both primary production (agriculture, forestry, the marine area, aquaculture) and in industry.

Combining ecology and economy through resource conservation

The bioeconomy provides an opportunity to combine ecology and economy. The uncoupling of economic prosperity from resource consumption requires that all resources be used efficiently and sustainably, and that energy and material flows remain closed in a circular economy to the greatest extent possible. Reducing the pressure on resources is both economically profitable and ecologically valuable.

The focus of bioeconomy research is, therefore, on a holistic approach to bio-based processes – from the production of the raw material, through processing and conversion, to the product and its end-of-life use. The recovery of resources is addressed, as is the recycling and reuse of byproducts, residues and waste streams. Research results should make it possible to link supply chains across sectors to create value networks that are as resource-efficient, ecologically advantageous and profitable as possible.

Approaches involving a coupling and cascade use of resources help to ensure that innovative areas of the bioeconomy continue to grow in conjunction with established supply chains. The establishment of value creation networks of this kind can also help forge a connection to new economic sectors and create the conditions required for a sustainable transformation to a high-performance bio-based economy.

Ensuring sustainability through bioeconomic solutions

The overarching goal at the heart of the development a bio-based economy is sustainability. The complexity of the bioeconomy means that it is necessary to consider the relationships between technical, ecological, economic and social factors when looking for sustainable solutions. As soon as the various sustainability goals are translated into concrete individual measures, conflicting aims often arise within these dimensions. To recognise conflicting aims at an early stage, and to prevent negative outcomes, bioeconomy research must be interdisciplinary and transdisciplinary. It must also pay close attention to global developments. Holistic perspectives require the inclusion of natural and technical sciences, while also incorporating social sciences and taking into account relevant ethical issues. Only in this way will the bioeconomy be able to ensure sustainability.

3.2 Building blocks for the implementation of research funding

The objectives behind the funding of bioeconomy research address complex issues and challenges. This necessitates the adoption of systemic approaches that integrate and merge different branches of science and areas of knowledge. Bioeconomy research encompasses natural, technical and also social sciences, and ranges from basic research through applied research to experimental development. The evolution of biological knowledge and cutting-edge technologies relevant to the bioeconomy does not always follow a continuous path marked by incremental innovations; it tends rather to progress in leaps and bounds, often through disruptive innovations.

The funding for research must be structured in such a way that the requirements highlighted above are met. For the purposes of implementation, modular building blocks that cover the various aspects of the bioeconomy have been defined. These modules substantiate research priorities and create a constructive scope for funding guidelines that will address specific funding needs thematically, methodologically and conceptually. They also make it possible to take up new knowledge and current developments. The interlocking building blocks allow the research policy goals to be implemented in a flexible way.

3.2.1 Biological knowledge as the key to the bioeconomy

Biological knowledge is the basis for the development of key technologies and makes possible the development of tailor-made bioeconomic innovations for both established industries and for new fields of application and sectors. Biological knowledge creates the conditions required for the sustainable solutions of the future. Sustainability means that the solutions are ecologically sound, economically competitive and socially desirable. In order to meet this comprehensive sustainability requirement, biological knowledge must be combined with knowledge of the corresponding ecosystem, economic and social relationships.

A central challenge facing bioeconomy research is the need to deepen and integrate knowledge about biological processes, their regulation and other interactions. The need to develop a comprehensive understanding of the system affects all levels, from elementary biomolecular processes to entire ecosystems and global cycles. Only on this basis can we achieve a holistic understanding of the diverse and dynamic processes occurring in biological systems, and their interaction with the environment.

The building block ‘Biological knowledge as the key to the bioeconomy’ follows this logic, incorporating research on topics ranging from basic biological processes to planetary perspectives.

Understanding and modelling biological systems

It is also important to promote systems biology approaches and to seek to merge the data obtained from the various corresponding fields of research such as genomics, epigenomics, proteomics and metabolomics (collectively referred to as ‘omics’) concerning new bioinformatic instruments and suitable infrastructures. Modelling and simulation approaches can map the underlying biological and ecological systems on this basis and thus make them accessible in all their complexity. By developing new integrative approaches, modular knowledge derived from the various omics fields shall be cross-linked at the various hierarchical levels of biological systems. System properties, that is, properties that cannot be explained or derived from the individual system elements, can be determined in this way. The goal is to establish systems biology approaches as a key not only to future life sciences technologies but to the bioeconomy as a whole.

Of particular importance here is the research on the epigenome of plants, the microbiome of plant roots, and the metabolic networks of microorganisms. Models that are able to make reliable statements about the functioning of regulatory mechanisms in living cells and the interactions between biological systems and the environment can also generate relevant insights that may lead to new sustainable solutions.

Building blocks of the research funding

1 Biological knowledge as the key to the bioeconomy

- Understand and model biological systems
- Develop novel production organisms for primary production and industry
- Derive innovative biotechnological process concepts for bio-based production systems
- Sustainably generate biogenic resources

2 Biological converging technologies and cross-disciplinary collaboration

- Promote inter- and transdisciplinarity
- Exploit nanotechnology, miniaturisation, digitisation, automation and artificial intelligence for the bioeconomy

3 Limits and potential

- Reduce pressure on ecological boundaries
- Recognise and tap sustainable potential
- Establish bioeconomy monitoring, quantify and evaluate the bioeconomy

4 Technology transfer

- Establish new value creation networks
- Support start-ups and small and medium-sized enterprises (SMEs)
- Strengthen infrastructures for research and technology transfer
- Promote young people and qualifications

5 Bioeconomy and society

- Research interactions and conflicting goals
- Undertake comparative sustainability reports and develop certification systems

6 Global research collaborations

- Promote cooperation in Europe
- Strengthen cooperation with non-European partners

Novel production organisms for primary production and industry

One of the fundamental conditions of the bioeconomy is the need for the sustainable production of biogenic raw materials and products in both agriculture and industry. In order to meet this requirement, and to produce efficiently while conserving resources, it may be necessary to adapt production organisms, in particular useful plants, but also insects, algae, fungi and microorganisms, to the respective environmental, climate and production conditions. Research should be open with regard to the methods and technologies employed, and should also include modern molecular biological approaches adopted within closed systems.

Important aims in the context of breeding for sustainable plant production are yield optimisation, optimal use of nutrients, resistance to and tolerance of flooding, heat, drought and plant diseases and pests, adaptation to soil quality, and the preservation of genetic diversity. In addition to plant crops, the role assumed in the modern bioeconomy by insects, fungi, microorganisms and aquatic life forms such as algae is also growing in importance. The German Federal Government will support this development with appropriate funding measures.

Research and development into new organisms plays an important role in industrial production and extends the portfolio of classic biotechnology. The properties of the microorganisms used industrially such as bacteria, fungi and microalgae can be specifically adapted to production conditions using innovative methods of metabolic engineering or

synthetic biology. In addition to the development of resilient and efficient production strains, research will also focus in particular on expanding the product range. It is important to promote research approaches targeting the development of new materials and products with tailor-made properties (for example, properties that are optimally tailored to a specific need or a new function, such as fully recyclable biopolymers, novel biopharmaceuticals to combat antibiotic resistance and environmentally compatible chemicals). This should facilitate an optimal adaptation to the requirements of the market and of the environment. In order to harness the potential inherent in the diversity of microbial species and their various metabolic properties, microorganisms that have not yet been used for this purpose but which are suitable for application in industrial production are to be identified and further developed as platform organisms for biotechnology.

In addition to the use of tailor-made microorganisms in industrial production, biotechnological research also presents opportunities to provide artificial and cell-free production systems for the bioeconomy. Such systems make possible, for example, the production of complex antibodies for specific medical applications and of substances that are toxic to cells. Artificial production systems represent approaches that significantly expand the potential range of application of bio-based production processes.

Innovative biotechnological process concepts for bio-based production systems

In the interests of sustainability, it is necessary that we view not only the organisms used in biotechnological production holistically but also the processes in which they are used. In some cases we may even need to completely rethink how we use these organisms. Innovative, efficient and modular bioprocess concepts should be developed so as to enable their flexible adaptation to different locations, raw materials and products.

Considerable research effort is yet required to get to the point where we can efficiently provide biomass for downstream production processes that is accessible, treated and in line with demand. The development of novel biotechno-

The establishment of the Fraunhofer Centre for Chemical-Biotechnological Processes in Leuna was supported by the BMBF and BMEL.

logical processes is essential for further optimisation of the use of biogenic residues and to convert byproducts and residue flows into valuable products. We need to create new concepts for coupled and cascade use, and to optimise biorefinery concepts holistically.

In closed reaction processes, waste streams that have not yet been recycled or which have an as yet unused potential value can serve as an ecologically and economically advantageous source of raw materials for industry and agriculture. This includes organic waste, municipal and industrial waste water, and industrial waste gases. The direct use of, for example, carbon dioxide or of the synthesis gas produced in industry as a source of carbon in industrial bioprocesses can contribute to the achievement of a high level of greenhouse gas neutrality in future industrial production. Important resources such as rare metals and phosphorous can also be recovered using tailor-made biocatalysts, and plastics can be broken down into their basic building blocks. The development of innovative methods and processes for the efficient processing and recycling of these often complex and toxic starting materials should be promoted in a targeted manner.

Generate biogenic resources sustainably

Agriculture and forestry are a central pillar of a bio-based economy. Nevertheless, these sectors are challenged to reduce their consumption of resources and space, and to reduce greenhouse gas emissions and biodiversity loss, as highlighted in recent reports by the World Climate Council and the World Biodiversity Council[14] . The effects of climate change and of conflicting objectives, such as competing demands in relation to land use, pose other major challenges.

Agriculture is vital, and in the future it will need to feed a growing world population. However, agricultural production is also a major cause of human-related environmental changes affecting land use, biodiversity, water balance, nutrient cycles and the global climate balance. There is a growing awareness that the agricultural sector itself must be viewed as an ecological system. Agricultural production relies on ecosystem services, and must in turn contribute to the protection of these services. Agriculture and forestry must be perceived holistically as agro-ecological systems and through research we must continue to expand our understanding of ecosystem relations.

Holistic perspectives that assess agricultural production systems not only on the basis of yield but also according to their ecological performance are especially important. Ultimately, this pertains not only to the agriculture and forestry sectors. Large parts of the planet's terrestrial and maritime ecosystems have been fundamentally changed by human activity. It is vital that in future the effect of human interventions in specific ecosystems and global material and energy cycles be taken into account in relation to all technologies and uses of resources. The bioeconomy can be a pivotal lever with which to achieve greater sustainability in the production of biogenic raw materials and in industrial manufacturing processes. This also involves conceiving new ways to produce biogenic raw materials for material and energy purposes.

Placing agriculture and forestry on an innovative and sustainable footing for the future necessitates not only substantial, broad-based fundamental research to better understand the underlying biological and (agricultural) ecological systems but also the development of suitable, application-oriented approaches. These may be based on cutting edge and key technologies, but also on concepts that combine existing agricultural techniques and ecological requirements in new ways. Through the development of appropriate sustainable cultivation and production systems, agricultural production can be adapted to respond flexibly to regional and location-specific conditions, for example, using new smart farming approaches. It is of central importance in this context that biodiversity conservation and the preservation of soil and water quality be recognised as prerequisites for the maintenance of ecosystem services, and that these considerations be incorporated into the valuation of bio-based products.

