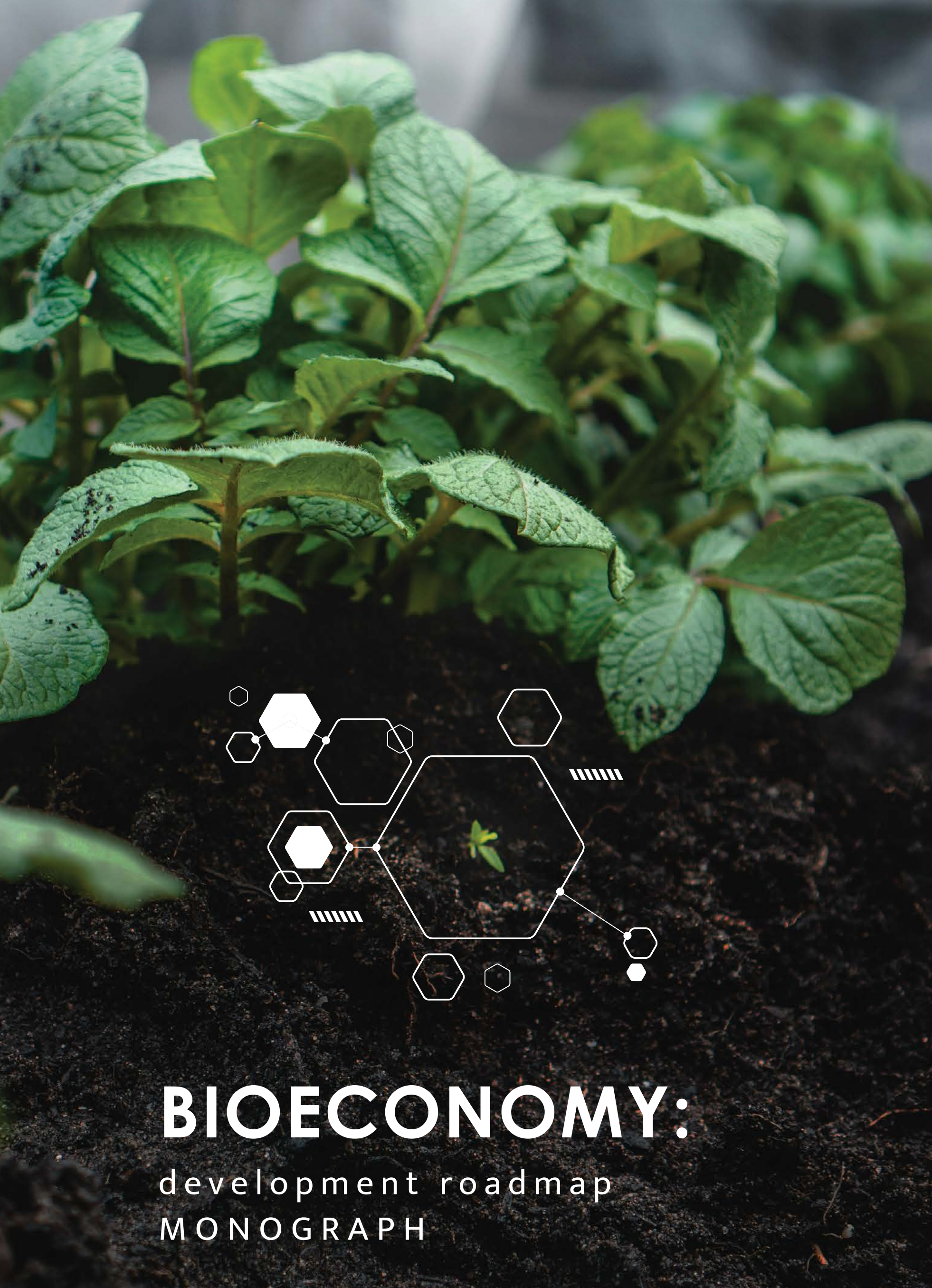

BIOECONOMY:

development roadmap

MONOGRAPH

JELGAVA, 2024

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TABLE OF CONTENTS

MONOGRAPH AUTHORS

Dina Popluga	*Dr.oec.* Professor, Faculty of Economics and Social Development of the LBTU – Chapters 1, 5, 6, 7
Arnis Lēnerts	*Dr.oec.* Assistant professor, Faculty of Economics and Social Development of the LBTU – Chapter 3
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INTRODUCTION

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The European Union first published the Bioeconomy Strategy (Innovation for Sustainable Growth: A Bioeconomy for Europe) in 2012. It has been 12 years since then, and I am pleased with the achievements and progress made in Latvia. Initially, there was not much support for bioeconomy development issues, and one could observe concerns, misunderstandings, and doubts, but today the word "bioeconomy" is becoming more familiar to the public, and the industry's development is supported by innovations, promoting the development of the bioeconomy in Latvia. Today, the bioeconomy plays a major role, as its contribution will be significant in promoting the European Union's green transition and becoming a climate-neutral economy by 2050. Thoughtful use of natural resources, increasing added value, creating new knowledge and jobs, and attracting young people - these are all today's challenges, but at the same time, they also present opportunities. Amidst the hectic pace of modern living, it is important to pause for a moment, collect thoughts and knowledge, outline conclusions about successes and mistakes, and agree on the next steps, as we cannot and should not stop. I am genuinely pleased that I have been on the path of bioeconomic development together with my colleagues from the Latvia University of Life Sciences and Technologies. Thank you for your responsiveness, interest, encouragement, and being together. Through collective effort, we will attain heights we never thought possible.

SUMMARY

By Kaspars Naglis-Liepa

The development of the bioeconomy has become an integral component of scientific discourse and an agenda that policymakers deal with daily, which consequently should lead to a real turn towards sustainable development. An increasing number of European countries design and implement bioeconomy strategies that emphasise the need to develop critically important bioeconomy industries, thereby utilising their relative advantages and achieving climatic, environmental and economic benefits. LBTU plays an important role in contributing to the bioeconomy in Latvia through sharing ideas among the international scientific community. At the same time, many findings and recommendations made during research activities and documented as teaching materials, project reports or discussions with policymakers have been integrated into bioeconomy courses delivered to students of all levels and represent support for policymakers. The monograph aims to comprehensively describe the most important aspects of the development of the bioeconomy. It is one of the first works that represents not a learning material for an individual course, not a research project report or an analysis of policy documents, but a scientifically based material for confirming the diversity of the bioeconomy, which could be of interest to a wider audience: researchers, policymakers, entrepreneurs and students. To achieve the aim of the monograph, the collective of authors defined the following specific research tasks:

1. To give an insight into the concept and historical evolution of the bioeconomy.

2. To describe ecosystem services and resources forming the bioeconomy, as well as the taxonomy, the principles of sustainability and their role in various industries of the bioeconomy.

3. To give an insight into the current situation in the bioeconomy both in the European Union as a whole and in Latvia, analysing the strengths and weaknesses, as well as the challenges and opportunities for the future.

4. To highlight the role of knowledge and innovation in the bioeconomy, emphasising the impacts of and prospects for digitalisation in the bioeconomy.

To perform the tasks, the monograph has been structured into seven chapters, each of which describes some aspect of the development of the bioeconomy, from the meaning and historical evolution of the bioeconomy concept, focusing on the taxonomy and sustainable use of ecosystem services and resources as well as describing the current state of the bioeconomy in the EU and Latvia through to conclusions on the role of knowledge and innovation in the bioeconomy, which is vividly illustrated in the last chapters on digitalisation in the bioeconomy.

In the first chapter, **Dina Popluga** describes an increase in research studies on the bioeconomy. At the same time, however, there is no consensus on the definition of a bioeconomy, which depends on the interests of scientists, politicians or entrepreneurs to emphasise some specific aspects characteristic of the bioeconomy. Undoubtedly, the unifying factor in all definitions is the sustainable use of resources of biological origin through innovation. Besides, D.Popluga has summarised and explained some related terms such as biotechnology, biomass, bioresource, bioenergy, bioproduct, biorefinery etc. There are many frameworks for economic analysis, often related to the bioeconomy concept. Concepts such as a circular bioeconomy, a bio-based bioeconomy, a circular economy and a green economy are sometimes referred to as more or less similar economic concepts. The author explains the similarities and emphasises the differences, thereby bringing certain clarity and consistency to the use of the concepts in both scientific and political discussions. The chapter ends with a classification of the bioeconomy based on the NACE Rev. 2 classification, which is essential for analyses of the bioeconomy and is described in the following chapters.

It is often said that the bioeconomy is nothing new because people have been managing bioresources for a very long time, and the revival of the bioeconomy is a step back to a more "natural" economy. It is refuted and addressed by **Kaspars Naglis-Liepa** in the second chapter, which is devoted to a historical review of relations between the biological and social systems, resulting in a new perspective on economic development, with great emphasis placed on the concept of bioeconomy. The social system is based on man-made concepts, language, ideas, knowledge, values, institutes and subsystems organised by them, which contribute to and develop individuals' ability to coexist with themselves, other individuals and the surrounding environment. It could be said that the social system is caused by the result of human mental activity, and the purpose of the social system is to ensure human wellbeing and the development of the human species. In contrast, an ecosystem is a complex of communities of organisms, and its existence in an environment that involves a physical basis and biological evolution is its core competence. Economic development could be perceived as an interaction between the two systems, which continuously exchange energy, materials and information. This nature of interaction largely represents humanity's opportunities to live better, consuming ecosystem services and in return providing nature with a flow of hard-to-assimilate-and-recycle materials (e.g. various wastes), unnecessary energy (e.g. heat pollution) and information that causes morphological changes in other species. As the number of people increases and technology progresses, the social system significantly affects the ecosystem, thereby reducing the ability of humanity itself to provide and maintain its wellbeing. There is no significant disagreement on the need for changes in the relations between the two systems, yet there are disagreements on the nature and kind of changes, which are described comprehensively in the chapter. Qualitative or quantitative changes in the ecosystem needed for the wellbeing of mankind is a complicated and relatively time-consuming problem, while changing the values that affect our economic activity is a simpler and more effective strategy for preserving the wellbeing of mankind. The final part of this chapter is devoted to the integration of prosocial values into economic activity and the stimulation of conscious consumption as an inevitable attribute of future human activities.

Inventorying bioresources is a basic prerequisite for resource use, and **Arnis Lēnerts** draws attention to this. The kinds of bioresources, their quality maintenance and the available quantities are the subject of analysis in the third chapter. As in the first chapter, bioresources are contrasted with fossil resources that have been estimated and whose depletion is predictable, which is one of the most important factors in making the transition to inexhaustible resources as much as possible. In the case of Latvia, the use of bioresources involves efficient land use because it is basically the soil that contributes to the formation of bioresources. Analysing the use of land, the author has concluded that forest areas and consequently the use of forest bioresources have increased significantly in almost 100 years, the area under cereals has also increased over the last 25 years, and cereal yields have increased by many times; the same applies to rapeseed, while the "second Latvian bread" – potato – is losing its importance, as the area under potato tends to decrease, as does the total output. Due to various reasons mentioned, the output of livestock products decreased, and the main reason was the collapse of the ineffective economic model of the former Soviet Union. At the same time, there was an increase in productivity across all the most important kinds of livestock production. Aquaculture is full of challenges and at the same time full of opportunities. The catches of fish in inland waters tend to increase, and aquaculture becomes popular, while the catches in the Baltic Sea and the Atlantic Ocean have decreased. It seems that this might indicate a trend towards making greater use of the previously untapped potential of the blue economy and stabilising and restoring the more traditional use of marine resources. Next, A.Lēnerts gives an insight into bioresource processing technologies and their connection with economic sectors and products, placing a focus on higher value-added products and complete use of bioresources, thus reducing residues and the impact on the ecosystem.

Resources represent only a small part of all the benefits provided by the ecosystem that are necessary for human existence. It is clear that adequate and relatively constant air quality, relatively stable climate conditions and self-regulation of air temperature or the water cycle are part of self-evident and mandatory prerequisites for human development. At the same time, a significant increase in the demand for resources and the unsustainable supply thereof pose a threat to many seemingly constant and inexhaustible benefits of nature that were considered to be available until the turn of the century. One of the largest scientific projects ever, the Millennium Ecosystem Assessment, was devoted to defining the benefits of nature and developing the concept of ecosystem services. It was analysed in the fourth chapter by **Līga Feldmane** who described the concept of ecosystem services, its historical evolution and meaning, the classification thereof and the connection with human wellbeing. Ecosystem services have also become an aspect of strategic and political decision-making. Therefore, from an economic perspective, the most challenging issue is the identification of the value of ecosystem services. The last part of the chapter is dedicated to a description of the valuation methods, which specifies the most popular methods, their advantages and disadvantages, as well as their potential use in decision-making.

The results of several international research projects were used to describe the bioeconomy profiles of the EU and Latvia. The fifth chapter of the monograph is dedicated to the profiles, with **Sandija Zēverte-Rivža, Vineta Tetere, Dina Popluga** and **Aina Muška** presenting the results of the projects and the lessons learned and describing the successes and challenges in the development of the bioeconomy so far. The Council of the EU believes that a sustainable circular bioeconomy plays a decisive role in achieving climate neutrality by 2050. Policy document packages have been prepared by the EU institutions, which require close cooperation between and action by the EU Member States when creating a new environment full of challenges and opportunities for bioeconomy industries. The turnover of the EU bioeconomy is estimated at EUR 2.3 trillion, including EUR 8.4 billion for Latvia. Almost half of the turnover of the EU bioeconomy is provided by food, agriculture is the next most important industry, as well as the production of bio-based chemicals and pharmaceutical products. In Latvia, the most important bioeconomy industry is forestry and the manufacture of wood products, followed by the food industry and agriculture; the production of higher value-added products makes up a significantly smaller share of the turnover than that in the EU. One in 13 employed persons in the EU and one in 9 in Latvia are employed in some bioeconomy industry. To contribute to the sustainable development of the bioeconomy, it is important to analyse the flow of biomass, which was successfully performed in this chapter. The most important conclusion is that the majority of EU biomass flow involves food and fodder supply, whereas in Latvia it is biomass for energy and exports. Both economies equally incur biomass losses (15% of the total flow), while in Latvia, almost twice as much food is wasted. Overall, Latvia has huge potential to develop the bioeconomy industries, but at the same time, it is only of nominal importance if this potential stays untapped. The authors described the diversity of the bioeconomy in the regions of Latvia by applying two differentiation criteria: the location coefficient for the bioeconomy and the proportion of bioresource primary production companies in the total number of bioeconomy companies. The municipalities of Latvia were divided into three groups according to their bioeconomy performance, and it was concluded that each of the groups had a different profile and opportunities to develop the bioeconomy, the processing industries were dominated by low-tech segments, as well as the local governments lacked understanding of the role of the municipality in fostering business and lacked ambitions for new achievements in its policy documents.