This can pave the way for the maintenance of innovative and sustainable agricultural and forest systems that are resource-efficient, competitive and resilient in the face of changing climate and environmental conditions, while continuing to provide the necessary supply of biogenic resources. Funding for research will support in particular the development of novel, circular and lower input cultivation and production systems, including in organic farming. These may be regionally adapted on-site agricultural, forestry or aquatic production systems targeting a closed circuit of material flows. Alternative forms of production are also conceivable for use on sealed land in urban and peri-urban areas, such as (modular) high-tech production systems that work in a controlled environment with low space and energy requirements and in largely closed circulation systems. One example of this is vertical farming.

In the long term, research must lead to a variety of adaptation strategies and key innovations, identify integrated solutions and pool resources in order to create synergies for the benefit of people and the environment, and to reduce trade-offs. These integrated solutions shall combine

technological approaches with location-specific procedures to create alternative concepts promoting sustainability.

3.2.2 Converging technologies and cross-disciplinary collaboration

Promising starting points for bioeconomic innovations can be found particularly in systemic, interdisciplinary and transdisciplinary approaches that combine biological knowledge with converging technologies. Converging areas of knowledge and technologies such as nanotechnology, miniaturisation, digitisation, automation and artificial intelligence are of great importance for the bioeconomy.

The use of synergies and interfaces between the various specialist disciplines should be promoted, especially in the context of research and development for future technologies. Suitable instruments, such as virtual interdisciplinary centres or new multidisciplinary and cross-sectoral funding concepts, are needed to strengthen networking amongst stakeholders and to establish cross-disciplinary cooperation.

Digitisation has an important cross-cutting function in relation to the generation and use of biological knowledge and in connecting different technologies. Using the latest tools in computer science, and with the development of computer-aided mathematical models, large amounts of data collected at different scales in various branches of the life sciences can be evaluated intelligently. Researchers can gain valuable insights into the functioning of biological systems, opening up new dimensions for the use of biological knowledge. A prerequisite for the efficient and successful use of digital data is data harmonisation, in combination with efficient data management systems, advanced interface concepts and the development and use of standards.

Digitisation also holds great potential for innovation in the bioeconomy in relation to simulation and modelling. Models can be used not only to describe biological processes and systems, but should also increasingly be used for the purposes of impact assessment, prediction and the targeted design of efficient and tailor-made bio-based processes. For faster development and better monitoring and control of biotechnological production processes, technological progress will be supported in the areas of smart sensor technology, artificial intelligence, automation, miniaturisation and parallelisation of process steps, as well as high throughput analyses. Corresponding technological developments can also increasingly be used in the agricultural sector, for example, to analyse the interaction of soils, microorganisms, plants and the environment, or to record the appearance of organisms quickly, precisely and non-destructively.

3.2.3 Limits and potential

Humans have always intervened in nature and changed their environments. Since industrialisation the extent of humankind's exploitation of nature has increased, with the result that natural systems have been thrown out of equilibrium. Climate change, loss of species and endangered ecosystems are the consequences. The continuation, expansion and acceleration of the current production and recycling of raw materials will lead to further environmental damage, biodiversity losses, and an increase in greenhouse gas emissions according to reports of the World Climate Council and the World Biodiversity Council published in 2019. The planet's ecological boundaries are increasingly being stretched to the limit and have in some cases already been exceeded. The contribution the bioeconomy seeks to make is to ensure that we remain within these limits. It is vital, therefore, to know the stress limits of the ecosystems that are of importance for the bioeconomy. To recognise and to tap the potential of the bioeconomy necessitates an understanding of the environment. In order to ensure that the bioeconomy operates within ecological boundaries and that it does not exacerbate the pressure on resources, our knowledge of ecosystem effects and planetary cycles must be expanded and meshed.

Quantification of the bioeconomy

To successfully design a sustainable bioeconomy it is important to measure and assess the exact economic, ecological and social effects of bio-based management. Data and calculation methods are needed to determine the level of greenhouse gas emissions and the extent of the use of materials, energy, water and land of different qualities that are associated with certain forms of production, including how more intensive use affects biodiversity. It is important to assess the availability of biomass – differentiated in terms of space, time and ecological importance – on the one hand, and the demand for biomass on the other. The demand for biomass that is exempted from use, for example, for the purposes of CO2 fixation and for biodiversity protection, must also be considered. It is essential that we understand biomass flows and cycles, and that we can estimate them using suitable methods.

It is only by adopting a holistic perspective that also includes possible alternatives that we can find the best pos-

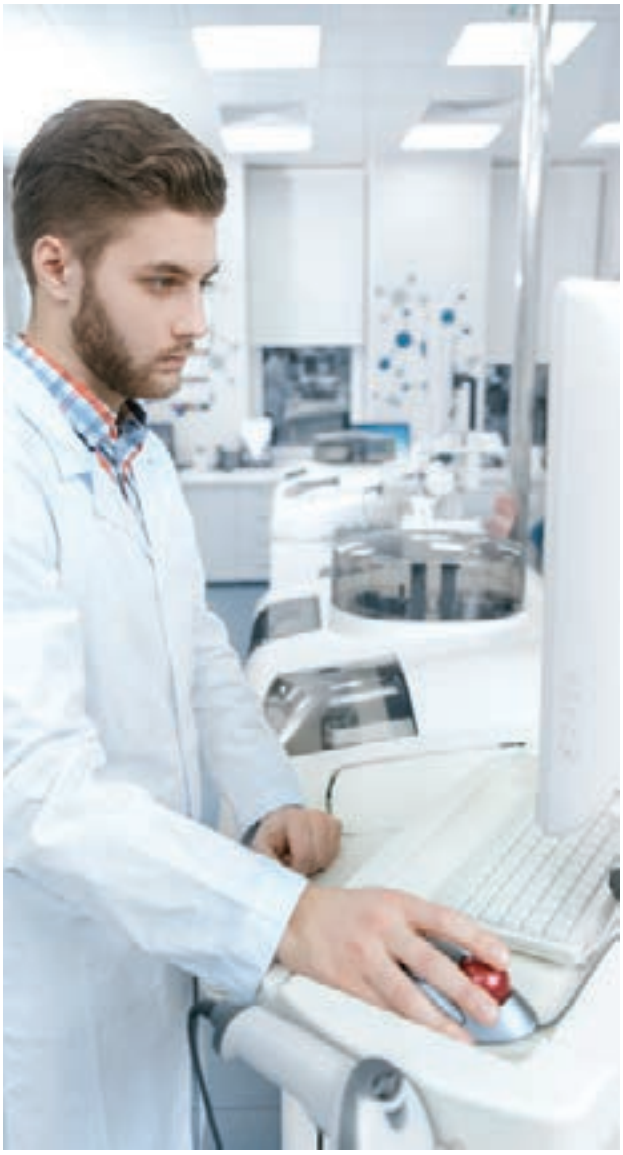
sible solutions satisfying a comprehensive interpretation of sustainability. The necessary instruments are currently only available in part. With the aid of research these gaps should be closed in the coming years. First of all, it is necessary to develop indicators that make it possible to record all dimensions of the bioeconomy and to back these up with corresponding criteria. Existing and new data must be identified and merged. A holistic equilibrium can only be achieved when we can either measure or estimate precisely the extent of the use of biomass over the entire life cycle, from production to reuse, and of the application of bioeconomic processes with all their outcomes and feedback effects. Comprehensive and reliable impact assessments of technical, economic and ecological developments in the bioeconomy can also be carried out on this basis.

The pilot phase of an extensive monitoring process intended to create the scientific prerequisites required for just such a quantification of the bioeconomy has been initiated. This work should be continued and expanded upon as an overarching instrument of the National Bioeconomy Strategy (see section 5.6). The monitoring of the bioeconomy should help us better understand the development towards a sustainable bioeconomy. It should serve as the basis to evaluate steering and prioritisation at the policy level.

3.2.4 Transfer from idea to application

It is not enough to acquire biological knowledge and to develop sustainable technologies. Only when these are successfully transferred onto the market as products and processes will their positive impacts for the environment and society be achieved. Experience shows that not every good idea prevails. The risks often appear too high, and sometimes there is a lack of financing options for the necessary steps between the idea and the market launch. The Federal Government wants to prevent promising bioeconomic innovations from failing because of these barriers and intends to support innovation all the way to the point of application. It is necessary to create and develop interfaces between research and application, and to establish intimate connections between all of the actors involved in the innovation process. For this purpose, instruments that support the validation of research results for a transfer to practical application are provided.

The Agency for Breakthrough Innovations (Agentur für Sprunginnovationen), founded under the aegis of the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Energy, offers further



support for ground-breaking ideas on their way to application, and is also open to bioeconomic innovations.

Establishing new supply chains

A central element in the transfer of knowledge to application is a closer networking of the actors involved, both between research and industry and between different sectors of the economy. The German Federal Government supports the early and transparent integration of companies and those with economic expertise in the research and development process, because this ensures that these processes are sufficiently oriented towards the needs of the market. A suitable instrument in this regard are exploratory phases that precede the actual research project. It can be assumed that the increasing use of bio-based processes and products will serve to alter existing supply chains. In the course of this change, new value creation networks

often emerge. Part of the reason for this is that the complex mixtures of biomass often result in the creation in addition to the desired product of byproducts, which can in turn can serve as a raw material for other processes. To increase both efficiency and added value, alternative ways to use individual components or byproducts must be researched and tested. This is only possible if stakeholders work together, and if expertise from different disciplines is bundled. The same applies to the circular economy. Ideally, product design should already take into account how a particular product can be processed or recycled at the end of its useful life. The German Federal Government supports networking between the producers and users in a supply chain by, for example, funding suitable collaborative projects or establishing clusters.

Support for start-ups and small and medium-sized enterprises (SMEs)

Start-ups and young companies, as well as small and medium-sized (SMEs) enterprises, are important drivers and providers of innovation within the bioeconomy. However, often they lack sufficient funding opportunities. Due to the longer-than-average development times and innovation cycles often associated with product development in the life sciences, these companies frequently require targeted funding beyond that necessary in many other industries. Specific measures to promote small and medium-sized enterprises and start-ups are currently under development. The Central Innovation Programme for SMEs (Zentrale Innovationsprogramm Mittelstand, ZIM) of the Federal Ministry for Economic Affairs and Energy is also available as a means of support for innovations in the bioeconomy.

Infrastructures for research and technology transfer

The successful conversion of scientific knowledge to competitive products and processes is only possible if the requirements of the market and industry, such as raw material availability, technical requirements, regulatory challenges and cost factors, are considered at an early stage of the research and development process. It is very important that infrastructures for bioeconomy research be created that facilitate application-oriented collaboration even more efficiently than has been the case to date, including across disciplinary boundaries. A number of important steps have already been taken in this regard in recent years. It is also necessary to create spaces that allow for the targeted conversion of scientific knowledge into marketable and competitive applications. Demonstration and living laboratories provide an opportunity to test innovations integrated within established processes. In order to minimise the high investment risk associated with launching bio-based products and processes, an opportunity to test innovations on a larger scale in pilot plants should also be created.