Kaspars Naglis-Liepa and **Dina Popluga** see the transformation of the bioeconomy of Latvia from low-tech to high-tech segments through the development of knowledge and the promotion of innovations. The role of knowledge in the bioeconomy is described in the sixth chapter of the monograph. The modern economy could be characterised as a competitive race where innovation must outpace externalities and demand growth created by the economy itself. Knowledge has become an important factor of production and largely shapes the country's competitiveness. To an even greater extent, this applies to the knowledge-based bioeconomy, which is part of the transformation of the modern economy into a knowledge-based economy. The four essential prerequisites for successful economic transformation are as follows a) economic incentives and the institutional regime, b) an educated and qualified workforce, c) an effective innovation system and d) a modern information system. The bioeconomy development strategies analysed in the chapter could also be viewed through such a perspective, with a large role being assigned to knowledge management and the creation of an appropriate ecosystem. It is expected that by providing entrepreneurs with an opportunity to create new substitute products, fostering decarbonisation, stimulating new processes and products, promoting new consumer values and finally contributing to sustainable changes in the behaviour of producers and consumers, a constant level of public wellbeing could be maintained to a large extent, despite the depletion of resources and an increase in demand in the world.

The seventh chapter focuses on development possibilities for the digital bioeconomy, which is one of the essential prerequisites for the development of a knowledge-based bioeconomy. **Dina Popluga** and **Sandija Zēverte-Rivža** describe the basis of and obstacles to digitalisation in the bioeconomy, which are largely affected not only by the available technologies but also by the diversity and quality of the available data, as well as by society's desire to accept and use digitalisation opportunities. For agriculture, this means precision agriculture solutions, data integration, data optimisation solutions, and of course, the intriguing and at the same time scary robotization. However, several obstacles are expected for digitalisation, which are analysed in the chapter using PEST criteria. Next, giving some practical examples, the chapter analysed the possibilities of using artificial intelligence, providing more accurate data-based decision-making and robotization solutions. A vivid example is a description of the principle of operation of weeding robots, which gives a more practical idea of artificial intelligence and robotics solutions in agriculture.

LIST AND EXPLANATIONS OF ACRONYMS, ABBREVIATIONS AND SYMBOLS USED IN THE MONOGRAPH

% – per cent
AI – Artificial intelligence
UN – United Nations
JSC – joint stock company
USA – United States of America
USA – United States of America
BioSAM – Bioeconomy Social Accounting Matrix database
C – carbon
cnt – centners
CO – carbon monoxide
CO2 – carbon dioxide
CO2eq – carbon dioxide equivalent
CSP – Central Statistical Bureau
DataM – EC data platform for modelling the resource economy
EC – European Commission
EAFRD – European Agricultural Fund for Rural Development
EAGF – European Agricultural Guarantee Fund
MoE – Ministry of Economics
EU – European Union
ETS – Emissions Trading Scheme
EUBA – European Bioeconomy Alliance
EUR – euro
g – gram
pcs – pieces
GJ – gigajoule
GWh – gigawatt-hour
GMO – genetically modified organism
H2O – water
H2S – hydrogen sulphide
ha – hectare
GDP – gross domestic product
Iot – Internet of Things

kg – kilogram
km – kilometre
kW – kilowatt
kWh – kilowatt hour
l – litre
LAD – Rural Support Service
LBTU – Latvia University of Life Sciences and Technologies
LDDK – Employers' Confederation of Latvia
LIAA – Investment and Development Agency of Latvia
LIBRA – Latvian Bioeconomy Strategy 2030
AL – agricultural land
LLU – Latvia University of Agriculture
LQ – location quotient for bioeconomy
LR – Republic of Latvia
LZP – Latvian Council of Science
m – metre
m^2 – square metre
m^3 – cubic metre
MFM – Material Flow Monitoring Methodology
mn – million
MJ – megajoule
MK – Cabinet of Ministers
bn – billion
MW – megawatt
MWh – megawatt-hour
N2O – nitrous oxide
NACE – statistical classification of economic activities in the European Community
No. – number
O2 – oxygen
OECD – Organisation for Economic Co-operation and Development
PEST – business analysis method
VAT – value added tax
RTU – Riga Technical University
sec – second
SIA – limited liability company

t – tonne
TEEB – global initiative "Economics of Ecosystems and Biodiversity"
thsd. – thousand
etc. – et cetera
CIT – corporate income tax
VARAM – Ministry of Environmental Protection and Regional Development
VID – State Revenue Service
VK – State Audit Office
SAP – single area payment
VTT – Technical Research Centre of Finland
VZD – State Land Service
MoA – Ministry of Agriculture of the Republic of Latvia
GPP – green public procurement

FOREWORD

Humanity has reached an unprecedented level of prosperity for a large part of its population, while at the same time we are forced to reckon that further increases in prosperity are under threat. It is important to recognise that the most significant contributor to this threat is humanity itself, consuming more and more resources, reducing nature's capacity to absorb and reduce harm caused by waste and pollution, contributing to climate change and reducing biodiversity. We need to be able to transform economic activity, reduce negative side-effects and innovate to achieve true sustainable development, recognising that this may be a unique opportunity to make a difference now. The bioeconomy, which was a topic of scientific debate and very little on the political agenda a decade ago, has become one of the most important concepts for change. In scientific research, the concept of bioeconomy covers a wide range of challenges, from the goal of transforming the drivers of societal development, which includes not only the transformation of sectors of economies, but also changes in human behaviour, moving ever closer to informed demand and consumption.

It seems that the most complex and challenging task to move towards sustainable people management is to broaden the scope of consciousness, to re-understand and shift the paradigm from non-classical economic theories to a more integrated, and at the same time, broader view of human wellbeing. To paraphrase the famous dictum by the classic economist A. Smith that no society can surely be flourishing and happy, of which the far greater part of the members are poor and miserable, we must say today that no society can be happy if it has to put up with a declining capacity for the diverse functioning of the planet's ecosystem. While A. Smith called for a look at society's responsibility for the common good, thousands of scientists are now calling for a look at our responsibility to co-exist with nature and ultimately with each other. From caring for another person to caring for the whole planet, our only home. We believe that awareness and knowledge are crucial for change, and this book is a small contribution to that end. The book was originally conceived as a tool for students of LBTU Faculty of Economics and other faculties, but at the same time the LBTU Science Council had its own vision, insisting that it should be a scientific monograph of the authors. This explains the kaleidoscopic nature of the book, which covers a wide range of topics related to the bioeconomy. All topics are part of a bioeconomy-related study course, of which there are several in the LBTU's Faculty of Economics and Social Development (ESAF): "Bioeconomy 1", "Bioeconomy 2", "Digitalisation of Bioeconomy", "Innovation in Bioeconomy", "Knowledge-intensive Bioeconomy", as well as of other courses where the term "bioeconomy" does not appear in the title. Each lecturer has a personal view on the development of the bioeconomy, and therefore on the teaching of bioeconomy courses, emphasising different things. I think this is an asset to the book, because each of the authors has a different perspective on the key societal challenges for society in developing the bioeconomy. I see it primarily as a transformation of human values, knowledge transfer and behavioural models, while Sandija Zēverte-Rivža, for example, sees it through the prism of digital transformation, or Arnis Lēnerts – as a transformation of business models. This perspective does not focus on a narrow understanding of the bioeconomy on the political agenda, allowing academic thought to develop without the dominant political "'framing", which is of course subject to change. At the same time, the current policy objectives will not be achieved without responding to technological change or transformations in the value system of society. The book sometimes takes a different form of writing, sometimes scientific and sometimes academic, sometimes aimed at scientists and sometimes at students and everyone else interested in the subject. This is primarily explained at the outset, where its two natures are described: to think about contributing to education while maintaining the form necessary for a scientific monograph. At the same time, the study process is not something fixed, but a dynamic process based on the latest developments in scientific thought. In essence, the contemporary educational process is based on the analysis of classical basic knowledge and the results and interpretations of a huge body of research, always forming a new perspective on the prospects for the development of society. This is the reason for the title of the book "Bioeconomy: Development Roadmap" – the bioeconomy as a result of past development and the bioeconomy as a condition for future development. It should be noted that the scope of LBTU research in bioeconomy is enormous, and this book does not even attempt to cover it all. I would like to recommend the reader to visit the LBTU website (https://bioekonomika.lbtu.lv/), which offers a broad, but still only partial, overview of LBTU's work on bioeconomy development.

We hope that this book will justify our efforts and will be a useful tool for students and anyone else who might be interested in a broader perspective on the development of the bioeconomy.

Short insight into the chapters of the monograph

Chapter 1 introduces the concept of the bioeconomy, how the bioeconomy links to the green economy and the circular economy. It will explain the many definitions of the bioeconomy, the creative process behind its creation, and the constant evolution of science and practice. Here you will also find a classification of bioeconomy sectors.

Chapter 2 will look at society's path to the bioeconomy. The population explosion has continuously increased the demand for food and other bio-based products. Interactions between the environment and the economy, sustainability of the bioeconomy are described.

Chapter 3 deals with biological resources and biological processes, biomass production. It looks at land use and the development of biomass industries. It gives an overview of the wide range of biomass conversion technologies. This helps to identify how additional added value is created.

Chapter 4 identifies the potential of ecosystem services for bioeconomy development. These include both tangible and intangible goods – food, drinking water, timber, climate, landscape and many other services and methods for measuring them.

Chapter 5 concludes that in 2020, Latvia's bioeconomy turnover was EUR 8.4 billion, with forestry, wood processing and wood products accounting for 64.3%, followed by agriculture, food and beverages. The contribution of bio-based electricity, biofuels, bioplastics, pharmaceuticals and similar bio-based products to the bioeconomy turnover should be increased in the future, with a focus on high value-added products.

Chapter 6 examines the role of innovation in the bioeconomy. Emphasis is placed on the knowledge-intensive bioeconomy, based on research to create new products with higher added value. In particular, research-business coherence.

Chapter 7 explores new horizons in the rapid journey to the bioeconomy. It offers insights into the creative development and use of digitalisation and artificial intelligence in the bioeconomy.

Chapter 8 provides an overview of the history, need and importance of the Bioeconomy Strategy in Latvia and other countries, as well as the main results and achievements of the multi-year implementation of the strategy in different areas of the implementation of the Latvian Bioeconomy Strategy 2030.

The scientific monograph "Bioeconomy: Development Roadmap" is a pioneering work of its kind that can be used by students and others interested in the field to creatively develop the bioeconomy sector. It is a roadmap for understanding the bioeconomy and how it can play a greater role. I hope that this roadmap will have opened a new chapter in the development of the bioeconomy. With the participation and efforts of all stakeholders – researchers, students, entrepreneurs, civil servants and politicians – we will get the results we want.

We will be pleased if this roadmap encourages more productive use of bioeconomy resources and enhances their role in Latvia's economic development.

Kaspars Naglis – Liepa

Voldemārs Strīķis Professor Emeritus

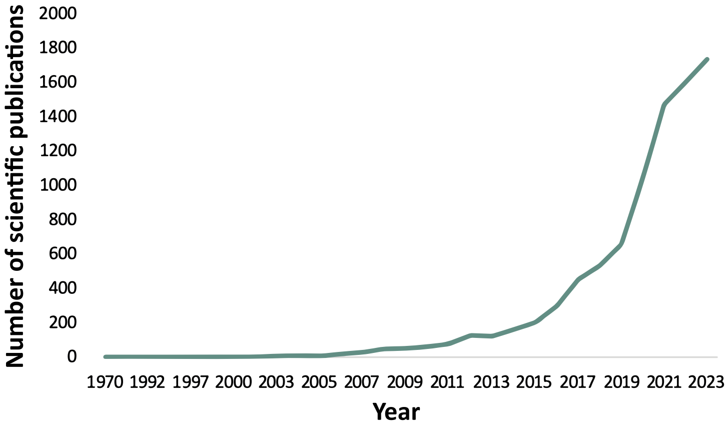
1. THE CONCEPT OF BIOECONOMY AND ITS INTERPRETATIONS

Author: Dina Popluga

The bioeconomy is a relatively unfamiliar term to the general public, so the aim of this chapter is to provide a comprehensive overview of the conceptual content and nuances of the bioeconomy, its most commonly used keywords and related terms. The chapter also includes a classification of the sectors and sub-sectors that make up the bioeconomy to give an idea of the size and scope of the bioeconomy.

1.1. Definition of bioeconomy and related keywords

Since the beginning of the 21st century, interest in the term "bioeconomy" – both as a research topic and as a focus for economic, technological and national security policy – has grown considerably. From 2010 onwards, the number of scientific publications reflecting the results of research in the bioeconomy has increased rapidly (Figure 1.1). This is a clear indication of the growing research interest and activity in the bioeconomy. Alongside research interest, policy interest has also been activated, and the fact that the global bioeconomy summits in 2015, 2018 and 2020 have been followed by large-scale learning about bioeconomy strategies in different countries and regions plays a large role.



Source: author's compilation based on information available in the Scopus database.

Figure 1.1. ***The number of publications listed in the Scopus database with the terms "bioeconomy", "bio-economy", "bio-based economy" and "bio-based economy" appearing in their title, summary or keywords***

What explains this recent surge in interest? After all, people have been growing crops and livestock, brewing beer and using wood for building materials and fuel for thousands of years. The use of biological resources remains an essential part of the modern economy, with sectors such as agriculture, forestry and fisheries being referred to as the "primary sectors" of the economy. Three factors have contributed to this growing interest in the bioeconomy, based on the potential for bioeconomy development.

1. Advances in life sciences and biotechnology offer promising new commercial applications for products and services.

2. In many countries, depleting fossil resources are being replaced by renewable bio-based resources in the production of electricity, fuels and chemical goods to mitigate climate change, ensure energy self-sufficiency, develop rural economies and boost exports.

3. Biodiversity and genetic resources are seen as raw materials es-

sential for the discovery and production of new pharmaceuticals and other biological products.

In the context of the development potential of the bioeconomy, several authors (Frisvold et al., 2021; Barañîñano et al., 2021) point out that the conceptual nature and content of the bioeconomy, based on biology and biosciences, have raised high expectations for a path towards a sustainable future. This is why the bioeconomy is supported in research and policy strategies – with the aim of developing a sustainable economic paradigm that encourages the creation of innovative value chains while protecting the environment.

Bioeconomy and sustainability

The bioeconomy provides solutions to the major challenges facing humanity today, almost all of which are related to climate change.

- Ensures food security and reduces water stress.
- Ensures sustainable management of natural resources to avoid over-exploitation.
- Reduces dependence on fossil fuels and promotes the production and use of renewable energy.
- Develops actions to mitigate and adapt to climate change.
- Creates green jobs and boosts productivity and competitiveness.
- Reduces greenhouse gas emissions and improves public health.

For example, the development of sustainable agriculture, where synthetic crop fertilisers are replaced by plant growth biostimulants (seaweed extracts, amino acids and micro-organisms, etc.), often used as organic fertilisers, can improve plant nutritional efficiency and soil health. At the same time, input costs and the climate impact of farming practices, i.e. greenhouse gas emissions, are reduced.

For more information on examples of the bioeconomy and its contribution to the Sustainable Development Goals, see the European Bioeconomy Alliance:

The idea and conceptual content of the term "bioeconomy" was formulated by Joseph Leslie Glick in his 1982 article "The industrial impact of the biological revolution", published in Technology in Society, where he expressed the belief that discoveries in biology and biotechnology would change the world economy. This idea was further developed by two geneticists, Juan Enriquez-Cabot and Rodrigo Martinez, in their 1998 article "Genomics and the World's Economy", published in Science, in which they argued that the commercial and industrial exploitation of biological and biotechnological discoveries will transform the world economy and bring about fundamental changes in many industrial processes.

Looking at the evolution of the concept of the bioeconomy, it is clear that the understanding of the concept has evolved and broadened, with two distinct and complementary dimensions (Table 1.1). Around the early 2000s, the bioeconomy was interpreted from a fossil replacement perspective, driven by the global expectation that oil prices would continue to rise and that fossil energy resources would soon run out. Since 2010, the concept of the bioeconomy has been seen from a broader perspective of biotechnology innovation, driven by the Paris Agreement targets and the need for new solutions to move faster towards a greener, more climate-friendly and sustainable economy.

Table 1.1.

Variable dimensions of the bioeconomy and their characteristics

RDESCRIPTOR	Dimension 1 **RESOURCE SUBSTITUTION PERSPECTIVE** (2000–2010)	Dimension 2 **BIOTECHNOLOGY INNOVATION PERSPECTIVE** (2010. gads – pašlaik)
General justification	Substitution of fossil resources	Innovations for sustainable development
Main driving force	Expectations that oil prices will continue to rise	Paris Climate Agreement
Attitudes towards fossil resources	"Peak oil", depletion of fossil energy resources	New oil exploration technologies, low, volatile prices

Source: author's compilation.

There is currently no broad consensus among countries, organisations or academia on the precise definition of the bioeconomy. There are different interpretations of what activities and sectors are covered by the bioeconomy. A major challenge in trying to define the bioeconomy is that its activities span many sectors and scientific disciplines. Definitions of the bioeconomy have often emerged in response to each country's economic priorities, biological resource base, technological capacity and regulatory approaches to biotechnology deployment. Table 1.2 summarises some of the most commonly used definitions of the bioeconomy, which have been developed by different authors representing different regions of the world, such as the White House in the United States of America (USA) and the European Commission (EC) in the European Union (EU).

Table 1.2.

Definitions of the bioeconomys

DEFINITION	AUTHOR
The set of economic activities related to the invention, development, production and use of organic products and processes.	Organisation for Economic Co-operation and Development (OECD), 2009
Economic activity stimulated by research and innovation in the life sciences.	The White House, 2012
Production of renewable biological resources and their conversion into food, feed, bioproducts and bioenergy.	European Commission, 2012
An economy in which the building blocks of materials, chemicals and energy are derived from renewable biological resources.	*McCormick and Kautto, 2013*
The bioeconomy involves the production of renewable biological resources and their conversion into food, feed, bioproducts and bioenergy using innovative, efficient technologies. In this context, it is the biological engine of the future circular economy, based on the optimal use of resources and the production of primary raw materials from renewable raw materials.	European Bioeconomy Alliance (EUBA), 2016

The bioeconomy is the part of the economy where renewable natural resources (plants, animals, micro-organisms, etc.) are used in a sustainable and intelligent way to produce food and feed, industrial products and energy.	Latvian Bioeconomy Strategy 2030 (LIBRA), 2017
The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries, and aquaculture); and all national economy sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services.	European Commission, 2018

Source: author's compilation.

The definitions of the bioeconomy summarised in Table 1.2 are diverse and show that the bioeconomy can be defined very concisely in one sentence or quite broadly in several sentences, emphasising its scale and nuances of expression. At the same time, the definitions as a whole highlight the key features of the bioeconomy:

- renewable resources of biological origin – the basis for all economic processes;
- economic activities (e.g. manufacturing) are boosted by research and innovation;
- a broad cross-sectoral and institutional focus;
- recognises the impact or role of knowledge from technology and the life sciences.

The definitions summarised here outline the main conceptual and substantive essence of the term "bioeconomy" – the sustainable use of renewable biological resources and organic waste to produce food, feed and bioenergy, as well as building materials.

It should be stressed that the diversity and constant evolution of definitions of the bioeconomy means that the concept of the bioeconomy is still a topic of debate among politicians, scientists and business people. The confusion, scepticism and criticism associated with the bioeconomy concept drive this debate and stimulate a productive exchange of information, ideas and values, positively influencing the development of the bioeconomy concept. Three viewpoints coexist in this debate:

Viewpoint 1 supports a broad interpretation of the bioeconomy to include all economic activities based on the production of renewable biological resources and their transformation into products, including agriculture, livestock farming, fishing, forestry and similar economic activities that have existed for thousands of years;

Viewpoint 2 takes a much narrower interpretation of the bioeconomy, limiting it to innovative and technologically advanced economic initiatives that result in high added-value products and services through the conversion of renewable biological resources;

Viewpoint 3 supports and considers the above two views to be complementary.

Taking into account and respecting these different viewpoints, bioeconomy activities can be classified as:

- based on natural resources, directly using bioresources (agriculture, fisheries, forestry) and providing further processing of biomass;
- further processing biomass as traditional production activities (food sector, timber sector);
- further processing biomass and/or biomass residues as new activities (bio-energy sector, bio-chemical sector).

Terms such as biotechnology, biomass, bioproduct, biological resource, bioenergy, biorefinery are very often used together with bioeconomy. They can be considered as keywords/terms for the bioeconomy, further clarifying the nature of the bioeconomy. Explanations of these keywords/terms are summarised in Table 1.3.

Table 1.3.

Keywords related to the bioeconomy and their explanation

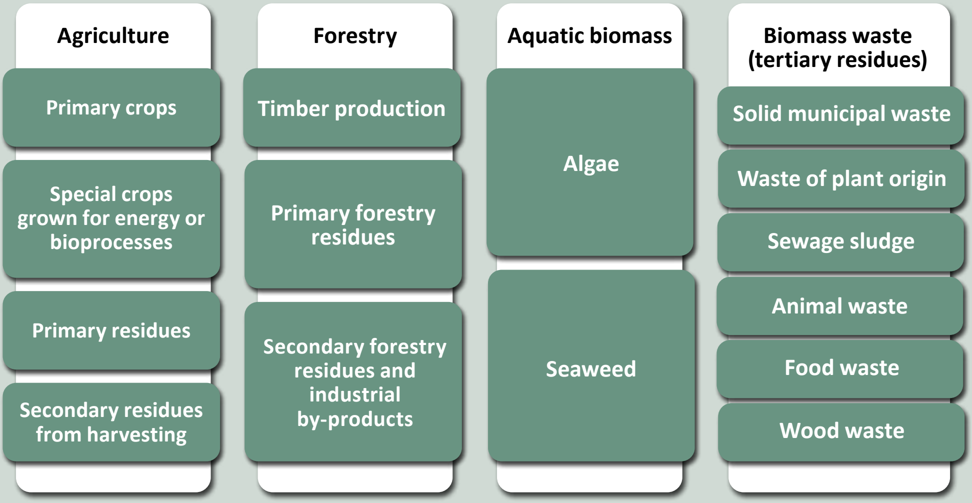
Keyword/term	Explanation	Source
Biotechnology	A branch of science and engineering that studies how biological processes can be used for industrial purposes, e.g. to produce biologically important substances (amino acids, enzymes, etc.).	Tezaurs.lv
Biomass	Biodegradable fraction of products, wastes and residues from agriculture, forestry and related industries (including substances of plant and animal origin) and biodegradable fraction of industrial and municipal waste.	Tezaurs.lv
Bioresource Biological resource	Any resource of biological origin.	yourdictionary.com
Bioenergy	Energy from biomass.	Tezaurs.lv
Bioproduct	A product which has been completely or partially produced from materials of biological origin, except for materials that are contained in geological formations and (or) have fossilised.	Latvian Bioeconomy Strategy 2030
Biorefinery	The coproduction of a range of biologically-based products (food, feed, materials, chemicals) and energy (fuels, power, heat) from biomass using a combination of physical, chemical, biochemical and thermochemical processes.	yourdictionary.com Barano et al., 2021

Source: author's compilation.

Availability of biomass as a key prerequisite for the development of the bioeconomy

The availability of biomass and competition between alternative uses of biomass (food, feed, fibre, bio-based materials, bioenergy and biomaterials, conservation of soil improvement) are the main limiting factors for the development of the bioeconomy. Biomass is a renewable, but finite resource, as biomass production requires land and additional resources (water, nutrients). Therefore, when developing the bioeconomy concept, it is important to analyse the demand for biomass in relation to the existing potential.

The figure below summarises the main sources of biomass and examples of these.



Sustainability of biomass feedstocks, efficiency of biomass use and economic aspects of biomass mobilisation are important in the context of bioeconomy development.

The limited availability of biomass for biomaterials calls for biomass prioritisation, which is an incentive for cascading biomass use that can lead to significant improvements in resource efficiency and optimal value creation. Biomass cascading would help reduce resource use and competition between different applications: food and feed, chemicals, materials, fuels and energy.

Further information on the role of biomass and bioenergy in the future bioeconomy is available in a publication by scientists at the European Commission's Joint Research Centre (Scarlat et al., 2015):

1.2. Bioeconomy, green economy and circular economy: common and different

In addition to the term "bioeconomy", there are a number of related terms that are often used in the context of issues related to bioeconomy. These are: green economy; circular economy; bio-based economy, which are further explained in Table 1.4.

Table 1.4.

Keywords related to the bioeconomy and their explanation

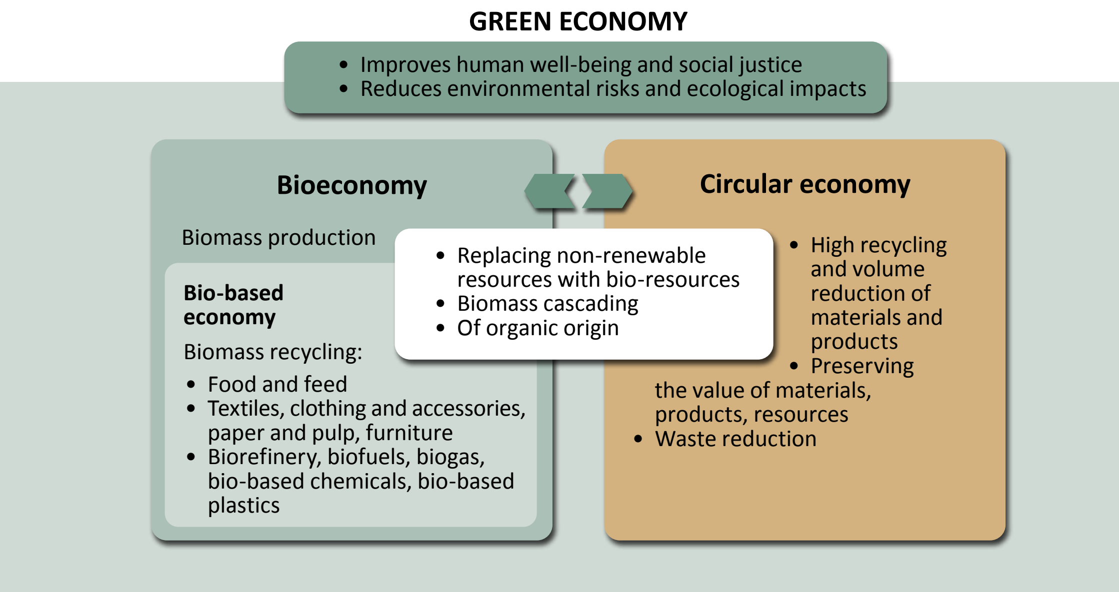
Term	Explanation
Bioeconomy	Industrial raw materials (e.g. materials, chemicals, energy) must be sourced from renewable biological resources.
Circular bioeconomy	Focuses on sustainable, resource-efficient valorisation of biomass in integrated, multi-output production chains (e.g. biorefineries), while also using residues and waste and optimising the value of biomass over time through cascading.
Bio-based economy	Materials and products are sourced/made from renewable resources.
Circular economy	Minimal input and minimal production of system "waste". Transforming a by-product of a particular industry into an input for another industry.
Green economy	Improved human well-being and social justice, while significantly reducing environmental risks and ecological vulnerabilities.

Source: author's compilation based on Kardung et al., 2021; Stegmann et al., 2020.

By comparing the explanations of the terms summarised in Table 1.4, and trying to grasp their commonalities and main differences, **the green economy** can be seen as an umbrella concept, understanding that this strand of economic thinking improves human wellbeing and social equity while significantly reducing environmental risks and ecological vulnerabilities. A green economy can also be seen as low-GHG, resource-efficient and socially inclusive economy. The **bioeconomy** is generally considered to be part of the green economy. It is more about fostering global economic growth and technological development than focusing on the constraints on growth due to resource scarcity, depletion and projected population growth.

The **bio-based economy** can be seen as part of the bio-economy and is concerned with the conversion of biological resources into products and materials. This is also known as bio-based production. Some explanations of the bio-based economy focus on innovative bio-based products such as biopolymers and bioplastics, while others focus on traditional bio-based products such as textiles, wood products, pulp and also paper.

The **circular economy**, which is growing in popularity and often adds to the understanding of the potential of the bioeconomy, can be described as an economy in which the products and materials used show a high degree of recycling and reduction, as opposed to a linear economic model. Replacing non-renewable energy sources with sustainably produced biomass is also an important part of the circular economy. Figure 1.2 visually illustrates the interrelationship and interaction of the conceptual content of the terms.



Source: author's compilation based on Kardung et al., 2021.

Figure 1.2. **Link between the bioeconomy, circular economy and green economy**

When assessing the synergies between the terms summarised in Table 1.4 and Figure 1.2 and their conceptual content, the growing synergies between the concepts of bioeconomy and circular economy are very significant. Several European industry associations, such as the Confederation of European Paper Industries and the European Association for Bioindustries, use and support the concept of a "circular bioeconomy" and promote greater integration rather than parallel development of the two areas. Also in 2018, the European Commission has introduced the term "circular bioeconomy" to link the bioeconomy and circular economy and to highlight the use of a circular approach in the bioeconomy, as well as to show the limitations of overlaps.