Young talent and qualifications

The complex questions confronted by the bioeconomy go beyond disciplinary boundaries and require an entirely new quality of systemic thinking and action. This calls for highly qualified experts who, in addition to their specialist knowledge, acquire during their training and studies the ability to engage in interdisciplinary and transdisciplinary work. Further training measures must also be provided to accompany them throughout their careers. Fundamental business knowledge should be imparted earlier than has been the case in the past. Special prizes and funding modules create incentives for bioeconomy career planning in science and industry as part of research funding. Further overarching instruments can be found in section 5.5 ‘Qualifications and skilled personnel`.

3.2.5 Bioeconomy and society

Climate change, demographic growth, supplying a growing world population with high-quality food and raw materials, the limited availability of planetary resources and the protection of the biosphere, including biodiversity, are the great societal challenges of our time. Technical means alone will not suffice to meet these challenges because technological innovations do not always lead to the solutions they were intended to provide. A basic understanding of systemic relationships and global change is a prerequisite for solution strategies in which technological innovations are meaningfully and successfully embedded. To understand these social transformation processes, and the socio-technical change, we require more extensive social, political and economic research.

Research interactions and conflicting goals

With the new National Bioeconomy Strategy, the Federal Government is assuming responsibility for sustainable development. The bioeconomy must help us to achieve the overarching political goals of climate protection and

sustainable development in line with the United Nations' Agenda 2030, to which the Federal Government has committed itself. Individual goals must not be achieved at the expense of other goals. We can only achieve our aims if we continuously expand our understanding of systemic relationships – from material cycles in individual cultivation systems through the functioning of ecosystems to planetary boundaries, which the current European bioeconomy strategy also emphasises.

The interdisciplinarity of bioeconomy research is of great importance for the production of this knowledge. This applies equally to the natural and technical sciences and to the social, political and economic sciences. Only across disciplines can real-world problems be captured in their complexity, their relationships and conflicting goals be analysed, and sustainable solutions that meet the needs and expectations of society be found.

The sustainability of the solutions found depends not least on the interactions between the technical possibilities and economic, social and ecological factors. These interactions also include conflicting goals, for example, in relation to competing demands over the use of land and resources. Bioeconomy research is a new, technology-open form of research and development.

New technologies, including biotechnologies, can serve to further intensify the existing competition between protection, use and marketing interests. It is necessary to examine comprehensively the opportunities and risks associated with the development and spread of specific new technologies. Issues such as the value of nature and of ecosystem services, access to resources, their fair distribution and sufficiency are also important. In many countries around the world, these issues are linked to fundamental questions about the relationship between human rights, democracy and nature conservation, all subject areas containing a strong ethical component. Ethical principles can help to identify conflicting goals in the bioeconomy and to provide solutions. In the context of global challenges (securing food, combating climate change, stopping biodiversity loss, protecting natural spaces), at the forefront of the global race for access to natural resources are land and soil, biodiversity and water. The more dynamic the expansion of the bioeconomy, the more urgent the need to address these questions in the social, political and economic sciences in order to find sustainable solutions. The aim of the research is to contribute to the assessment of the potential inherent in the bioeconomy, its practical design, the consequences with regard to various aspects of sustainability, and the options for action that are available.

Comparative sustainability reports and certification systems

To achieve optimal solutions, it is essential that comparative sustainability balances be created on the basis of comprehensive life cycle analyses revealing the conditions under which bio-based products and corresponding processes are superior to other solutions. This includes both conventional fossil-based alternatives and those based on the use of other renewable raw materials. Corresponding research projects provide a vital foundation for decision-making in relation to the ongoing development of the bioeconomy.

The development of meaningful synoptic indicators can also serve as the basis for possible certification systems that clarify the additional benefits and sustainability of bio-based products and thereby strengthen their market position. On this basis, political decisions aimed at steering biomass production can also be made.

3.2.6 Global research collaboration

The exchange of knowledge across national borders unleashes synergies, both for the cooperating partners and for the bioeconomy as a whole. The German Federal Government will continue to improve the conditions for international learning and research. The aim is to perceive of and to implement sustainability and the bioeconomy in a global context. Germany can benefit from this as a location for science, technology and innovation. An expansion and continuation of international cooperation reflects Germany's global responsibility.

The foundations for this cooperation have been laid. In recent years, the German Federal Government has promoted the establishment of transnational research networks intensively, and has taken measures to ensure that German research institutions enjoy an excellent reputation worldwide. The Global Bioeconomy Summit has become established as a platform for exchange between international experts, even beyond research. Initiated by the Bioeconomy Council, mandated to run from 2012 to 2019, and funded by the German Federal Government, this high-level summit has grown into an institution that provides important impulses for the further development and coordination of various bioeconomy approaches.

Cooperation in Europe

The Federal Government will continue cooperation in the areas of research, development and innovation for the bioeconomy in Europe and will work to strengthen this

collaboration. Intensive exchange with the EU Member States within appropriate working groups – including the Standing Committee on Agricultural Research (SCAR) and the States Representative Group of the Bio-Based Industries Joint Undertaking (BBI JU) – is a central pillar of this commitment. The German Federal Government will actively support the development of the bioeconomy at EU level through constructive dialogue with its partners and work towards the successful implementation of the European bioeconomy strategy.

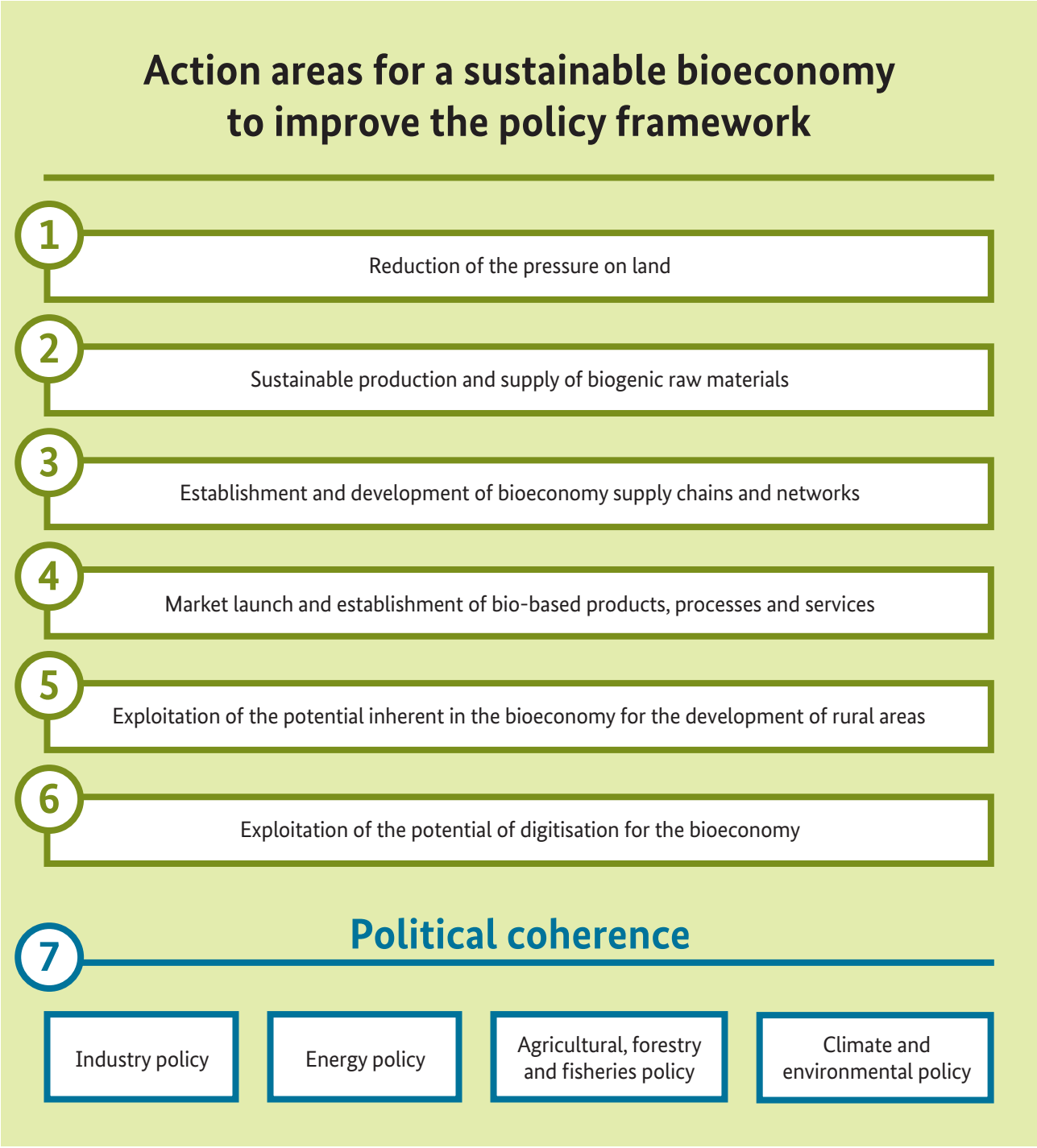
Cooperation with non-European partners

Beyond the borders of Europe, cooperation with non-European experts will also be continued and expanded. Priorities will be set through targeted bilateral research collaborations with selected countries. International measures supporting cooperation between German institutions and partners from other nations will be initiated. The Federal Government is convinced that each country and region can make an individual contribution to the global bioeconomy through its own mix of raw materials, technologies, knowledge and ideas. Cooperation can support the establishment of a bio-based economy and serve to link the individual approaches in the best possible way.

4

Areas of action to improve the framework for a sustainable bioeconomy

As a cross-cutting topic, the bioeconomy touches all economic sectors. To address the bioeconomy effectively, it is necessary to link different policy areas in a manner that is sensible and coherent. The central areas of action required to improve the policy framework are presented on the following pages.



As a cross-cutting topic, the bioeconomy touches all economic sectors. To address the bioeconomy effectively, it is necessary to link different policy areas in a manner that is sensible and coherent. In addition to the research policy already outlined (chapter 3), this includes, for example, industry and energy policies, agriculture, forestry and fisheries policies, and climate, environment and nature protection policies. The National Bioeconomy Strategy connects various policy areas and illuminates a path for bioeconomy policy in Germany. The aim of this policy is to create framework conditions conducive to supporting the transition to a bioeconomy and helping to defuse conflicts over competing goals and uses.

Policy makers shape the implementation of the bioeconomy by means of regulatory and support measures, and through communication and cooperation. The individual fields of action are designed to support the sustainable development

of the bioeconomy in Germany – defined in the SDGs and in the German Sustainability Strategy – and to make a contribution all along the supply chains in the bioeconomy (from the production of raw materials through the use, processing and marketing of biomass to the trade in and consumer use of products and also the use of residues and waste materials). To this end, the opportunities offered by digitisation should be exploited while cooperation at the international level should be strengthened and support for training and teaching enhanced.