1.3 Classification of bioeconomy sectors

The bioeconomy is undeniably the engine and driver of change in the 21st century. It is therefore particularly important to be able to assess its size, pace of development and key players. The European Commission's broad definition of the bioeconomy outlines the sectors that make up and are part of the bioeconomy, and states that the bioeconomy includes all economic activities related to the production and manufacture of biomass. One of the most common approaches to bioeconomy classification in the European Union (EU) and its Member States is NACE 2 (Statistical Classification of Economic Activities in the European Community), which identifies the economic sectors belonging to the bioeconomy.

The following types of economic activity are used to identify and classify bioeconomy sectors:

1. natural resource-based activities that directly use bioresources (agriculture, forestry, fisheries) and provide biomass as a feedstock for other sectors;

2. biomass from traditional activities (food, feed, tobacco, beverages, wood and wood products, textiles, clothing, leather, paper and pulp, furniture) from type 1 economic activities for further processing;

3. new activities to further process biomass and/or biomass residues from type 1 activities or to use processing residues from type 2 activities (biorefineries, biofuels, biochemicals, bioplastics, biogas).

The first type of economic activity can be fully attributed to the bioeconomy, and some of the second type of economic activity (food, tobacco, beverages, wood and wood products, paper and pulp) can also be attributed to the bioeconomy. The inclusion of other economic activities in the bioeconomy depends on the share of biomass use.

According to NACE 2, 16 sectors can be selected as belonging to the bioeconomy, divided into 3 groups according to the type of biomass production or use (Figure 1.3).

Biomass producing sectors: according to NACE 2, Division A, which includes biomass producing sectors, are the following: crop and animal production, hunting and related service activities (A01); forestry and logging (A02); fishing and aquaculture (A03).

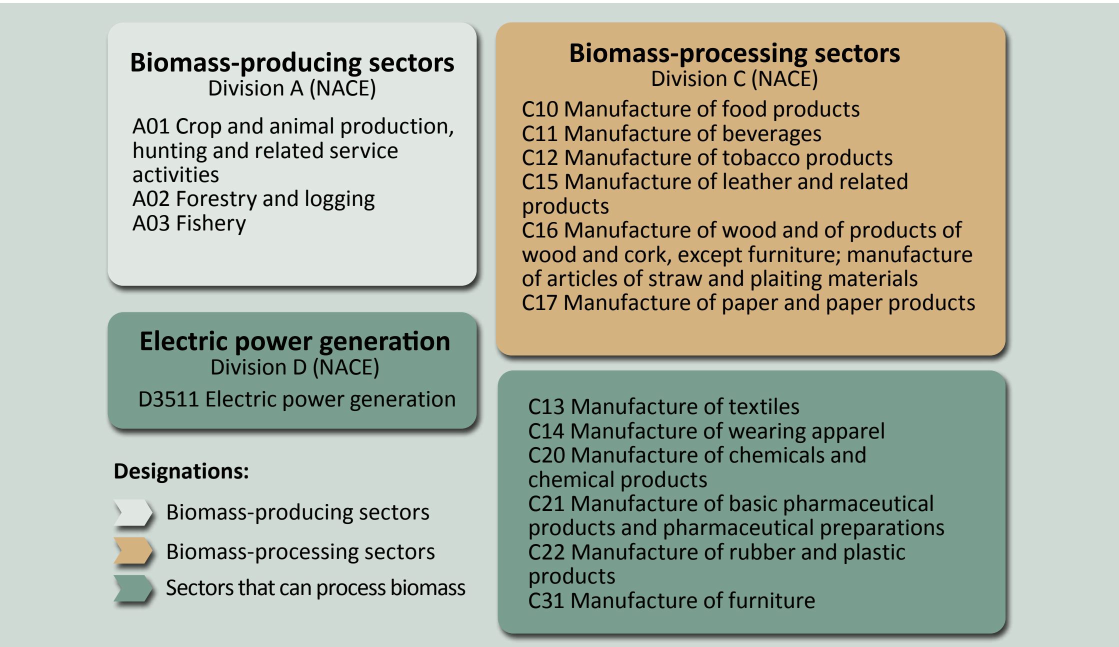
Biomass-processing sectors: according to NACE classification, Division C comprises biomass-processing sectors that use biomass to produce other products. Given that for some sectors biomass is an exclusive feedstock, while in other sectors biomass can be used as an alternative feedstock, two groups of sectors can be distinguished in Division C:

- sectors using only biomass as raw material are: food manufacturing (C10); beverage manufacturing (C11); tobacco manufacturing (C12); leather and related products manufacturing (C15); manufacture of wood and of products of wood and cork, except furniture (C16); manufacture of paper and paper products (C17);
- sectors that can use biomass as a feedstock are: manufacture of textiles (C13); manufacture of wearing apparel (C14); manufacture of chemicals and chemical products (C20); manufacture of basic pharmaceutical products and pharmaceutical preparations (C21); rubber and plastic products (C22); and manufacture of furniture (C31).

Electric power generation from bioresources: according to NACE classification, Division D includes electric power generation (D3511), where electric power generation from bioresources is separated and calculated.

Although the bioeconomy sectoral framework summarised in Figure 1.3 is the dominant one in the EU, it is not static and is subject to change. For example, M. Kardung and co-authors broaden the understanding of bioeconomy sectors to include water, sewerage, waste management and remediation activities (NACE E36, E37, E37), wholesale trade activities (NACE G46), construction and engineering activities (NACE F41, F42), botanical gardens, zoos and nature reserves (NACE R9104), biotechnology research and experimental development (NACE M7211), accommodation services (NACE I55).

FRAMEWORK OF BIOECONOMY SECTORS



Source: Muška et al., 2023.

Figure 1.3. **Sectors making up the bioeconomy according to NACE classification**

In the United States, many sectors are excluded from the bioeconomy framework: beverages and tobacco; leather and products; wood production; paper products; furniture production; clothing; healthcare; pharmaceutical products (wholesalers); agricultural supplies (wholesale); construction; water treatment and supply; nature tourism, hunting, fishing. This reflects the US understanding of bio-based industries, which is different from the EU's. In the United States, the bioeconomy's core sectors are biotechnology and innovation, biomedicine and health, and defence and national security (e.g. protection against biological threats).

Examples of sectors making up the bioeconomy

Food systems are a major niche in the bioeconomy. Bio-based products and bioenergy are added to these systems, which include sustainable agriculture, sustainable fisheries, forestry and aquaculture, as well as food and feed production. Biological products include bioplastics, biodegradable clothing and other products related to eco-design. Bioenergy, like biomass, a renewable form of energy, improves energy security, reduces energy dependence and creates new opportunities for growth and jobs.

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2. DEVELOPMENT OF THE BIOECONOMY CONCEPT

Author: Kaspars Naglis-Liepa

2.1. Society's path to the bioeconomy

The efficient use of resources is a key issue in economic analysis. How can resources be allocated efficiently so that humanity (country, city, community, family) can survive and thrive? Social systems are centred on the individual, i.e. the individual creates his or her own (preferred) pattern of life and tries to adapt the existing environment to it in order to ensure the desired conditions. The environment and development objectives determine the definition of resources, as their finite nature is an essential characteristic. In other words, the more unsuitable conditions people are forced to choose for various reasons (enemies, climate change, overpopulation), the more important resources become to help them adapt to previously unsuitable living conditions. In parables, it is like growing up in a family, where in childhood there seems to be no shortage of things to ask (or beg) your parents for, but later, as you grow up and realise your own personality and the limitations of meeting your needs, the importance of resources becomes more and more apparent.

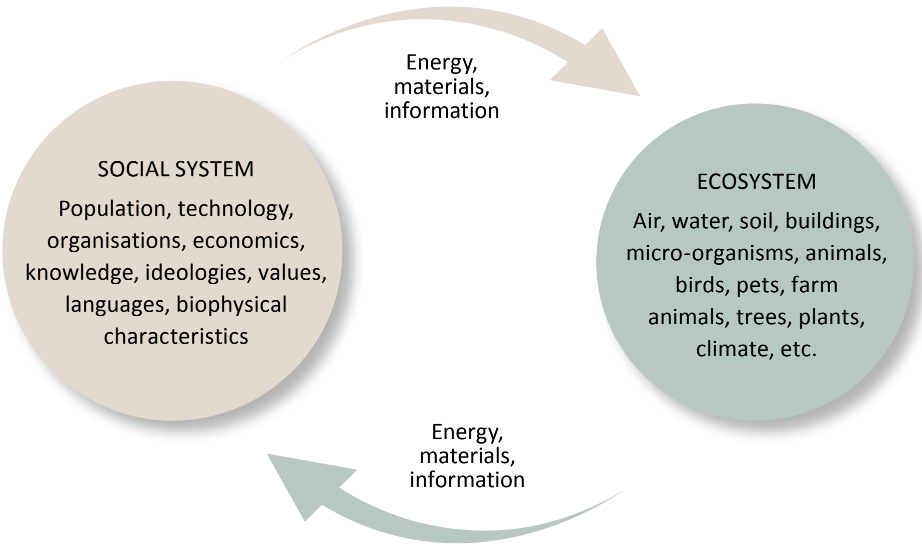
By analogy with Greek mythology, the development of the two systems of humanity and nature can be seen as the relationship between the ruler of the gods, Zeus (also the ruler of the ordered and the human world), and the Earth mother or Earth goddess, Gaia (the natural and primordial world). In the legend, Zeus is saved from the destructive power of Uranus (a god personifying the heavens) by Gaia, and he represents natural conditions and forces from the beginning of civilisation, i.e. that nothing on earth is possible without the origin of nature. On the other hand, it is the human will and desire to "grow", to focus on needs and to create opportunities to meet them, which can be conditionally called economic activity. At its core, the bioeconomy is a story of two systems interacting. It is the social system, as subjectively creative, consuming and providing for human development, and the natural or ecosystem, as objectively evolving and providing for existence.

A system is a concept, an idea

- A characteristic, certain order
- Is formed by the acceptance of a specific agreement
- Characteristic relationships between components
- Forms a coherent whole

Social system – the patterned series of interrelationships existing between individuals, groups, and institutions and forming a coherent whole (*Merriam-Webster*).

Ecosystem – a complex of communities of organisms and their existence in the environment, forming an ecological unit.

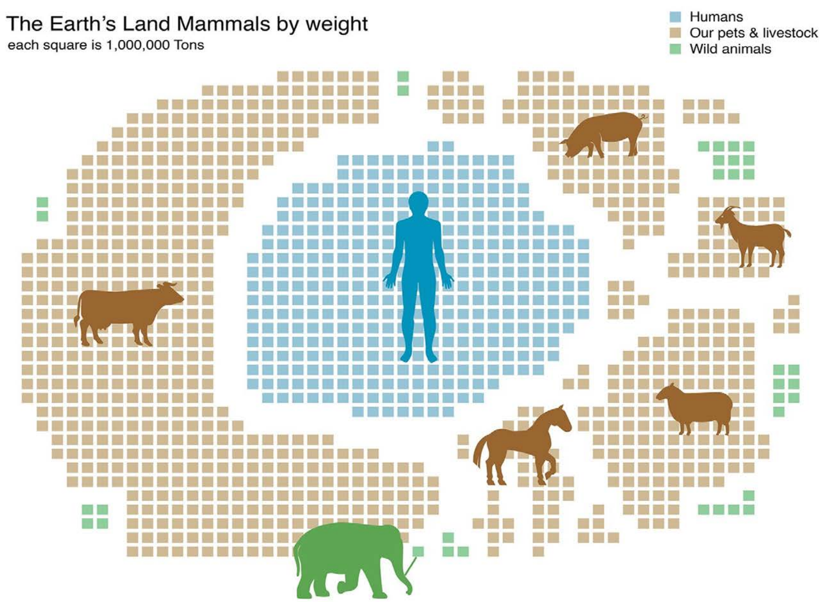


Source: by the author

Figure 2.1. **Social and ecosystem interactions**

Between these two systems, there is a constant exchange of energy, material resources and information, as well as a constant process of adaptation. Humans adapt to changes in the ecosystem, often by being the cause of those changes, and the ecosystem adapts to changes caused by humanity.

Humans are one species out of 8.7 million species, but it is clear that over 200 000 years they have become the dominant species with a major impact on the ecosystem. We have gone from being a gathering and hunting tribe, totally dependent on the capabilities of the ecosystem, to a species that has subjugated other species.



Source: Vaclav Smill, 2003 and Bar-On et al., 2018.

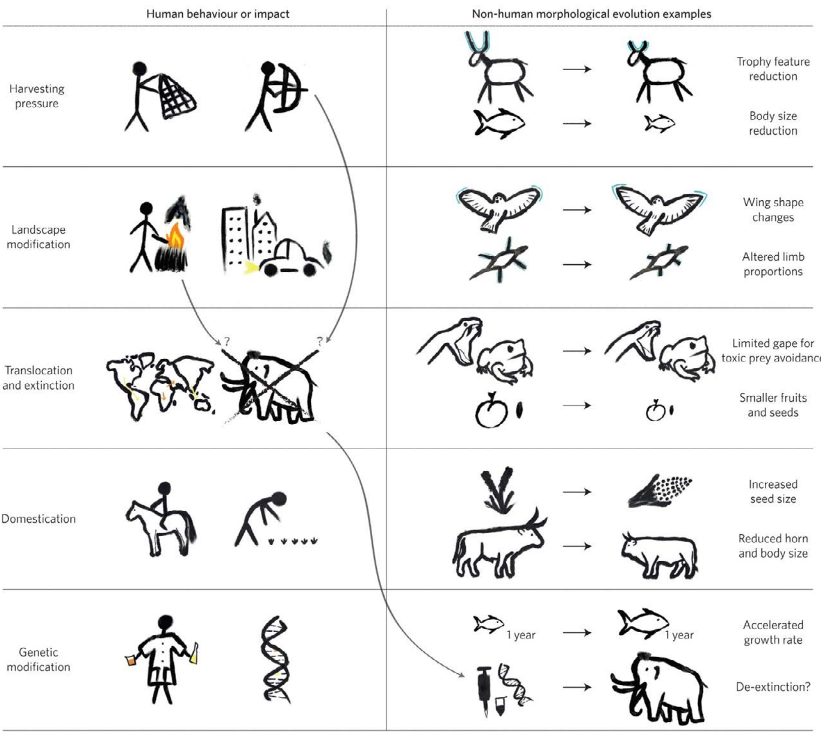
Figure 2.2 **Distribution of land mammals by mass**

As M. Maslin points out, humans account for 30%, domestic and farm animals – 67%, and wild animals – only 3% of the total weight of mammals. At the same time, the question of what human characteristics allowed such a population distribution to be achieved is crucial. Is it the ability to move vertically? But in this respect, we are no different from, for example, chimpanzees. Is it the ability to consume a wide variety of foods? In this respect, we are no different from pigs. Is the often-mentioned brain mass index (brain to body ratio) an indicator of the difference? We are far from having the biggest brains, because small birds have relatively big brains, and mice have brains similar to humans. It is possible that human superiority comes from the ability to think abstractly, tell stories and collaborate, as J. Harari suggests. The ability to build the abstract idea of Mount Olympus, going back to the Greek myths, created the conditions for man to rise to the top of the social system.