4.1 Reducing the pressure on land

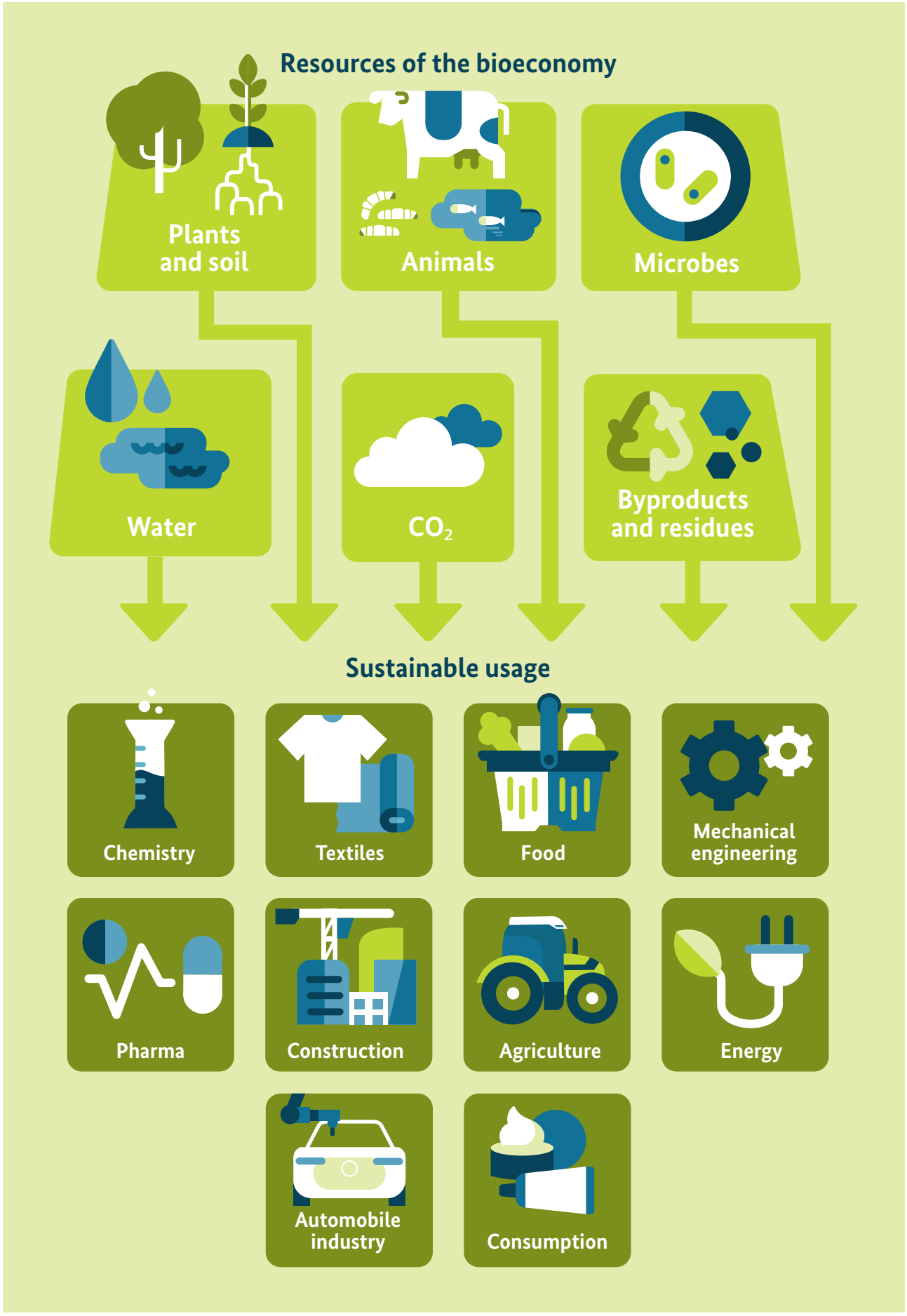
The increase in the use of biogenic resources expeced to occur as the global population grows, and the growing demand throughout the world for food of animal origin, implies a greater use of land. In theory this can only be achieved by expanding the production area, by intensifying use on existing production areas, or through a combination of both. The need for land can be lessened through more effective redistribution of food, and reduced production of animal-based food produce in combination with a low-meat diet. The pressure on land is exacerbated by the need to conserve natural habitats and biodiversity and its use for other purposes, including the expansion of settlements and infrastructure, the mining of abiotic raw materials (coal, sand, gravel, etc.), but also the creation of renewable energy systems. Even within biomass production there are competing demands placed on the biomass produced in terms of the potential use and processing pathways.

The expected increase in land use competition emerging not just as a consequence of production necessities but also due, for example, to the need to provide ecosystem services (such as habitats and feeding areas for insects and small game), poses a great challenge. At the same time, it represents an opportunity for improved and resource-saving forms of land use (for example, paludiculture). The bioeconomy policy relies on a combination of different approaches to defuse the competition over land use. These take in measures that serve to increase resource efficiency. Examples of this include implementing infrastructures and processes for the separation and recovery of secondary materials, and adopting methods for coupled and cascade use targeting an overall reduction in the use of raw materials. The use of biogenic resources that require little or no space (for example, waste and residues) can also lead to a significant reduction in the pressure on land.

Another approach adopted by the Federal Government to reduce pressure on the land is the recultivation of degraded and unused areas, and of land that is used inefficiently. Examples of this include the sustainable management of post-mining landscapes and of marginal yield sites in agriculture. Inherent in this approach is the recognition of the significance of fallow land and non-intensively used areas in the context of environmental services and biodiversity. Inner-city areas can also be used for agricultural or horticultural production (urban farming). Sustainable management may engender positive effects, such as the prevention of erosion and enhanced biodiversity.

In addition to putting sites occupied by past industries to new industrial uses in the context of the bioeconomy, another way to reduce pressure on the land is to increase the productivity of areas used for agriculture and forestry. This must, however, go hand in hand with the conservation of biodiversity and landscapes. An economically and ecologically sustainable increase in productivity on a unit area basis can be achieved through breeding and precision farming, thereby counteracting at the same time an increase in the demand for land area. Breeding can also contribute to a diversification in agricultural crop production by providing a wide range of species and varieties, and fostering resilient and ecological farming systems. This can in turn have a positive effect on agricultural biodiversity. The Federal Government will continue its activities in the field of plant breeding, targeting varieties that are more suitable for specific locations and climates, more efficient in terms of nutrient and water use, and more resistant to and tolerant of biotic and abiotic stresses. These activities will also address the further development of organic farming systems, including activities that will address adaptation to climate change.

The measures taken by the Federal Government and the governments of the individual German federal states to reduce the area of land sealed for settlement and infrastructural purposes will also help to reduce the pressure on the natural resource soil.


Resources of the bioeconomy
Plants and soil
Animals
Microbes
Water
CO_2
Byproducts and residues
Sustainable usage
Chemistry
Textiles
Food
Mechanical engineering
Pharma
Construction
Agriculture
Energy
Automobile industry
Consumption

4.2 Sustainable production and supply of biogenic raw materials

Agricultural land, forests and water ecosystems provide the most important biogenic raw materials used within the bioeconomy, materials supplemented by biogenic residues and waste materials. To preserve these natural foundations of life on Earth, resource use must take into account environmental, climate and nature protection goals, while also considering socio-economic and sustainability targets. This requires efforts that account for all factors within production systems and consideration of the location-specific circumstances and sustainability aspects. One example in this context is the preservation of healthy and fertile soils. Another is increasing the efficient use of residues and waste materials from agriculture and forestry, and from industrial production and private households.

The EU's Common Agricultural Policy (CAP) is an important instrument in the shaping of sustainable agriculture. The ongoing reform of the CAP should aim to make European agriculture more sustainable. However, the sustainable supply of biogenic raw materials should also be strengthened nationally, exceeding the framework of specific activities supported by EU subsidies. For example, organic farming plays an important role in the sustainable production of agricultural products for food. In order to service the increasing demand for organic products more comprehensively, and to expand the range of income opportunities for agricultural businesses, the proportion of the agricultural land dedicated to organic farming in Germany is to increase to 20 % by the year 2030.

The sustainability of agriculture should be improved continuously as part of national action plans and strategies. For example, the risks associated with the use of crop protection products in agriculture are to be reduced and animal welfare should be improved without impacting negatively on the productivity of German agriculture. To achieve this aim, the specifications for fertiliser application are continuously being adapted in line with environmental requirements and the corresponding European legal foundations.

Forestry is another pillar of the German bioeconomy. It provides the greatest part of the biogenic raw materials currently used in Germany. Forest plant breeding has an important role to play in adapting Germany's forests to climate change and securing the supply of raw materials. Another important aspect is the conversion of unstable stands to climate-adapted mixed forests comprising tree species appropriate to the site. The Federal Government's aim is to develop an enduring balance, adapted to future requirements, between the increasing demands placed on the forests and their sustainability, because the objectives of sustainable forest management require economic performance, ecological responsibility and social justice.

To secure the long-term productivity of agriculture and forestry in Germany, the Federal Ministry of Food and Agriculture (BMEL), in cooperation with the federal states, has drawn up an agenda for the adaptation of agriculture, forestry, fisheries and aquaculture to climate change. This agenda is to be integrated into the upcoming action plan intended as part of the German Strategy for Adaptation to Climate Change (Deutsche Anpassungsstrategie an den Klimawandel[15] , DAS). The aim is to adjust agriculture, forestry, fisheries and aquaculture to the expected changes to the climate so as to reduce the risks facing businesses without harming the environment.[16] The future availability of biogenic raw materials will, on the one hand, depend heavily on the changes that climate change will bring about in terms of production conditions (amount and distribution of precipitation, average temperatures, extreme weather conditions, etc.), but also on the ability of our agriculture and forestry to adapt to the new circumstances.

4.3 Establishing and developing bioeconomy supply chains and networks

The development of innovative bio-based products, processes and services that have positive properties exceeding those of fossil-based alternatives is a key driver of a bio-based economy and should, therefore, continue to be supported. In many cases, the development and establishment of regional biogenic supply chains can be achieved through greater networking amongst established players in individual supply chains. For this reason, support for networking activities should also continue in future. In the past, this was done, for example, through the funding of bioeconomy clusters. The German Federal Government sees particular potential for innovative supply chains centred around the increased use of biogenic raw materials derived from aquatic systems such as algae, cyanobacteria and aquatic plants. The use of aquatic resources will be especially strongly promoted in future in order to broaden the bioeconomy's raw material base.

In addition to promoting the establishment of new supply chains, existing bioeconomy supply chains must be optimised to reduce raw material consumption, protect the environment and climate by reducing the use of non-renewable raw materials, and improve their overall economic competitiveness. The Federal Government will support the technological development of existing production processes and the testing of innovative processes. Organisational and technical concepts are to be further developed at enterprise level and in downstream logistics chains. This will help optimise the production, storage and initial processing of renewable raw materials and so contribute to the more efficient use of biogenic resources. This can apply to both the collection of secondary and residual materials as well as the processing of raw materials sourced from agriculture and forestry to higher-quality intermediate products suitable and viable for transport, while taking into account sustainability aspects.

The improvements associated with optimisation can often be further enhanced by linking individual supply chains to value networks, creating positive synergy effects. Applying the concept of resource efficiency and sustainability, a cascade and coupled use of resources should be strived for – wherever it is possible and reasonable to do so. To increase resource efficiency, greater efforts should be made to ensure a cascade use of resources, to maintain biogenic raw materials in a circular material cycle for as long as is economically and technically possible. The use option with the highest added value should be pursued initially, and particular attention should be paid to the development of new, economically attractive byproducts that are suitable for coupled use. The principles of the German Circular Economy Act (Kreislaufwirtschaftsgesetz) governing the conservation of natural resources and the environmentally compatible management of waste must also be adhered to.