Nature has no loved ones, but only one species is actually important to humans – humans themselves. The abstract idea of God's right to give a voice to other species and to rule over other species economically implies that the rest of the ecosystem can, if necessary, be seen as resources for the development of the main species. Indeed, has anyone ever highlighted the right of cows to grow up in a full family, or don't pig farms resemble concentration (albeit sometimes well-maintained) death camps? And if so, we would count these people among the "green, unconscious romantics".

The ability to place human rights above the rights of all other species to exist and evolve is another aspect that has given humans an advantage in world domination. At the same time, humans seek to dominate not only other species, but also to dominate within their own species or territorial structure. Historically, economic development has long been linked to the ability to acquire, hold and manage new territories rich in potential resources. Sir William Petty summarises in Economic Writings (1662) that "land and labour are the mother and father of income". In essence, conquering territory (today still in the economic sense, including through the use of cheap labour) and using its resources, including human labour, is a formula for wealth creation. Historically, abstract thinking, as a necessary tool for the creation of new ideas and technologies, has only been possible for the highly educated. Moreover, with limited opportunities to make discoveries, because the right to manage resources belonged to a few high-born individuals, only a fraction of society benefited, and even then only when inventions were put into practice.

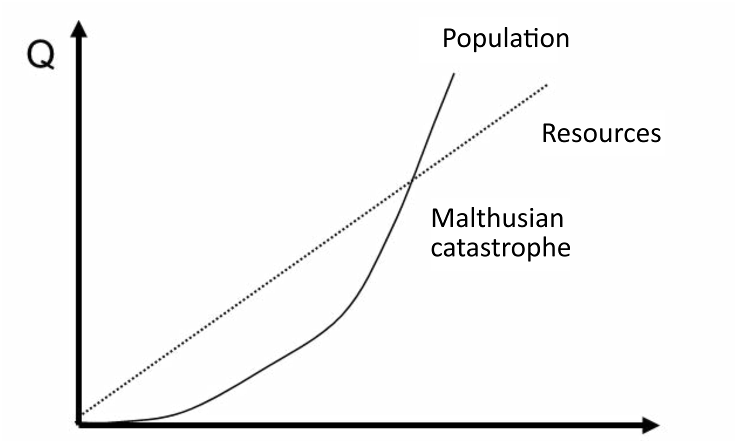
It should be stressed that for a long time the world of ideas, or the man-made world, was very mystical. It is a well-known fact that Roger Bacon, one of the founding fathers of modern physics, also pursued theological and alchemical studies alongside his understanding of the “principles of nature”. This period is marked by economic and physical territorial expansion, the conquest of the world’s territory. Looking at social-ecosystem interactions, up until the 19th century, the impact of the social system on the ecosystem was small compared to today. A. W. Crosby writes in his book “Ecological Imperialism” that the basis of European colonisation was the ability to use plants, animals and, indirectly, even pathogens to influence the colonised territories. At the same time, there is another side to this interaction of systems: not only do the elements of nature have an impact on people, but people have a significant impact on nature. A. Salivan and colleagues have developed a model showing that since the hunter-gatherer period, humanity has influenced the evolutionary morphology of species, with individuals often becoming smaller, changing colour and body characteristics, and maturing faster, with this process accelerating in the industrial period.



Source: Salivan et al., 2017.

Figure 2.3 **The impact of human behaviour on morphological changes in other species**

Human expansion leads to necessary changes in the social system as the number of people grows and localities have a greater platform for more diverse ideas and ways of implementing them. Humanist ideas are spreading not only in Europe but also, much more rapidly, in the new land of America. There is a growing incompatibility between the elements that are now seen as the building blocks of sustainable development. The existing social system cannot meet society's economic needs and cannot ensure a relatively efficient allocation of resources. At this time, Thomas Robert Malthus is highly critical of human nature – humans are primarily interested in eating and reproducing, which means that sooner or later humanity will face a scarcity of resources, a process known as the Malthusian catastrophe, which means a decline in the standard of living.



Source: by the author

Figure 2.4 **Representation of the Malthusian catastrophe**

There are constraints on population growth, which Malthus divides into positive constraints (positive checks) such as famine, scarcity, war, disease, and preventive constraints (preventive checks) such as moral restraint, marriage and birth control. These very trivial ideas of Malthus are set out in his classic work “An Essay on the Principle of Population”. Malthus has never lacked followers, and continues to have them today. At the same time, there have always been critics who, while recognising the limits of the natural system, emphasise the almost infinite nature of man-made ideas and technologies. The best known of the Malthusian works is the report of the Club of Rome “Limit to Growth”, 1972), which uses a system dynamics approach to show that growth cannot be infinite, just like the number of people.

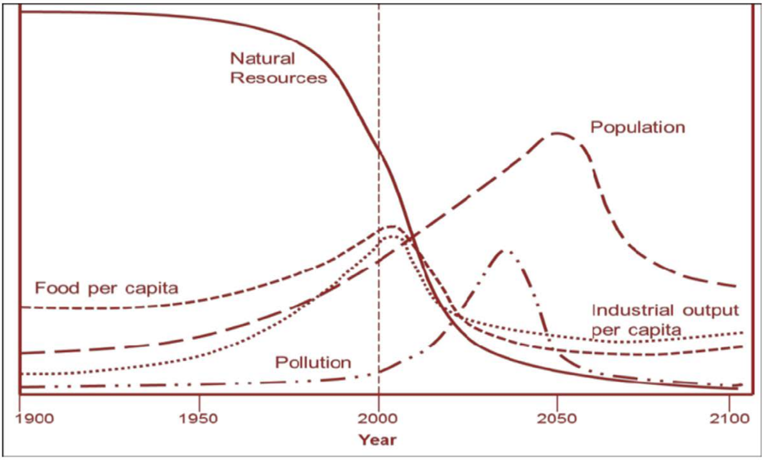


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Figure 2.5 **Initial projections of the growth limit model: increasing population to resource and pollution ratio, 1900 to 2100**

It should be stressed that the report has been praised, reviled and recalculated, but it has not lost its relevance thanks to its relatively precise trajectories.

Key insights from the growth limits

- The physical limits to growth under current policies would probably be exceeded within a generation.
- The most likely outcome of reaching these limits would be to exceed them, followed by a systemic collapse.
- The findings did, however, suggest a viable alternative to these results – one in which population growth and material production could be balanced against planetary constraints.
- Realistically, it would take 50 to 100 years or more for this alternative outcome to become a reality.
- Finally, the team found that each year that an action is postponed to achieve the alternative outcome, the number of options available to avoid the exceedance and collapse decreases.

Wars and revolutions in the 18th century in both America and France. During this time, James Watt creates his steam engine and, figuratively speaking, with more efficient use of natural resources (especially labour), the "Malthus catastrophe" should now be abolished. This "moving the end of the world" continues to be successful, which is linked to technological progress and innovation in general. Alongside revolutions of ideas in social systems, revolutions of ideas in economics are also beginning, from the 1st Industrial Revolution to the 4th Industrial Revolution ("Industry 4.0"), and the focus is now on the 5th Industrial Revolution.

In fact, the work can be seen as steadily acquiring another character, distinct from natural mechanical work and speculative usury, that of artisanal creative work as the mainspring of development. These conclusions will be formulated centuries later by Josef Schumpeter, but the process of industrialisation has been "liberated". The economic classics Adam Smith and David Ricardo advocate trade and industrial liberalisation, known as *laissez-faire* (meaning: *let them do*) because mutual self-interest will lead to the best win-win market equilibrium solution, as if guided by the "invisible hand". At the same time, D. Ricardo recognises that there is a certain order in nature that cannot be changed. Interfering with the natural order, including the economy, is a disruption of the natural order, and is not productive. In other words, humanity is not yet ready to oppose itself to the natural system, but feels itself to be part of it, albeit active and even reactionary.

At the same time, questions continue to be asked about the divinely ordained order and the natural order. The most popular answer today, at least in the Western world, is evolution. The obvious answer!? Either way, it is the most popular model of perception of the evolution of life, which began its journey into people's minds with the publication of Charles Robert Darwin's book "On the Origin of Species" in 1859. It should be pointed out that a year earlier, Darwin had received a letter from his colleague Alfred Russel Wallace outlining a similar theory of natural selection, based on studies in South America and Asia. So the two geniuses came to similar conclusions at the same time – that natural selection produces new species best suited to their living conditions, with altered body parts, from feet to eyes, and that this is a major determinant of species diversity.

The question of nature's "reasonableness" or established order, however, has not been fully answered, and probably never will be. Hermann Reinheimer contributed to this understanding with his 1915 publication "Symbiogenesis: The Universal Law of Progressive Evolution", which uses the term "bioeconomy" to refer to the "natural economy" and emphasises the importance of cooperation in the division of labour. Reinheimer's understanding of the bioeconomy is not part of a social system, as it is today, but part of an ecosystem. The basic idea is that evolution exists because there is competition between species and within species, which forces individuals to choose the most efficient strategies for the continuation of the species. Evolution is essentially a set of principles that determines the ability of species to exist and evolve. These universal principles of the bioeconomy were formulated by Peter A. Croning as the organising principles of nature. Different types of synergistic functional effects of cooperation have been necessary at all levels of biological organisation. It is a unifying theory of complexity. The idea that these principles apply not only to the natural system, but also to the social system, is a little provocative, but easy to justify. It is easy to recognise that the business environment is crucial to the economy, and that resource (energy in the broadest sense) scarcity is at the heart of the economic problems, etc. An interdisciplinary approach is very tempting because it is one step closer to a "complete" understanding of the natural order, or a theory of everything. At the same time, it is also quite dangerous – not only in terms of misunderstanding, but also as a cause of human tragedy. Darwin stressed that there were various physiological and mental differences between the human races; it was a scientific hypothesis that was understandable, although later turned out to be unfounded and wrong, in the context of evolutionary theory. Joseph Arthur de Gobineau and Samuel Morton developed this idea further and concluded that racial mixing will lead to the death of humanity.

The reckless transfer of scientific ideas to the social sciences has led to the creation of "scientifically justified" pseudosciences such as eugenics or eugenetics (Greek: ευγενες from *eu* 'good' and *gennaô* 'to be born'), on whose "scientificity" segregationists and Nazis feed. The extreme caution in interpreting ideas from the natural sciences in the social sciences

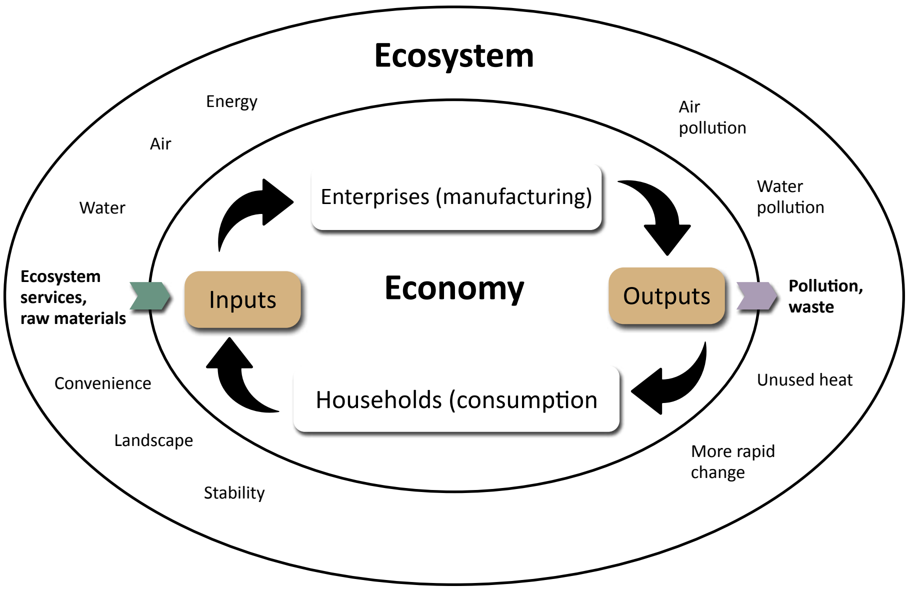
Universal principles of the bioeconomy in the natural economy

- Survival problems are always context-dependent. The problem parameters are based on the relationship between the organism and the environment.
- Getting energy and the right information on how to access and use it are two important requisites for organisms to survive and reproduce.
- Time and energy are always limited, so they must be used relatively efficiently.
- Species use different strategies and tactics to stay alive. Some act alone, some use symbiotic cooperation (mutualistic or parasitic). Some species are sexual and some asexual, some use the body as a weapon, others choose materials to make weapons, etc.
- Ecological competence is a common feature of ecosystems, but it is balanced by interdependence, cooperation, symbiosis and division of labour. Moreover, competence is not a fundamental organising principle of the natural economy, as is often assumed. The most important criterion is the acquisition of the necessities of life and reproduction – "adaptation"; competition and cooperation are subsidiary phenomena. They form the "survival strategy".

is therefore understandable. On the other hand, the accelerating pace of human development calls for an increasingly integrated view. One has to be able to see the world in a holistic way, as a single dynamic system.

The last century has been marked by the fastest development ever seen. The process that J. Schumpeter calls innovation creates more and more products for more and more people. Despite the two world wars, humanity has never before provided such favourable conditions for life. The economy's success brings to the fore the already forgotten Malthusian predictions about resource scarcity. Humans are beginning to influence the ecosystem processes of planet Earth to such an extent that a new term is emerging in geology: the Anthropocene, a new geological epoch. Anthropocene – an imaginary geological epoch characterised by significant human impacts on geology and ecosystems, including anthropogenic climate change. The term will only enter the scientific nomenclature of geology in 2022, but much has been said about the phenomenon in the past. At the same time, there is no common understanding of the origins of this human epoch (the Anthropocene). As mentioned above, significant changes begin with the industrial period, which could also be the reference period (1780). This year does not see a radical change, but an acceleration of processes that started earlier, and perhaps a 12 000 year history with the beginnings of agriculture can be seen as the reference period. In fact, it is easy to see that the issue is the interaction between two systems (social and ecosystem) and the impact of the social system on the ecosystem. It seems that the winning view in this dispute is to see it not as an epoch, but as an event. One could hypothesise that if human activity can have a significant negative impact on the ecosystem, causing mass extinctions of species, accelerating climate change, depletion of geological wealth, changes in ecosystem parameters (air composition, water acidity, global ocean temperatures, etc.), then these processes can also be halted and the bioeconomy can be conditionally managed or controlled.

The dominant idea of capitalism had to be strongly opposed, which of course happened, and somewhat confusingly, one of the most prominent of the opponents was J. Schumpeter's pupil, Nicholas Georgescu-Roegen. Turning to rather classical economic research, Georgescu-Roegen's understanding of the world is confronted with the second law of thermodynamics, also known in physics as the law of increasing entropy: in nature, processes work in such a way that entropy either remains (reversible process) or increases (irreversible process). Since there are no completely reversible processes in nature, real processes always involve an increase in entropy. Again, the integration of natural science ideas into the social sciences comes into play, and N. Georgescu-Roegen postulates: "The economic process is not mechanical, but entropic. Economic processes are the transformation of natural resources (low entropy) into worthless waste (high entropy). This is just the physical side of the process. The real products of the economic process are an immaterial current, a joy of life, whose relation to the entropy of matter-energy is still shrouded in mystery."



Source: by the author

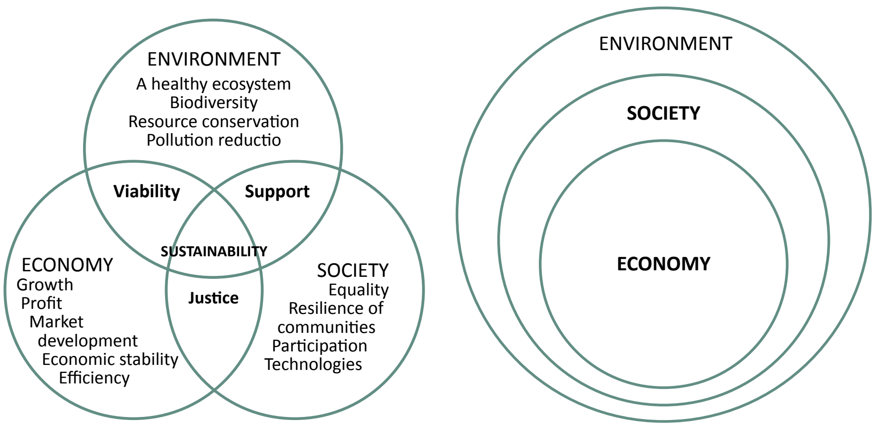
Figure 2.6 **Interactions between the environment and the economy**

Georgescu-Roegen's critique is based on the idea that humanity is turning natural low entropy into high entropy by intensively and often unconsciously consuming resources and transforming them into waste. He called this understanding of economy a new kind of dialectical economy, or bioeconomy. Georgescu-Roegen's bioeconomy is not a "nature economy" but a "natural economy" – an economy that takes into account natural (thermodynamic) constraints and stands in opposition to the use of economic terms in "all cases of life", such as the interpretation of the validity of the theory of consumption. Georgescu-Roegen develops a minimum bioeconomy agenda to be completed in order to avoid a catastrophe.

Minimum bioeconomy agenda

1. Ban arms production altogether, redirecting production towards more constructive ends.
2. Emergency aid for underdeveloped countries.
3. Gradual reduction of the population to a level where the population can live only on organic farming.
4. Strict regulation and avoiding, where necessary, wasteful use of energy.
5. Not getting hooked on "extravagant devices".
6. "Discarding fashion".
7. Creating reusable and repairable goods.
8. Curing workaholism by balancing work and rest.

Admittedly, this agenda is provocative and extremely difficult to legitimise given the existing policy challenges and the implementation agenda. These views are very much those of strong sustainability: the economy is part of the social system, which in turn is part of the natural system. This is the sustainability on which the ecological economy is based.



Source: Pelenc, 2015

Figure 2.7 **Comparison between strong and weak sustainability**

Key differences between strong and weak sustainability

	Weak sustainability	Strong sustainability
Essence	Natural capital and other forms of capital (manufactured, etc.) are perfectly substitutable.	The substitutability of natural capital with other forms of capital is very limited.
Conse-quences	Some human actions can have irreversible consequences.	Technological innovation and monetary compensation for environmental degradation. Sustainability issue.
Task	The total capital value should at least be maintained or ideally increased for the next generation.	Preserving irreplaceable "stocks" of critical natural capital for the benefit of the next generation.
Concept	Natural capital is critical.	Optimal allocation of scarce resources.

Most of the public recognises the need for measures to mitigate the environmental and social damage caused by the economy, but the "minimum" agenda is seen by many as going beyond the "maximum" agenda. This is why a new consensus on sustainability is emerging: the three dimensions of environmental, social and economic relevance are of equal importance on the path towards it. This view of weak sustainability, as expressed in the Brundtland Report (1987), is typical of another school of economy – environmental and resource economy. At the same time, it is clear that economies need to grow, driven by people's desire to live better, but do economies always need to grow, or is prosperity possible without growth? Herman Daly defines and justifies a steady state economy – an economy with stable consumption, stable inputs and stable outputs.

Globālajā ekonomikā lielākā daļa ekonomiku spiesta cīnīties par izaugsmi, kas lielā mērā saistīta ar valstu fiskālo politiku. Vienlaikus H. Dalija pieeja ilgtspējas nodrošināšanai ir pieņemamāka un tiek īstenota dzīvē. In the

H. Daly's insights on sustainability (4 points)

1. There is a need to maximise resource efficiency by assessing the use of renewable resources in terms of sustainable benefits.
2. Resource use needs to be controlled by limiting the use of off-limit resources.
3. Technological progress should ensure that sustainable development efficiency gains outpace increases in use.
4. Mineral resources must be replaced by renewable resources

global economy, most economies are struggling to grow, largely as a result of national fiscal policies. At the same time, Mr Daly's approach to sustainability is more acceptable and is being put into practice. These 4 points should take into account the principle of steady-state economics: that an economy can be without growth while ensuring steady prosperity and number of population. Both flows (capital and population) are limited by natural resources, without exceeding them. If these objective natural resource limitations are exceeded, then the size of the economy needs to be reduced, or degrowth promoted, until a sustainable limit is reached. Primary sectors have a key role to play in implementing the H. Daly's 4 points. The bioeconomy is often seen more narrowly as a process of primary industries and related innovation. This view of the bioeconomy is part of EU policy. Agriculture has always been an important economic sector in Europe, and an important part of culture. At the same time, with each successive industrialisation or *innovation cycle,* the role of agriculture and forestry in the economy diminishes. This does not indicate an inability of agriculture and forestry to produce, but a limit to the growth of production. Information technology performance increased manifold over the 20th century, but the productive capacity of the Earth cannot, due to objective reasons. In other words, the value added in the innovation sectors is several times higher than the value added in agriculture. In economics, agriculture is known as a *diminishing return* sector; marginal output cannot be increased significantly, so growth must be linked to acreage expansion. This means that it is hard for small farms to get rich unless they buy up neighbouring land. This is one of the main reasons for the protectionism of the European agricultural market, which is at the same time detrimental to both global producers and European citizens.

Reaching smart and green growth requires combining primary resource extraction, including agriculture, with innovative industries such as information technology or materials science, resulting in higher value-added products. This helps agriculture escape the trap of falling profitability, as it is no longer competing in the food market, where, according to D. Ricardo's old and well-known international trade theory, less developed countries have a comparative advantage and are able to produce agricultural products more cheaply. Essentially, this means that European farmers will no longer just produce food, but high-quality food, energy, substitutes for petroleum products, from fuel to plastics, without causing additional environmental damage. This is a huge challenge, not only for science and agriculture, but for European culture as a whole.

It is clear that scientists and politicians alike are pinning their hopes on the bioeconomy as the future direction of development, while there is a strong and diverse debate among different stakeholders about the direction and pace of progress. The issues raised range from gradually shifting the dominant resource base and stimulating demand to maintain economic growth and stability to radically forcing a change in human behaviour to prevent irreversible climate change. The practical solution is not yet clear, as it depends on reconciling the views and arguments of many stakeholders, but it is clear that the bioeconomy is the next stage of human development, and one that involves a fundamental reassessment of values.

Tracing the emergence of the bioeconomy as a result of the interaction between the social and ecological systems, it is also necessary to underline the change in the functional view of man from *homo economicus* to *homo bioeconomicus.* The ability to see the broader implications of human economic activity requires a shift in perspective from a rational, self-interested and need-driven one to a broader one that seeks not only to consume now, but also to preserve for future generations. It is also about not only trying to consume more, but to consume more consciously, taking into account the impact of this consumption on the environment, on the quality of life of others, on values such as traditional culture, landscape and way of life.

2.2. *Homo bioeconomicus*

In contemporary Western society, food and other consumer goods are not just a basic condition of biological existence, but involve a complex set of judgements that are subjective, but at the same time influence social behaviour in a densely populated society. In the context of neoclassical economics, it is a matter of subjective judgements of validity and corresponding market behaviour, which in turn affects the supply side. At the same time, it is often not just about actions in the market, but about the activities of a wider social group. According to *value belief norm theory,* altruistic, traditional openness to change creates a new ecological paradigm that influences consciousness, leading to changes in personal norms, in the public and private spheres. In the light of this theory, for consumers, for example, food represents certain values and belonging to a certain group. Although, of course, patterns of pro-social behaviour are complex and can also be strongly influenced by contextual factors.

Sometimes it is not possible to define a single most important value that defines a behavioural pattern. Thus, for example, the desire to consume less meat products may be linked to both environmental concerns and personal health concerns. It is true that relatively selfish health concerns are more prevalent (a person who takes care of his or her health improves the overall health of society). Pro-social consumer behaviour through volunteering, participating, donating or choosing products with a social benefit is becoming increasingly popular. At the same time, it can lead to a juxtaposition of pro-social and conventional buyers. Research findings that organic food consumers are more pro-socially motivated are mixed. For example, one study found that organic food consumers are less likely to engage in supporting strangers in need and are significantly harsher in their moral judgements. This may be due to the fact that in some cases specific product choices, such as organic food, are based on people's de-

Pro-social behaviour – behaviour that is motivated by altruistic motives such as helping, saving, comforting someone else.

Pro-social values – values such as preserving nature, caring for the climate, caring for national traditions, etc.

sire to fit into a group (even to be a luxury or fashion consumer), without environmental or other pro-social motives. Or consumer behaviour is driven only by concern for nature, but humans are the cause of environmental damage and therefore deserve to be criticised. Be that as it may, it is clear that the German philosopher Ludwig Feuerbach's famous saying "You are what you eat!" from his essay "Concerning Spiritualism and Materialism" (1863) takes on a broader perspective. Not only food influences our mood, but we choose food to match our mood and outlook on life.

Economic theory is anchored in the notion of low-value goods, defined as goods whose consumption falls as the income of the buyer rises. Essentially, it is about goods that can be used to meet basic survival needs relatively easily (cheaply). In this case, the utility of the good is relatively high, as is the elasticity with respect to income. As incomes rise, shoppers are willing to quickly change their previous buying habits in favour of goods with higher utility. Food in general is traditionally considered to have inelastic demand, due to its importance in household consumption, while the extremely high supply on the food market forces consumers to choose in favour of a particular commodity. The question of the consumer's choice criteria is important: what criteria – economic, social and environmental – will play a role in assessing the utility of the goods chosen by the consumer?

Low-value goods are characterised by being relatively simple, often locally sourced goods that are needed to meet so-called basic needs – in the case of food, to provide nutrients to sustain life. The nature of such locally sourced goods is justified by their relatively low price, which protects against high competition. On the other hand, the very nature of the goods may also be the reason why unprocessed food is usually of local origin. It is quite plausible to assume that:

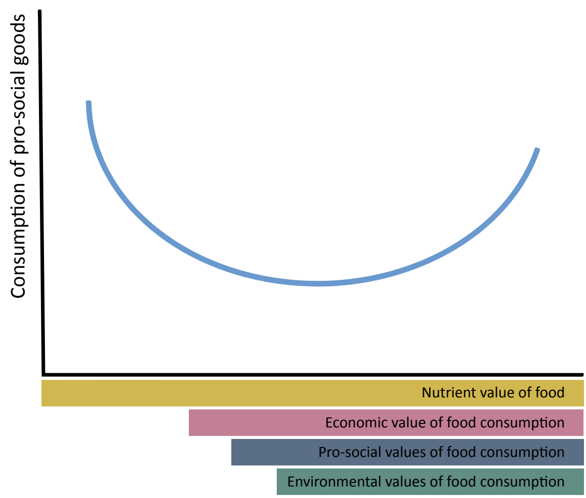
a) goods of local origin are fresher, as the transport journey is shorter;

b) the ingredients of products are typical of the local cuisine, accepted by the customer;

c) there is a higher level of confidence in the origin of the products, their production and extraction technologies;

d) there is an emotional connection to the national product, perceiving it as “one’s own” as opposed to something coming from “outside”.

A contradiction can be seen: although low-value goods are inelastic in demand, they may nevertheless contain a certain valuation that increases the utility of the goods, thus increasing their elasticity, and this may mean that products of domestic origin have a higher price than those imported from abroad. At least in Latvia, we value local products, which are often priced higher. It can be hypothesised that as societies evolve, they will consume more products with pro-social values, while maintaining their interest in relatively simple, unprocessed products of known origin.



Source: Naglis-Liepa et al. 2022

Figure 2.8 **Pro-social consumption and values**

Increasing the quality of food products, which also includes the way they are processed, inevitably increases the price, which is a key condition for the competitiveness of imported products. It significantly increases competition by offering a wide range of products of relatively high quality, and by offering a relatively large number of added values such as climate change mitigation, fair trade schemes, sustainability certificates. In this segment, local products often lose their importance, their elasticity decreases and consumers relatively easily choose products without attaching much importance to the origin of the product. At the same time, it is the most important part of the food market, providing the majority of the daily food basket. The "future survival" of local products and the decisions that consumers make to choose local products are important. In this context, we can also talk about different models of expectations and the possibility to compare their expectations with the actual offer after using the product. If it meets or exceeds the expectation, then the customer will return and buy the product again, but if the expectation is not met, then the purchaser will look for an alternative product.