4.4 Market introduction and establishment of bio-based products, processes and services

Bio-based products often have advantages over their fossil-based counterparts in relation to climate, the environment, resource efficiency and sustainability. Nevertheless, the introduction and establishment of innovative bioeconomy products and processes on the market represents a major challenge as they must compete with products that are already familiar to users and benefit from established marketing channels, recognition and infrastructure. Although the willingness of consumers to buy bio-based products is occasionally so great that they will pay higher market prices, the initial demand for bio-based product alternatives is frequently not sufficiently high for their production to be economically viable.

Through the inclusion of various actors in bio-based supply chains, and through exchange with these stakeholders within the framework of tried and tested dialogue processes such as technical discussions, workshops, platforms and

conferences, measures to promote the increased use of certain biogenic raw materials can be developed and implemented. One example of this is the 'Charter for Wood 2.0'[17] initiated by the BMEL. This approach operates on the basis of the motto 'Protect the climate. Create value. Use resources efficiently' and follows a holistic approach aimed at increasing the use of wood derived from sustainable forest management. As a milestone in the 2050 climate protection plan, the Charter for Wood includes aspects of value creation and resource efficiency as issues closely related to climate protection.

Other important components that support the market establishment of bio-based products are information and the raising of consumer awareness of the specific advantages and disadvantages of these products. Product labels and, where applicable, certification labels create transparency and strengthen trust in bio-based products. Selecting and publicising good examples of sustainable uses of bio-based raw materials as beacons help to raise public awareness of these issues and create additional incentives for the use of renewable raw materials. The Federal Government will continue to hold competitions such as 'HolzbauPlus', as part of which the BMEL awards prizes to particularly sustainable buildings made with a holistic choice of materials and also to projects involving wood used in conjunction with other renewable raw materials in construction, insulation and finishing.

Public procurement is another important tool that can be wielded to support the establishment of bio-based products. Public procurement is estimated to be at least € 300 billion a year. A stronger focus of public procurement on bio-based, sustainable products can support the establishment of such products from the demand side. The market power and role model function of the public sector can serve as market openers for new products and services.

The 'German Innovation Partnership' (Deutsche Innovationspartnerschaft, DIP), implemented with funds issued by the BMEL and the Landwirtschaftliche Rentenbank, is yet another example of how product developments can be successfully brought to market maturity.

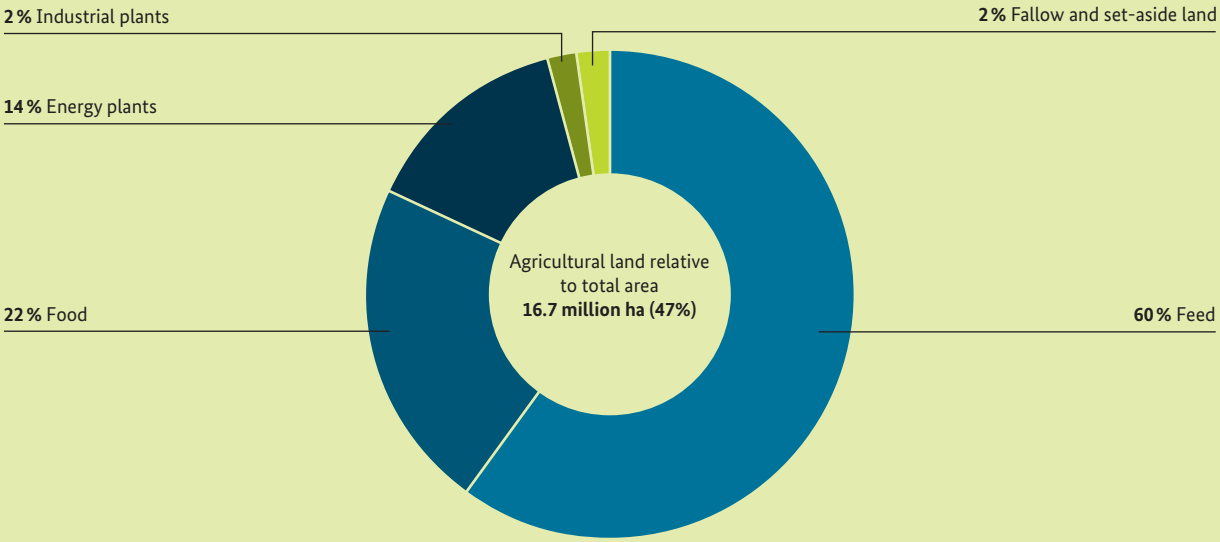
4.5 Using the potential inherent in the bioeconomy for the development of rural areas

Most of the biomass in Germany is produced and processed in rural areas, and used as food or feed or for material or energy purposes. Rural areas play a central role in the bioeconomy. The expansion of the bioeconomy in Germany holds great potential in terms of value creation, jobs and the quality of life in rural areas.

The potential inherent in the bioeconomy differs from region to region depending on the existing infrastructure, the raw materials available and the skills possessed by the local stakeholders. Up until now the processing of biogenic resources, and the associated creation of value, has often occurred at a remove from where the resources have actually been produced. In some cases biomass is transported over long distances to be processed, often centrally in large plants. Among other issues this results in transport-related CO_2 emissions. As part of the expansion of the bioeconomy, the development of regional bioeconomy concepts involving local actors and regional administrations will be supported. One focus shall be on the local processing of biogenic raw materials to higher-quality materials suitable for subsequent processing stages. This can help create employment and added value in rural areas, while also reducing transport. Supporting regional forms of product marketing adapted to local conditions can also generate regional added value.

The availability of qualified employees, modern infrastructure and local amenities are the foundation stones for inno-

Agricultural land in Germany in 2017



Source: FNR according to Federal Office of Statistics, BMEL (2017)

vative processes in relation to production and services, and are often central to the emergence of new business ideas in the bioeconomy. The German Federal Government is working together with the federal states and local umbrella organisations in the 'Equal Living Conditions' (Gleichwertige Lebensverhältnisse) commission to address these issues. An analysis will be carried out to identify regions with previously untapped potential for the development of bioeconomy supply chains. The results of the study should serve as the basis for the identification of region-specific measures and ultimately lead to the development of regional bioeconomy strategies.

4.6 Exploiting digitisation for the bioeconomy

The high potential for innovation associated with greater implementation of digitisation along entire bioeconomy supply chains will lead to opportunities for process optimisation. Connecting the bioeconomy with the ongoing process of digitisation also creates scope for innovative business models. This applies to all areas of production. For example, the use of digital innovations in agriculture and forestry can lead to large savings in relation to resources such as soil, crop protection products, fertilisers and energy. The resultant reductions in costs and increases in efficiency render primary production more competitive and environmentally friendly. There is great potential for gains to be achieved through the use of sensor technology, big data, fast data connections and of robotics in the production and processing of biogenic raw materials and in the context of precision agriculture. It is important to explore how we can make optimal use of digital technologies, for example, in green professions, to improve animal welfare, protect the environment and biodiversity, and to achieve sustainable development. Digital technologies can also serve to improve animal protection, to make work easier for individuals and to analyse which types of innovative business models are sustainable in a particular context. This should be developed upon in the context, for example, of digital experimental fields on agricultural holdings. The planned competence network for the coordination of this activity is an important first step.

Information provided digitally concerning sustainable production methods can also help raise consumer awareness of sustainable products and thus influence purchasing decisions. The basis for the greater implementation of digital solutions is the clarification of open questions in relation to data interfaces, open data, standardisation, com-

patibility and data platforms, and legal security. It is also necessary to clarify the extent to which the additional energy demand associated with greater digitisation reduces or even negates any efficiency gains (rebound effect) and to determine how this problem might be solved. These questions should be investigated and solved in pilot projects, especially in rural areas.

4.7 Policy coherence

The framework conditions for the transition to a bioeconomy are strongly influenced by specific policies at regional, national and international levels. These vary considerably, which often hinders the marketing of otherwise viable bio-based products, and may even lead to a raw material-specific competitive disadvantage. In the case particularly of innovative bio-based products and processes with the potential to replace conventional processes, often the product-specific advantages or disadvantages are not taken into account in existing regulations because these were previously either not relevant or not known.

In addition to regional differences in regulations pertaining to the cultivation and processing of biogenic raw materials, and the circulation, consumption and use of bio-based products for various applications, the requirements for the approval and to ensure the sustainability of innovative bio-based products also vary depending on the region and the use pathway. Ensuring a coherent political framework for the transition to a more bio-based economy requires the closer integration of policies and strategies, particularly those applying to the areas in which bio-based materials are produced or processed. This includes agriculture, forestry and fisheries policies, as well as regulations in the areas of environment, construction, energy, biodiversity, waste management, resource efficiency and sustainable finance. Within the Federal Government activities in this regard will continue in the interministerial working group on the bioeconomy (Interministeriellen Arbeitsgruppe zur Bioökonomie, IMAG). The various activities undertaken by the Federal Government to implement the new National Bioeconomy Strategy will be coordinated by IMAG.

The Federal Government has also identified the need for an advisory body comprising broad expertise across all dimensions of the bioeconomy and which combines different perspectives (see also section 5.1). Synergies should be identified and used to ensure the coherence of policy decisions made across different administrative levels. The exchange between stakeholders at various administrative levels (EU, federal, state) should be strengthened, and also with stakeholders and experts from individual sectors of the bioeconomy and representatives of environmental and nature conservation. As part of this exchange, an analysis should take place to determine, for example, whether the market launch of innovative bio-based solutions is hampered by regulatory restrictions and whether any discrimination against bio-based products or processes might be remedied by regulatory and technical adjustments. The biomass flows and the various uses should also be evaluated and prioritised.

5

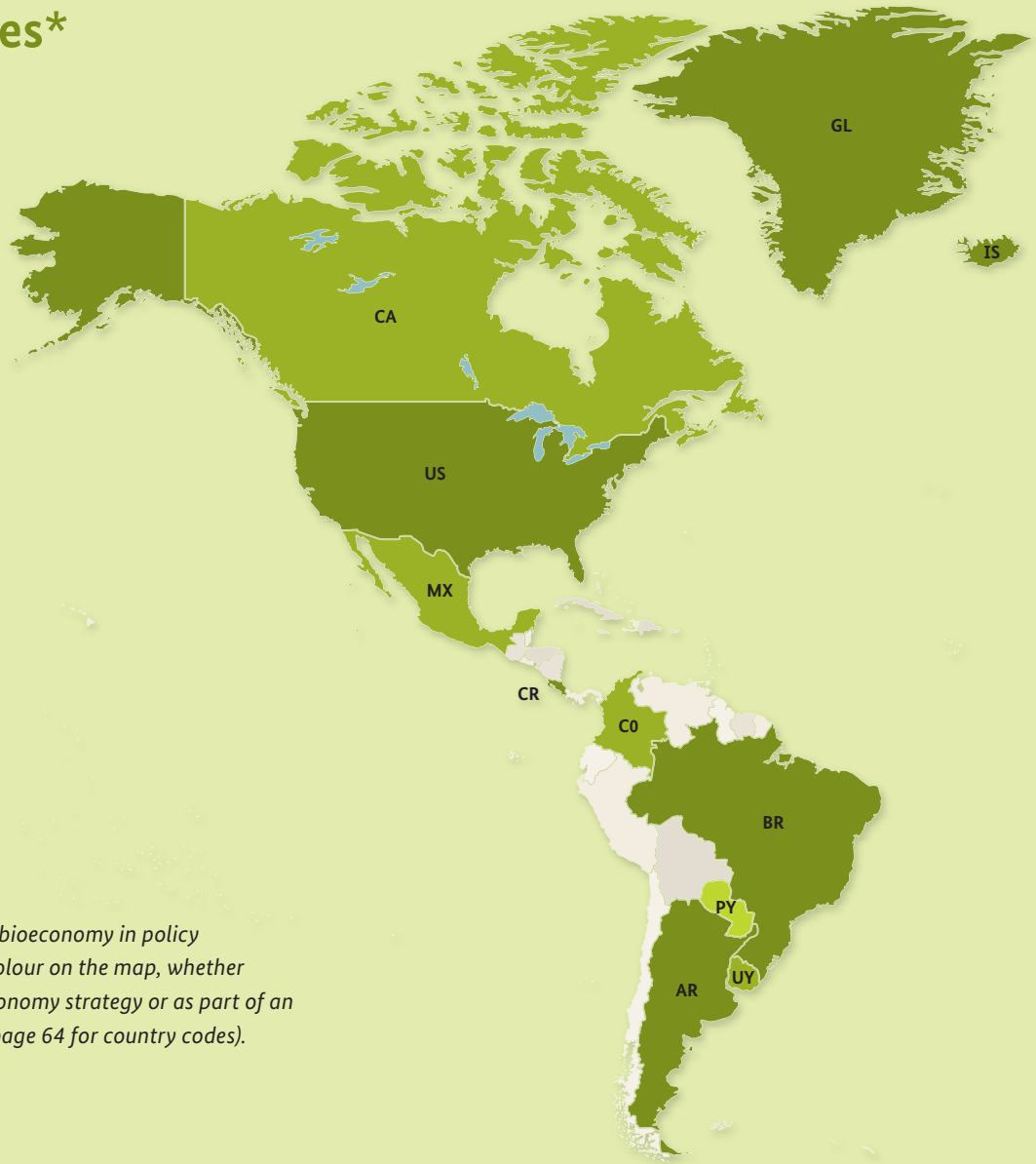
Overarching instruments

As part of the implementation of the National Bioeconomy Strategy the Federal Government plans a variety of activities in addition to the measures undertaken to promote research and to improve the framework conditions for the bioeconomy.

5.1. Establishment of an advisory body with broad participation of society

A new body comprising extensive expertise in all dimensions of the bioeconomy will advise the Federal Government as a successor to the German Bioeconomy Council, which sat for two periods between 2009–2012 and 2012–2019. The advisory board should cover as many perspectives on the bioeconomy as possible, and include experts from science and industry, as well as representatives of thematically relevant civil society organisations. Its duties include making recommendations, preparing position papers and promoting public debates on the bioeconomy. With the broad participation of civil society, the body should pay particular attention to any conflicts that may arise in relation to the achievement of the sustainability goals linked to the bioeconomy. Another task of the advisory body will be to develop proposals and recommendations for the plan for the implementation of the National Bioeconomy Strategy. This plan shall be drafted in a participatory process, and will be updated throughout the term of the strategy. The implementation plan should contain recommendations for specific policy measures, taking current developments into account. The Federal Government will consider the positions put forward by the board and, based on these positions, initiate measures to achieve the goals of the National Bioeconomy Strategy.

Countries with bioeconomy-related policy activities*

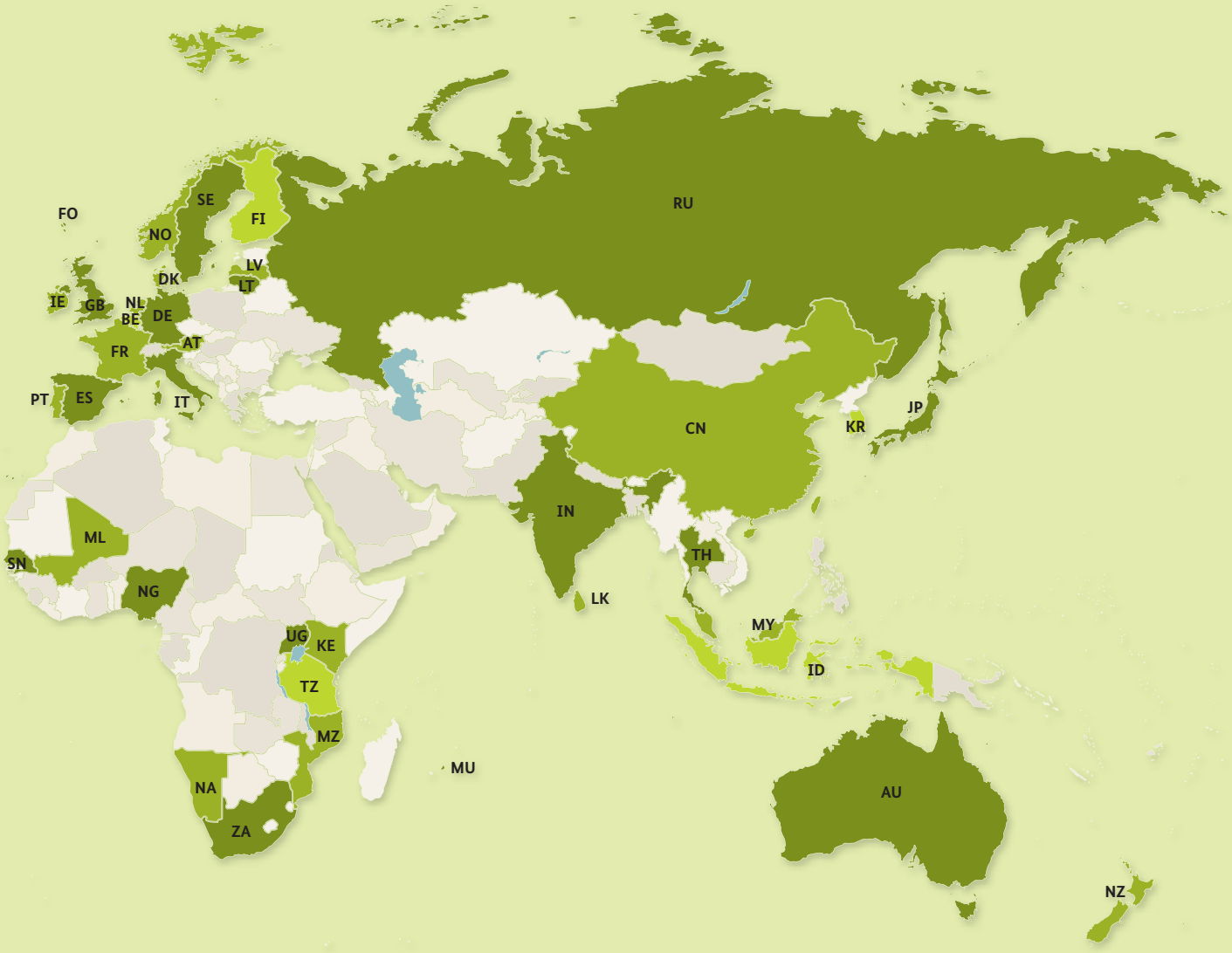


**All countries that address the bioeconomy in policy programmes are indicated in colour on the map, whether addressed in a dedicated bioeconomy strategy or as part of an overarching measure (refer to page 64 for country codes).*

5.2 Cooperation between the Federal Government and the federal states

The Federal Government welcomes the fact that independent bioeconomy strategies have been developed at the federal state level. These strategies address the specific challenges on the ground and seek to exploit the opportunities offered by the bioeconomy for both rural and urban areas. It is important that all levels of administration interact with each other.

The National Bioeconomy Strategy benefits from the efforts made by the federal states to develop their own strategies, launch funding initiatives, develop region-specific profiles of the bioeconomy, and build clusters and regional networks. Examples of successful initiatives are the many clusters, competence centres and model regions that have been set up on the theme of bioeconomy. The Federal Government will establish a working group with the state governments to coordinate these and other measures so that the development of the bioeconomy in Germany proceeds as efficiently as possible.



5.3 European and international cooperation

The bioeconomy is growing in importance worldwide. More than fifty countries had launched their own bioeconomy strategies at the time of publication of this new German National Bioeconomy Strategy. A broad portfolio of approaches and concepts has emerged that reflect regional and national peculiarities. Various bioeconomies differ on the basis of the prevailing climate and geographic conditions, and the specific biological diversity. There are also specific focal points in the research and industrial landscape, which means new development opportunities and options for specialisation within individual regions. It is only through the interaction between these regions that the system as a whole can function efficiently.

International cooperation is essential for the success of a sustainable bioeconomy. The first steps towards greater international exchange have already been taken, and in recent years the German Federal Government has been instrumental in enhancing this cooperation. International cooperation – both within the European Union and with other international partners – will be further expanded and intensified as part of the implementation of this strategy. The German Federal Government will promote the discourse on the bioeconomy and the associated conflicts in an international context in order to better network with stakeholders, to exchange knowledge about measures and strategies, and to advance the establishment of a sustainable bioeconomy with strategically important partners. To this end, bilateral contacts, cooperation and engagement in multilateral processes and committees will be intensified.

Cooperation on the bioeconomy at the European level will be continued and strengthened. Many EU Member States and the European Commission are striving to support the bioeconomy through the pursuit of dedicated strategies. The German Federal Government will actively promote exchange on the bioeconomy between the EU Member States and the European Commission, and will support and steer joint activities. The German Federal Government will actively support the development of the bioeconomy at the

Bioeconomy is the theme of the German Science Year 2020/21. To kick off the Green Week in Berlin the BMBF showcased a range of bio-based products.

EU level through a constructive dialogue with the relevant partners. The central pillar of this dialogue is the exchange with EU countries in appropriate working groups. The exchange of experiences between the Member States will also be pursued through a series of informal talks focusing on national bioeconomy policy measures.

International cooperation beyond Europe will seek to achieve the best possible linking and enhancement of various individual approaches to establish the bioeconomy. Bilateral relationships will be used to make progress towards the establishment of a global bioeconomy in multilateral formats. The German Federal Government will work to ensure that the bioeconomy receives greater attention in future international processes so as to improve the international harmonisation of the measures and strategies needed to promote a sustainable bioeconomy, to resolve the associated conflicts between goals and to clarify the opportunities in terms of climate, environmental and resource protection. Examples of this are the G20 and G7 formats, as well as the annual Conference of the Parties to the UN Framework Convention on Climate Change (COP conferences). The international exchange will also address how the bioeconomy's raw material base can be produced and made accessible in a way that is sustainable. Cooperation with the United Nations' Food and Agriculture Organization (FAO) will also be intensified.

5.4 Communication und dialogue

Demographic change and global economic growth are leading to an increase in the demand for the limited land and biomass available. Human activities have an impact on the environment, nature and biodiversity, and the contrasting implications inherent in the different activities must be examined. The world population needs healthy and safe food, energy and materials, jobs, housing, and infrastructure for mobility. Through their decisions, consumers exert an influence over how these needs are met, which foods are consumed, which forms of energy are used in households, and which products are bought. Society can, therefore, contribute to driving the bioeconomy forward.