2.3. Behaviour-influencing factors

The relevance of values changes as a result of different factors. The impact of income elasticities on the validity assessment has already been mentioned above. At the same time, neoclassical economics fails to respond to the actions of a large number of economic agents, which are determined by seemingly "illogical" decisions. One explanation would be to recognise that the consumer is not a logical decision-making machine. This is based on the recognition that human behaviour is determined by evolutionary factors. Humans are biological beings who primarily value the ability to pass on their genetic information through their children. One of the most popular ideas about the dominance of this function in human behaviour is Richard Dawkin's idea of the "selfish gene" – the motive for human action is determined by competition, natural selection and the replication of the most relevant genes for survival in followers. On the one hand, this view is in line with the classical economic postulates about the economic man, *Homo economicus*. On the other hand, it is rational behaviour to care more about children than for one's own personal existence. This apparently altruistic behaviour is in fact based on rational behaviour and is consistent with the goal of utility maximisation.

It would be logical to assume that people with children have different values of validity, judged more broadly. Children, as decision influencers, are not necessarily equally effective on parents or on the purchasing role. Interestingly, the age of the children matters, for example, one study shows statistically significant differences in organic fish consumption for families with children under five. Parents can be assumed to take special care of their children, trying to give them the best they can, depending on their understanding and abilities. At the same time, children are not just passive influencers of consumption decisions, as they start consuming different information channels at a relatively early age, which influences their role in the purchasing process. Children can have a significant influence on parents' choices. At the same time, factors other than the presence of a child should be taken into account, such as the demographic characteristics of the parents (family type, mother's employment status), socio-economic status, family communication characteristics, child demographics (age of children, number of children, gender), type of product.

Bounded rationality explains the purchase of goods as a cognitive-emotional process that does not ensure a rational choice of goods. Thus, maximising the benefits of food consumption requires a conscious analysis of the current situation and a deliberate implementation of predefined values, which is essentially a kind of utility maximisation function. On the one hand, it is essential to reduce the activity of system 1 (automatic, fast, without conscious control), in D. Kahneman's terminology, by promoting the activity of system 2, which is associated with greater cognitive effort and concentration. On the other hand, informed purchasing is only a tool that does not contain any evaluation or decision-making attributes. This is preceded, as in the value belief norm theory discussed above, by a choice of values, whether hedonic or altruistic. It is possible to use not only individual values, but also entire value systems, such as religions or secular philosophical systems.

Conscious consumption – the process of making an informed purchase decision, assessing and taking into account the wider ethical or environmental impacts of consuming a product.

There is a growing movement towards *conscious* consumption, which aims to increase consciousness in purchasing decisions, taking into account the health, environmental and social values of the consumer. Access to appropriate information is an essential condition for informed decision-making. Alongside other food-related aspects, knowledge about healthy, ethical and resource-intensive food consumption is becoming increasingly important.

Labels are the most important information media in the food context. The EU determines the content and amount of information that must appear on the packaging of goods. Most food producers, however, do not limit themselves to this information, recognising that it is an important means of communicating with consumers. Social media communication with the public is the norm today, with bloggers and vloggers posting daily about products, their origins, the production process, what is safe and what is not. The public consumes this information without always critically evaluating opinions, facts and distinguishing between truth and fiction. In some cases, however, consumers choose not to be aware of information that implies the negative effects of eating their preferred foods (calorie count in sweets, carcinogens, etc.). However, there is no denying that the availability of information has an impact on the ability of consumers to improve their wellbeing, although in some cases consumers lack the will, the ability, the time to analyse the information they receive, for example on the effects of specific chemical food additives.

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3. RESOURCE TAXONOMY AND USE IN THE BIOECONOMY

Author: Arnis Lēnerts

The inevitable global paradigm shift in resource use has led to a situation where each country needs to be aware of the types of resources available in its territory, and how to use them most efficiently. Socio-economic differences between countries have existed in the past and continue to exist today. However, it is necessary for each country to develop its economy by assessing the resources at its disposal and to find ways of using these resources that are economically sound and improve the quality of life of its citizens. Economic development in Latvia will be boosted by a shift in the economic model from fossil to renewable resources, as Latvia has a comparative advantage in using the natural renewable resources available on its territory for priority economic growth in the bioeconomy sectors. Successful development of the bioeconomy sectors requires a clear identification and inventory of the resources available and deployable in these sectors.

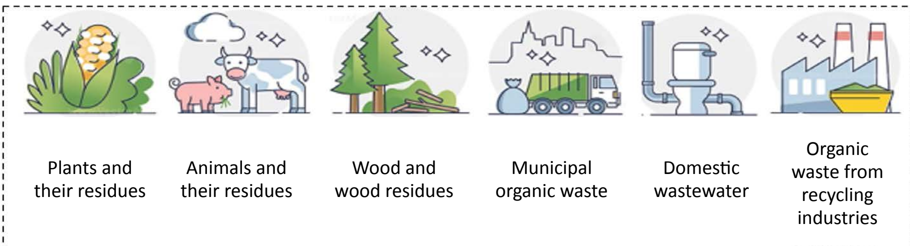
Resource use in the bioeconomy involves the use of nature's renewable biological resources (soil, plants, animals, micro-organisms such as microalgae) and biological processes (biotechnology, biochemistry, bioengineering) to produce goods and services in different sectors of the economy, while addressing the challenges of climate change, food security, energy sovereignty and environmental protection.

There are different ways to classify and categorise the resources and biological processes used in the bioeconomy sectors. The most common approach to identifying and classifying the resources available in a country is to use a resource taxonomy. A resource taxonomy is a system that classifies and groups resources according to their origin, type, qualitative characteristics (e.g. oil and starch content or mechanical strength), sustainability (impact of the production process on the natural environment) and the bio-processing used.

Using this taxonomic approach, biological resources and biological processes are grouped into four categories.

Biomass

Biomass is a biodegradable material (bioresource) in products, wastes and residues from agriculture, forestry and related industries (including material of plant and animal origin) and a bio-transformable fraction of industrial and municipal waste (Kalniņš, 2005). Biomass is biological material (bioresources) that can be used as feedstock by the bioeconomy's processing sector. Biomass includes: plants, animals, algae, micro-organisms, animal waste, biological waste, agricultural and logging residues. The types of biomass are summarised in Figure 3.1.



Source: author's construction based on www.vectormine.com

Figure 3.1 **Types of biomass**

Biomass processing technologies

Biomass conversion technologies are physical, chemical, biological or thermochemical processes that can convert biomass into intermediate or final products. Biomass processing uses fermentation, hydrolysis, gasification, pyrolysis, extraction and biocatalysis.

Intermediate products

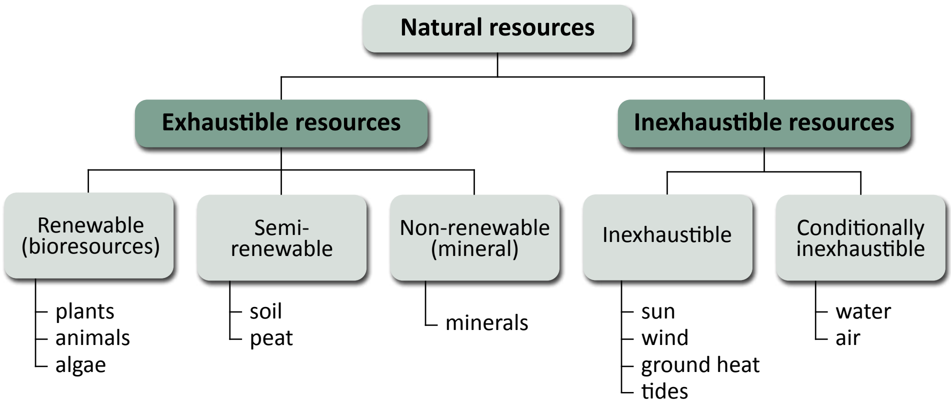
Intermediate products are biomass products, substances obtained by converting biomass that can be further processed into final products. These intermediates include sugars, starches, oils, fats, proteins, lignin, cellulose, hemicellulose, biogas, synthesis gas, bio-oil and biochar.

Final products

Final products are goods and services derived from intermediate products that can be used for final consumption purposes. Final products include food, animal feed, biofuels, bioplastics, biocomposites, biopolymers, biochemicals, biopharmaceuticals and other bio-based products. They are grouped according to the economic activity of the sector producing the final products, using the NACE 2 code classification (NACE classification).

3.1. Biomass

Natural resources are crucial for biomass production. Latvia's location is ideal for biomass production, as all the conditions are in place for photosynthesis to take place, which is the basis for biomass regeneration and growth. In fact, it can be argued that the process of biomass formation directly and indirectly makes life on planet Earth possible. During photosynthesis, carbon dioxide (CO_2) in the atmosphere is absorbed as biomass is formed and micro-organisms carry out chemical synthesis using water in the green leaves of the plant; the absorbed solar energy is converted into chemical energy, sequestering atmospheric carbon (C) in the plant biomass while releasing oxygen (O_2) into the atmosphere. The direct product of life support is oxygen, and the indirect product is stored energy in the form of biomass. Practical studies (Radmer, Kok, 1977) have shown that the efficiency of the photosynthetic process can be as high as 12% in individual plants, indicating a potential that has not been exploited so far. Access to a usable natural resource – land – is critical to the photosynthesis process. The land must provide favourable growing conditions for plants. The overall classification of natural resources by type (exhaustible, non-exhaustible) is shown in Figure 3.2.



Source: author's own

Figure 3.2 **Classification of natural resources**

The classification of land as a natural resource depends on the type of land use. The classification of land by use is linked to the primary sector, which uses land resources to produce primary products. Forestry and agriculture are the main primary product (bioresource) producing sectors in Latvia that use land as a natural resource. Fishing uses the water resources of Latvia's lakes, rivers and ponds, as well as open sea water resources, to produce products. Aquaculture, where production takes place in closed water bodies, is a separate subsector of fisheries.

The land use classification is determined in accordance with the laws and regulations adopted in Latvia. By aggregating the data of the State Land Service (VZD) and grouping them by type of land use, significant changes in the quantitative indicators of different land use groups can be observed. For the sake of clarity, and in order to illustrate the dynamic nature of changes in quantitative indicators, the data are aggregated from 1935 onwards and presented in Table 3.1.

Table 3.1

Land use in Latvia, 1935-2022, thsd. ha

Year	**Land area,** thsd. ha	**Forest land**		**Agricultural land**		**Other land** thsd. ha
		thsd. ha	% of area	thsd. ha	% of area	
1935	6579,0	1742,0	26,5	3679,0	55,9	1158,0
1950	6457,3	1964,1	30,4	3352,3	51,9	1140,9
1970	6458,9	2561,7	39,7	2907,8	45,0	989,4
1990	6458,9	2803,2	*43,4*	2567,0	39,7	1088,7
2010	6458,9	2955,0	45,8	2430,0	37,6	1074,0
2015	6448,6	3347,4	51,8	2350,8	36,4	760,7
2022	6448,7	3439,2	53,3	2271,7	35,2	737,8
Change in base, %	-1,9	+92,2	+25,3	-36,1	- 19,5	-47,8

Source: compiled by the author, based on VZD and CSP, 2023

The analysis of the data shows an increasing trend in forest area and a projected increase in biomass produced by the forestry sector. This is due, on the one hand, to the problems in the agricultural sector (changing land ownership, fragmentation of farms, unfavourable market conditions) and, on the other, to the rapid development of the forestry sector. The growing demand for forestry bioresources for energy production in Latvia and worldwide, as well as climate change mitigation policies, play an important role. The area of agricultural land continues to decrease over the period analysed, and according to statistical data, in 2022 only 1 970.4 thousand ha were used for agricultural production. Less than 14% of the available land resource is not used for agriculture because it is overgrown or uncultivated. This situation is not conducive to competition, as it could be the basis for the problem of inefficient land use in Latvia. Land policy scenarios foresee a growing demand for agricultural land in the coming decades, driven by an increasing demand for food (Land policies..., 2008).

In order to keep accurate records of the products produced in the primary forestry sector, annual statistics on changes in the area of tree species growing on forest land are compiled in accordance with the legislation in force in Latvia (Table 3.2). Information is collected on the quantity, quality and sustainability of the woody biomass produced, as well as other indicators of forestry performance.

Table 3.2

Forest area by dominant tree species in Latvia, 2010-2022, thsd. ha

Year	**Area of tree species,** thsd. ha								
	Pine	Spruce	Birch	Black alder	Grey alder	Aspen	Oak	Ash	Other tree species
2010	895,9	556,5	888,2	162,6	316,0	248,4	21,3	25,3	64,2
2011	888,4	564,9	882,8	165,3	311,0	255,5	20,9	23,2	64,7
2012	883,3	562,2	891,9	170,4	310,4	251,1	20,0	22,4	64,6
2013	874,7	570,3	*893,0*	175,3	309,0	257,5	20,6	20,4	63,0
2014	869,8	571,6	895,7	180,5	313,1	257,0	20,2	17,6	63,4
2015	865,3	577,1	893,1	182,9	315,0	262,1	20,6	18,5	63,6
2016	863,5	581,9	885,0	184,6	319,8	267,6	19,9	17,7	65,9
2017	860,3	592,8	887,8	187,3	329,9	266,1	21,1	16,8	63,6
2018	857,0	597,3	887,6	191,6	328,8	267,5	21,8	16,8	62,1
2019	850,5	605,7	888,4	193,1	330,4	266,4	22,8	15,3	60,7
2020	844,3	617,4	886,4	197,0	332,5	262,9	23,1	13,2	64,4
2021	841,4	623,3	889,5	202,1	325,5	257,8	24,5	11,3	64,4
2022	838,2	628,7	881,3	205,9	323,3	262,8	22,8	9,6	65,6
Change, %	-6,44	+12,97	-0,78	+26,63	+2,31	+5,80	+7,04	-62,06	+2,18

Source: compiled by the author, based on CSP, 2023

Following changes in the demand for forest biomass, Latvia is witnessing a change in the structure of tree species cover. The largest increase over the period analysed is in black alder plantations (+26.63%), due to the shorter production cycle of this tree species. The biggest decrease was observed in ash (-62.06%). Given the long cycle of woody biomass production (in some cases more than 100 years), it is difficult to predict future forest biomass demand. The choice of land use for the cultivation of specific species should take into account the qualitative value accumulated in the woody biomass, with possible future uses. The main biomass quality criteria for the extraction of biochemical intermediates are summarised in Table 3.3.