As an overall concept, the bioeconomy remains largely unknown to the German public. Individual elements of the bioeconomy such as the digitisation of agriculture, modern breeding methods and certain fields of application for synthetic biology have been met with reservations. Other elements, however, such as the production of active medical ingredients and the substitution of chemicals harmful to health and the environment with harmless biological substances, have been positively received.

It is important to take into consideration societal requirements and society's expectations in relation to the development of the bioeconomy. It is also necessary early on in the process to facilitate discussion and to evaluate important issues for the future and potential risks and trade-offs, and to involve all of the stakeholders. Research must be open and transparent. The results of government-funded research should be made available to the public, free of charge wherever possible. Educational institutions such as museums and botanical gardens have a valuable contribution to make, as do civil science research projects. A good information base is vital to create the conditions required for an informed public discussion about the bioeconomy.

Late in 2018 the Federal Ministry for Economic Affairs and Energy initiated a dialogue platform called 'Industrial Bioeconomy' (Dialogplattform 'Industrielle Bioökonomie') with representatives of industry, associations, science and society. The obstacles and problems encountered in converting the economy to a sustainable bio-based economy were discussed in order to develop joint solutions. The open dialogue between the public, science and government about the design of the bioeconomy must be continued and intensified. As with all processes of profound change, it is important that impulses and concerns be addressed at an early stage and that appropriate public debate is supported. The German Federal Government employs various transparent dialogue and participation formats to involve civil society groups. It is important to exchange ideas with all interested groups in society – both with the pioneers and advocates of the bioeconomy and with those who are critical of various aspects of the bioeconomy. The aim of this dialogue is to identify undesirable developments early on and to take timely countermeasures wherever they are required.

The infoportal for bioeconomy in Germany:
biooekonomie.de

5.5 Qualifications and skilled personnel

The bioeconomy extends across all economic sectors and encompasses numerous scientific disciplines. Linking different fields and areas of knowledge creates new opportunities, but also new requirements in terms of professional qualifications. Specialists with interdisciplinary expertise at the interfaces between sustainability, production processes, markets and consumption are needed. They are the prerequisite for innovation and growth, and will make an essential contribution to the sustainable bioeconomy in Germany.

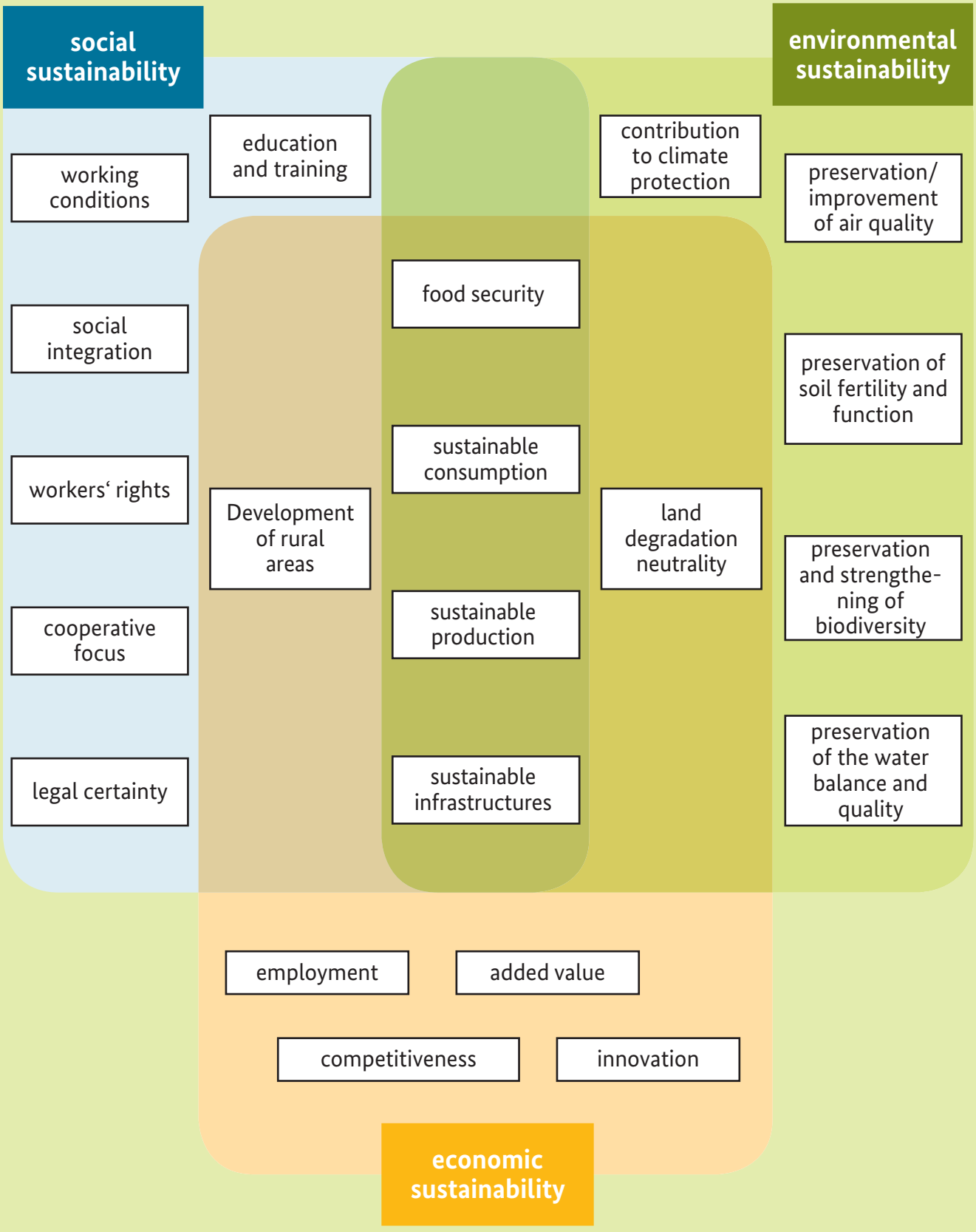
With its research funding for the bioeconomy, the Federal Government has promoted the development of knowledge and interdisciplinary networking in science. In over 2,000 research projects funded under the National Research Strategy 'Bioeconomy 2030' since 2013, many young scientists have been able to acquire valuable qualifications. In addition to project funding, new training and further education programmes, and courses at vocational and technical schools, technical colleges and universities should also offer targeted content dealing with the bioeconomy. Similarly, converging technologies should also be integrated within a revised bioeconomy education.

A particular focus should be placed on the use of digital technologies in breeding and in agriculture and forestry. Training, continuing education and advisory services for sustainable production, new technologies and digital applications are extremely important for specialists and managers in the agricultural sector. The successful development and implementation of the bioeconomy requires the integration of various research disciplines. There are already a number of good examples of this. As part of the National Bioeconomy Strategy, additional models of cooperation shall be developed and implemented to promote the stronger networking of research institutions and industry. This will facilitate the transfer of knowledge into practice and the development of interdisciplinary career profiles. UNESCO's Education for Sustainable Development (ESD) initiative plays an important role. It attributes 'high quality education' (SDG 4) a key function in the implementation of the remaining sixteen Sustainable Development Goals. Through education for sustainable development, people acquire the skills and capacities needed to shape and promote sustainable development in our society. In order to anchor education for sustainable development structurally in all areas of education, the 'National Action Plan for Education for Sustainable Development' (Nationale Aktionsplan Bildung für nachhaltige Entwicklung) was adopted by the National Platform for Education for Sustainable Development (Nationale Plattform Bildung für nachhaltige Entwicklung) in 2017[18] . The measures for vocational training for sustainable development take into account aspects of the bioeconomy both in the training and in the continuing education of the educational staff and the operational management.

5.6 Bioeconomy monitoring

The guidelines and goals of this strategy demonstrate that the bioeconomy is committed to the overarching goals of sustainable development and climate protection, as well as to sustainable value creation in industry, to the strengthening of rural areas and to the conservation of biological diversity. To achieve these goals, it is important that we take the right path. Observing, measuring and evaluating the process of transformation towards a sustainable, bio-based and natural cycle-oriented economy are an important prerequisite in ensuring that we do not achieve individual goals at the expense of others. They are also necessary to make certain that we set priorities correctly. This requires reliable data, comprehensive balance sheets and meaningful indicators that can provide guidance for all involved. To this end, the German Federal Government initiated a comprehensive monitoring programme for the bioeconomy in 2016. Monitoring is a central tool to evaluate the impact of the strategy, but it is also intended to map the development of the bioeconomy as a whole and to provide reliable knowledge for practical purposes. The work being carried out in the ongoing pilot phase of the programme will be continued in order to track trends in the development of the bioeconomy over longer periods and to better understand dependencies and impacts. The corresponding indicator system will be assessed for its relevance and further developed in cooperation with experts from all areas of society.

Goals and dimensions of the bioeconomy



Source: SYMOBIO project, Egenolf; Bringezu 2019, own depiction[19]

Conclusion and outlook

With the new National Bioeconomy Strategy, the Federal Government is setting out the direction German policy will take over the coming years. The way taken must be towards economically, ecologically and socially sustainable development. The bioeconomy will play an important role in this. Given that Germany is as an economically and financially strong country, it has a special responsibility to tackle the upcoming transformation process and to do so with determination. This gives us the opportunity to play a pioneering role in the development of technological and social innovations in the sustainable world of tomorrow.

The German Federal Government will ensure that its funding for bioeconomy research will accommodate research and development projects that are open to any and all technologies and that they follow an interdisciplinary approach. This will provide a better understanding of the diverse interactions between biological systems, bioeconomy process chains and their effects on the environment, nature and the landscape, and with climate and health. This will make it easier to provide evidence-based recommendations for action. This research will include various scientific disciplines and a number of key technologies from biotechnology, nanotechnology, digitisation, automation, sensors, robotics and artificial intelligence. Basic research and experimental development projects will be funded, as will application-oriented projects.

Active support for the development of a sustainable bioeconomy requires measures that go beyond just research and development. Research and innovation must be reflected in new production processes and marketable products. It is not only down to policy makers and scientists, but companies and consumers are also key players in this process. Without their willingness to develop and take up new bio-based products, the transition to the bioeconomy cannot succeed. The German Federal Government will continue working on specialist communication to make the achievements of the bioeconomy more tangible to the public. The dialogue between citizens, science, business and policy about the design of the bioeconomy – the opportunities and benefits, but also the possible risks and problems – will remain open and be further intensified. The German Federal Government wants to expand international cooperation focusing on bioeconomy-related topics. Given the nature of global markets and trade relationships, the set-up and establishment of a sustainable bioeconomy can only succeed in an international context.

All of the measures that the German Federal Government will take in the coming years in the various fields of the bioeconomy – research, agriculture, forestry, fisheries, aquaculture, environment, climate, industry – will be evaluated for their effectiveness. Due to the dynamic developments in the bioeconomy, it is necessary to constantly review the strategy and, where necessary, to develop it further by updating the implementation plan.

Glossary

abiotic | referring to the inanimate in nature; processes, substances or environmental factors in which living beings are not directly involved, e.g., water, light, rock and metals

agroecology, agroecological | scientific branch of ecology that understands agricultural production as a part of ecosystems (e.g., with regard to ecosystem services, soil fertility, biodiversity) and that deals with the relationship between cultivation systems, nature and resource conservation. The Food and Agriculture Organization of the United Nations (FAO) also perceives agroecology as being a practical concept for the transformation of agriculture in low-income countries, combining traditional smallholder farming methods and local knowledge with knowledge and methods from modern science. The aim is to secure an income for smallholder farms based on local cycles while largely avoiding external inputs (synthetic fertilisers, pesticides).

agricultural production | production of biomass for the provision of food, for material or energy use, or for industrial processing into other products. In addition to crops and livestock, insects, algae and other forms of marine life are becoming increasingly important in modern agricultural production.

agricultural system | all factors related to agricultural production – biotic and abiotic resources, cultivation and harvesting methods, use of technology and energy, environmental conditions, demands on ecosystem services, etc. – including all upstream and downstream economic sectors

artificial production systems | production systems that mimic biological principles to produce desired products. In contrast to classical biotechnological processes, no microorganisms are used as production units, or at most only individual components thereof

big data | large, unstructured or only poorly structured quantities of data that are too complex, too heterogeneous or change too quickly to allow for evaluation using conventional data processing methods. Big data technologies are methods used to extract information from such data using algorithms or artificial intelligence. Large amounts of digital data accrue in, e.g., the sequencing of the genetic makeup of organisms.

bio-based | generated or processed based on the use of biomass and/or using biotechnological processes

biogenic raw materials | based on biomass. Biogenic raw materials or resources refer to any type of biomass, i.e., renewable raw materials specifically cultivated and any other type of biomass, including biotic residues and waste materials.

biological | referring to life, living things, organic products and knowledge about them

biomass | in a narrow sense, the organic substance formed by photosynthesis; in a broader sense, the amount of substance of all plant and animal life and their organic products. Also referring to residues and waste materials such as organic waste from households, from animal production, and from food and feed production. Fossil raw materials also originated from biomass at one point; however, the bioeconomy is based exclusively on the use of non-fossil biomass.

biopharmaceuticals | drugs manufactured using biotechnology methods, e.g., hormones, nucleic acids and antibodies

biopolymers | basic building blocks of living organisms that are made up of several basic units. Examples of biopolymers are proteins, nucleic acids (DNA and RNA, multiple sugars (polysaccharides)). The term also describes technical polymers that have been produced in a bio-based manner and/or are biodegradable (e.g., bioplastics).

biorefinery | refinery based on biomass. A biorefinery is characterised by an integrative, multifunctional overall concept that uses biomass as a diverse source of raw materials for the sustainable production of a range of different intermediate and end products (chemicals, materials, bioenergy including biofuels) using all raw material components as fully as possible.

biosphere | also biogeosphere; denotes the living space of a planet, above and below its surface, i.e., in the atmosphere, in the ground and under water. The Earth is the only planet currently known to possess a biosphere. The sphere of the Earth with proven life ranges from about 5 km below to about 60 km above the planet's surface.

biotechnology | interdisciplinary and application-oriented science at the interface of biology, medicine, chemistry and engineering. Biotechnology uses organisms, cells or biomolecules in technical applications to manufacture products for different industries or to develop new technologies.

biotic | of living things

cascade use | repeated use of biomass over several stages in order to maintain raw materials, or the products made from these materials, in the economic system for as long as possible. Generally a cascade use includes multiple uses of a material with a declining added value with each generation and a final use of the material for energy or as compost.

cell-free production processes | cell-free production processes represent an alternative to the production of biological components such as enzymes that cannot be produced by living cells (e.g., microorganisms) or only very poorly. Examples are cell-free protein biosynthesis and cell-free biocatalytic systems.

circular use | processed resources and goods are reprocessed using modern recycling methods and put to a new use. In order to achieve the highest possible degree of reuse, the ideal exploitation of the cycle should be taken into account in the early product design.

converging technologies | the term refers to the convergence of different technologies or areas of technology and knowledge. Cross-cutting technologies such as nano-, bio- and information technologies and sciences, and cognitive sciences, are often involved. Broader concepts addressed in this strategy include a significantly larger number of sciences and technologies.

conflicting goals | conflicting goals arise when two or more legitimate goals are pursued, the simultaneous fulfilment of which is mutually exclusive, or the pursuit of which leads to contrary effects. In some cases, conflicting goals can be resolved through a hierarchy that prioritises the competing goals. The bioeconomy recognises the primacy of food security over the industrial use of agricultural products. In many cases, creating a hierarchy of priorities – e.g., between increasing agricultural yields and protecting biological diversity – is simply not possible because all goals are equally legitimate or even indispensable. A typical example relates to the discussion of the term sustainability, which encompasses ecological, economic and social goals equally. Research funding in the context of the bioeconomy is geared towards precisely analysing conflicting goals and defusing them through intelligent strategies and innovative production methods.

coupled use | use of one or more byproducts to achieve the sustainable and most effective use of raw materials while increasing added value. Examples of paired use are the use of the byproduct glycerine in biodiesel production or the use of the byproduct bagasse in bioethanol production.

ecology, ecological | a branch of biology that focuses on the interactions between living organisms and their environment. Colloquially the term ‘ecological’ often refers to the commitment to a gentle treatment by humans of their natural environment.

ecosystem services | all material and non-material services of nature from which humans benefit. Ecosystem services include biodiversity, climate regulation, healthy soils and clean water.

epigenomics | study of all epigenetic modifications to the genetic material of a cell and their systematic analysis using the latest molecular biological techniques

epigenome | sum of the chemical changes to the DNA of an organism through which the activity of genes is dynamically influenced depending on environmental conditions. The epigenome is involved in, e.g., the development of cells and tissues. Epigenetic changes do not affect the DNA sequence, but can be passed on to offspring.

future technologies | novel technologies that have a high potential for innovation, but are currently still at the level of basic or applied research

genome editing | collective term for molecular biological tools (e.g., CRISPR / Cas) with which DNA in the genome of organisms can be edited, i.e., copied, moved or removed

genomics | genomics analyses the set of chromosomes that is the entirety of DNA, a cell or an organism

innovation, incremental and disruptive | incremental innovations are understood as the process of constantly optimising a technology, e.g., increasing the output and reducing the consumption of internal combustion engines. Disruptive innovations replace one technology with another, sometimes with consequences for entire sectors or supply chains. It is difficult to predict when a technical invention will become a disruptive innovation. Disruptive innovations are sometimes referred to as leap innovations.

metabolic engineering | targeted molecular-biological changes in the metabolism of organisms with the aim of increasing the production rate of desired compounds or preventing the formation of unwanted byproducts

metabolomics | research branch that examines the entire metabolism including the intermediates in cells and organisms

microbial production | use of microorganisms for biotechnological production

microbiome | the microbiome encompasses all the microorganisms on Earth. Microbiomes are also often discussed in the context of individual organs, organisms or ecosystems. In the narrower sense, it refers to all microorganisms that colonise humans or other living things.

modular bioprocess concepts | concepts for the development of new processes for biotechnological production. These concepts provide for bioprocesses to be broken down into individual process steps (modules) which, depending on the objective and the general conditions, can be combined quickly and flexibly into different production routes.

omics technologies | omics technologies are high-throughput methods with which, e.g., the entirety of genes (genomics), RNA (transcriptomics), intermediate products of metabolism, metabolites (metabolomics), proteins (proteomics) or lipids (lipidomics) of a biological system are counted. The high-resolution molecular profiles of biological systems allow for new insights into the course of molecular biological processes.

organic | of the living part of nature

plant phenotyping | phenotyping is a part of plant research that quantitatively analyses and measures the appearance of plants. This should make it possible to assign certain traits to plant genes.

planetary boundaries | ecological limits that result from the fact that the natural habitats and resources on Earth are finite and require certain periods of time to regenerate. The boundaries and where exactly they run is still the subject of intensive discussion. However, it is undisputed that humankind, and its economic activities, is increasingly endangering the limits of the Earth and with them its own livelihood.

platform organism | microorganism that has been optimised for use in biotechnological processes using molecular biological methods. Platform organisms are also characterised by the fact that the corresponding industrial bioprocesses are established and the organisms can be used to manufacture various products.

production organisms | generic term for organisms such as useful plants, insects, algae, fungi or microorganisms that are used to produce biomass or specific ingredients

proteomics | different methods to analyse the complete proteome of a cell, tissue or organism at a specific point in time. In contrast to genomics, proteomics records the actual amounts of all proteins.

renewable raw materials | raw materials derived from agriculture and forestry that are used for material or energy use

sustainability | sustainability became a key political term in the 1987 Brundtland Report for the United Nations. It describes the goal of satisfying the needs of current generations without taking away the opportunity of future generations to meet their needs as they see fit. Sustainability has three pillars: economic, ecological and social sustainability. There are ongoing debates about, in particular, the compatibility of economic and ecological sustainability.

smart farming | smart farming describes the use of modern information and communication technologies (ICT) in agriculture to achieve a more precise and resource-efficient and thus more productive and sustainable agriculture

smart and high-tech | includes technologies and methods that correspond to the latest technical and scientific standards and that are considered to be progressive and intelligent

sufficiency | concept of an economy that provides that which is necessary in sufficient measure while using as little energy and raw materials as possible. Sufficiency is, therefore, an alternative to growth-oriented economic models and an extension of the goal of using raw materials as efficiently as possible. Sufficiency cannot be achieved through technological advances, but requires a fundamental change in consumption patterns.

synthetic biology | in a narrow sense, the term encompasses the redesign and construction of novel biological components, cells, organisms or even cell-free biological or biochemical systems (e.g., synthetic genomes, minimal cells, use of non-natural amino acids); in a broader sense, molecular biological approaches to redesign known organisms. Increasingly using computer-aided design and modelling processes, these approaches go beyond the classic genetic engineering processes.

systems biology | systems biology aims to gain a comprehensive understanding of the dynamic interactions between the components of a biological system. The aim is to understand and predict the behaviour of the system as a whole. For this, mathematical concepts are applied to biological systems.

systemic | looking at systems in their entirety and their interactions with one another, from the fundamental molecular principles to the complex interplay in ecosystems

supply chain | a supply chain (also: value chain) encompasses all stages (institutions, people, facilities) of the transformation process that a good goes through from raw material to end product

value network | networks linking supply chains, at the nodes of which institutions, people or production processes are connected with one another via mutual material and information flows. Approaches related in particular to coupled and cascade use contribute to innovative parts of the bioeconomy growing together with other established sectors to create value networks.

Endnotes

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Country code

AR	Argentina
AT	Austria
AU	Australia
BE	Belgium
BR	Brazil
CA	Canada
CN	China
CO	Colombia
CR	Costa Rica
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FO	Faroe Islands
FR	France
GB	Great Britain
GL	Greenland
ID	Indonesia
IE	Ireland
IN	India
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KR	South Korea
LK	Sri Lanka
LT	Lithuania
LV	Latvia
ML	Mali
MU	Mauritius
MX	Mexico
MY	Malaysia
MZ	Mozambique
NA	Namibia
NL	Netherlands
NO	Norway
NZ	New Zealand
PT	Portugal
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UY	Uruguay
ZA	South Africa

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