Table 3.3

Qualitative criteria for the classification of biomass resources

Type of biomass	Primary sector	Chemical composition of biomass (chemical formula)
Plants Animals Micro-organisms	Forestry Agriculture Fisheries Aquaculture Algae and micro-organisms Bio-waste	Sugars (glucose, $C_6H_{12}O_6$) Starch $(C_6H_{10}O_5)n$ Cellulose $(C_6H_{10}O_5)n$ Hemicelluloses (xylose, $C_5H_{10}O_5$) Lignin (coumaryl alcohol, $C_9H_{10}O_2$; coniferyl alcohol, $C_{10}H_{12}O_3$; sinapyl alcohol, $C_{11}H_{14}O_4$) Oils (triglycerides, oleic acid, $C_{18}H_{34}O_2$) Proteins (amino acids, alanine, $C_3H_7NO_2$)

Source: compiled by the author, based on Zorb, Lewandowski, 2018

Biomass extraction in agriculture is grouped according to the length of the plant biomass production cycle. A statistical distinction is made between permanent plantations, which include perennials, grasslands and pastures, and arable land, where plant seeds for biomass are reintroduced each year. Permanent crops and arable crops are sources of plant biomass of agricultural origin, while grassland is mainly used as a forage base for animal biomass.

Table 3.4 summarises the changes in quantitative indicators of agricultural land use in Latvia from 1990 to 2022 by type of use.

Table 3.4

Types of agricultural land use in Latvia, 1990-2022, thsd. ha

Year	LIZ thsd. ha	Utilised AL		Cropland		Permanent crops		Meadows, pastures		Unutilised AL	
		thsd. ha	%	thsd. ha	%	thsd. ha	%	thsd. ha	%	thsd. ha	%
1990	2567,0	2534,0	98,7	1656,0	65,4	35,9	1,4	847,7	33,5	33	1,3
1995	2501,3	1832,1	73,2	1002,3	54,7	19,3	1,1	800,5	43,6	669,2	26,8
2000	2484,9	1587,2	63,9	969,9	61,1	11,5	0,5	605,7	38,2	897,7	36,1
2005	2474,4	1733,7	*70,0*	1091,8	62,9	12,8	0,7	628,9	36,2	740,7	30,0
2010	2430,0	1815,5	74,7	1173,4	64,6	6,8	0,4	625,2	34,4	614,5	25,3
2015	2350,8	1884,8	80,2	1229,8	65,2	6,7	0,3	648,3	34,4	466,0	19,8
2022	2271,7	1970,4	86,7	1356,7	68,9	10,3	0,5	603,4	30,6	301,3	13,3
Change in base, %	-1.5	-22.2	-	-18	-	-71.3	-	-28.8	-	+913	-

Source: compiled by the author, based on CSP, 2023

A series analysis of the overall dynamics of the indicators points to a decline in agricultural land use, with negative base growth in all indicators related to use. However, an analysis of the growth rate of the chain of indicators of utilised AL shows an increase in the area of land used for agriculture since 2005. There has been an increase in the use of arable land, meadows and pastures, but the use of agricultural land for permanent crops continues to decline. As a result of these changes, there has been a decrease in the area of unutilised agricultural land, but still 301 thousand ha of AL were unutilised in 2022. Objective factors have contributed to the improvement in the quantitative indicators of AL use:

- since 13 July 2010, the Cabinet of Ministers of the Republic of Latvia Regulation No. 635 “Procedures for Surveying and Determining the Area of Non-Cultivated Agricultural Land and Providing Information Thereof” (Procedures for..., 2010) has been in force.

They require the Rural Support Service (LAD) to survey and record the use of agricultural land. As a result of the survey carried out by the LAD, municipalities can apply a higher rate of real estate tax to the owner of non-cultivated agricultural land.

- As of 10 March 2015, changes have been introduced to the Cabinet of Ministers of the Republic of Latvia Regulation No. 126 "Procedures for Granting Direct Payments to Farmers" in granting payments to owners of agricultural land from the European Agricultural Guarantee Fund (EAGF). There are restrictions on the single area payment (SAP) for agricultural land where production-related land use conditions are not met (Procedures for Granting..., 2015).

The quantitative, qualitative and sustainability indicators of the biomass produced from agriculture are determined by the type of arable crops sown. Statistical information on the main types of arable crops sown is summarised in Table 3.5.

Table 3.5

Area of major arable crops in Latvia 1990–2022, thsd. ha

Year	Utilised AL		Total area sown		Cereals		Rapeseed		Potatoes		Vegetables	Flax
	thsd. ha	Δ chain	thsd. ha	%	thsd. ha	%	thsd. ha	%	thsd. ha	%	thsd. ha	%
1990	2534,0	0	1627,0	64,2	675,4	26,7	1,9	0	80,3	3,2	10,8	11,9
1995	1832,1	-27.7	930,2	50,8	408,4	22,3	1,1	0,1	75,3	4,1	17,5	1,4
2000	1587,2	-13.4	881,1	55,5	420,0	26,5	6,9	0,4	51,3	3,2	9,7	1,9
2005	1733,7	*+9.2*	999,6	57,7	468,9	26,5	71,4	4,1	45,1	2,6	12,9	2,4
2010	1815,5	+4.7	1102,7	60,7	541,5	29,8	110,6	6,1	30,1	1,7	8,1	1,1
2015	1884,8	+3.8	1168,8	62,0	672,4	35,7	89,0	4,7	24,8	1,3	8,1	0,2
2022	1970,4	+4,5	1302,4	66,1	780,1	39,6	160,3	8,1	14,9	0,8	6,5	0,2
Change in base, %	-22.2	-	-19.9	-	+15,5	-	+8336	-	-81.4	-	-40	-98

Source: compiled by the author, based on CSP, 2023

There has been a structural change in the use of AL between 1990 and 2022: (1) in 2022, cereals accounted for 39.6% of the total utilised agricultural area. Although cereal area in 2022 has reached the 1990 levels, its share in the total cropped area has increased by 15%; (2) a major structural change is the increase in rapeseed area. Rape and flax sown are counted as industrial crops in the statistics, as the output is not used for food.

All the main crop groups have shown an increase in productivity over the period analysed. The biggest increase in productivity is in cereal production, which is the basis for the increase in total yield or total biomass. Latvia's total cereal yield in 2022 was up 102% compared to 1990, and the increase was achieved by raising yields. Cereals in 1990 and 2022 were grown on similar areas, but the yield growth was 75%.

The analysis was carried out using the average crop yields and total yields compiled by the CSP and the results are summarised in Table 3.6.

Table 3.6

Changes in the main crop indicators in Latvia 1990–2022

Crops/year area	1990	1995	2000	2005	2010	2015	2022	Δ Change in base,%
Cereals: thsd. ha	675,4	408,4	420,0	468,9	541,5	672,4	780,1	+15
-total yield, thsd. t.	1599	689	924	1314	1435	3022	3 243,7	+102
-Δ chain, %	0	-57	+34	+42	+9	+110	+7	-
-yield, t/ha^{-1}	2,37	1,69	2,20	2,80	2,65	4,49	4,16	+75
-Δ chain, %	0	-28	+30	+27	-5	+69	-7	-
Rapeseed: thsd. ha	1,9	1,1	6,9	71,4	110,6	89,0	160,3	+8336
-total yield, thsd. t.	3,8	0,9	10	145,7	226,3	292,7	354,9	+9239
-Δ chain, %	0	-76	+1011	+1357	+55	+29	+21	-
-yield, t/ha^{-1}	1,95	0,81	1,46	2,04	2,05	3,29	2,21	+13
-Δ chain, %	0	-58	+80	+39	+0.5	+60	-33	-
Potatoes: thsd. ha	80,3	75,3	51,3	45,1	30,1	24,8	14,9	-81
-total yield, thsd. t.	1016	864	747	658	484	497	246,7	-76
-Δ chain, %	0	-15	-13	-12	-26	+2	-50	-
-yield, t/ha^{-1}	12,7	11,5	14,6	14,6	16,1	20,1	16,6	+31
-Δ chain, %	0	-9	+26	0	+10	+24	-17	-
Vegetables: thsd. ha	10,8	17,5	9,7	12,9	8,1	8,1	6,5	-40
-total yield, thsd. t.	169	224	106	172	151	195	102,4	+15
-Δ chain, %	0	+32	-52	+62	-12	+29	-47	-
-yield, t/ha^{-1}	14,2	12,2	10,0	12,3	17,2	22,5	15,7	+11
-Δ chain, %	0	-15	-18	+23	+39	+30	-30	-
Maize: thsd. ha	44,8	0,6	1,2	2,9	7,1	25,5	22,5	-50
-total yield, thsd. t.	967,3	13	24,1	58	209	730,2	672,6	-30
-Δ chain, %	0	-98	+85	+140	+260	+249	-8	-
-yield, t/ha^{-1}	21,6	21,9	19,7	19,9	19,6	28,6	29,9	+38
-Δ chain, %	0	+1	-10	+1	-1	+45	+5	-

Source: compiled by the author, based on CSP, 2023

The EU's Common Agricultural Policy (CAP) support measures, aimed at implementing the Europe 2020 initiative "A Resource Efficient Europe", have boosted rapeseed cultivation. Rape sowings account for 5-6% of the total area, and is the second most sown crop. Maize area and yields are also increasing, but the historic peak of 1990 production has not yet been reached. The increase in quantitative indicators points to an intensification of crop production.

The quantitative and qualitative indicators of animal biomass are statistically recorded on the basis of animal species (determines the specialisation of the holding and is the quantitative indicator) and breed (which determines the qualitative indicators of biomass).

Table 3.7 summarises the changes in the main production indicators of the livestock sector over the period analysed.

Table 3.7

Changes in the main livestock farming indicators in Latvia, 1990–2022

Year Specialisation	1990	1995	2000	2005	2010	2015	2022	Δ change in base, %
Dairy farming: -number of animals, thsd.	535	292	204	185	164	162	127,8	-69
-Δ chain %	0	-45	-30	-9	-11	-1	-21	-
milk produced, thsd. t.	1893,2	947,7	825,0	810,3	834,5	978,1	973,8	-48
-Δ chain %	0	-50	-13	-2	+3	+17	-1	-
-milk yield, kg cow^{-1}	3437	3074	3898	4364	4998	5905	7 492	+71
-Δ chain %	0	-10	+26	+12	+14	+18	+27	-
Pig farming: -number of animals, thsd.	1401	553	393	428	390	334	307,9	-76
-Δ chain %	0	-60	-28	+9	-9	-14	-8	-
-pork, carcass weight, thsd. t.	138,2	62,6	31,5	38,5	37,2	35,9	38,7	-74
-Δ chain %	0	-54	-50	+22	-3	-3	+8	-
Cattle for meat: -number of animals, thsd.	904	245	163	202	215	257	725,5	-71
-Δ chain %	0	-72	-33	+24	+6	+19	+182	-
-meat, carcass weight, thsd. t.	125,1	48	22,3	20,4	18,4	18,8	15,9	-84
-Δ chain %	0	-61	-53	-8	-9	+2	-15	-
Poultry farming: -eggs, mn	818,9	421,0	437,1	545,7	714,9	698,2	872,2	-15
-Δ chain %	0	-49	+4	+26	+31	-3	+25	-
-meat, thsd. t.	40,3	10,8	7,2	17,2	23,5	29,7	38,4	-26
-Δ chain %	0	-73	-33	+138	+36	+26		-

Source: compiled by the author, based on CSP, 2023

In the main livestock specialisation areas, there have been significant changes in production figures over the period analysed. The results of the time series chain of production indicators and the changes in the base show that dairy farming in Latvia has entered a period of growth after a significant decline in production until 2000 (-56% of milk collected). The growth of the dairy sector has been driven by a significant increase in productivity, with milk yield per cow per year increasing by 71% over the period analysed.

In Latvia, significantly less biomass is produced using water resources. Countries in the Baltic Sea region have significantly reduced their catches in the sea. This is due to the rapid decline of fish populations. By tackling environmental pollution in the Baltic Sea and reducing catches, the development of the fisheries sector is gradually being boosted by using inland water resources. Table 3.8 summarises the total biomass produced by fisheries in external and inland waters and aquaculture.

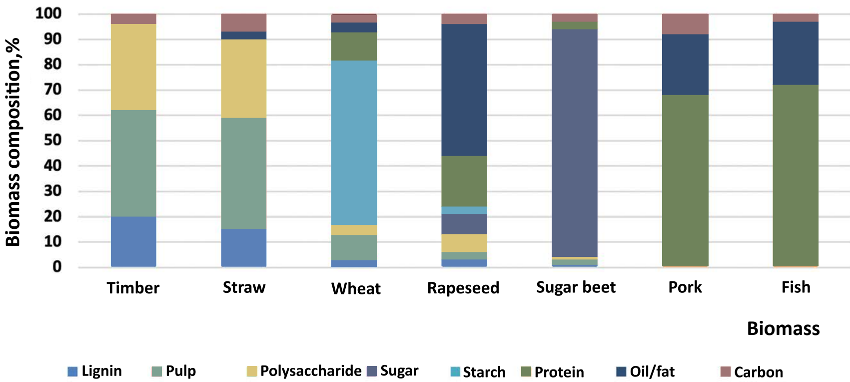
Table 3.8

Fish catches and production of other marine products by catch area in Latvia, 2010–2022, (thsd. tonnes)

Year	Production of fish and other marine products, thsd. tonnes			
	Inland waters	Atlantic	Baltic Sea and Gulf of Riga	Aquaculture
2010	0,90	164,5	74,0	0,55
2011	0,90	155,0	63,2	0,55
2012	0,90	89,5	57,6	0,57
2013	1,00	115,8	61,0	0,64
2014	1,00	119,4	59,9	0,69
2015	1,10	81,2	62,5	0,74
2016	1,00	113,2	60,4	0,73
2017	1,10	117,9	67,4	0,81
2018	1,20	135,2	70,4	0,83
2019	0,90	110,6	69,7	0,63
2020	1,00	103,3	60,8	0,73
2021	1,10	98,0	58,8	0,90
2022	1,10	102,2	61,1	0,87
Change in base, %	+22,22	-37,87	-17,43	+58,38

Source: compiled by the author, based on CSP, 2023

The efficient use of bioresources and the implementation of circular economy principles in the primary forestry, agriculture and fisheries sectors of the bioeconomy will be ensured by the production of suitable biomass. Science-based biomass production will help reduce resource consumption and pollution, increase resource productivity and reuse, and contribute to sustainable growth and competitiveness. The results of the scientific and practical studies on the chemical composition of the dry matter content of biomass from different origins are summarised in Figure 3.3. Chemical composition is used to group biomass resources to produce intermediate or final products with similar composition.



Source: compiled by the author, based on Zorb, Lewandowski, 2018

Figure 3.3 **Components of the chemical composition of the different types of biomass, % of dry matter**

When deciding on the production and further use of biomass, it is essential to understand that it should be used as a priority for food security. To avoid ethical problems, the bioeconomy's recycling sectors primarily use by-products or waste from agriculture, forestry and fisheries. From this perspective, biomass can be divided into food and non-food biomass.

The EU has adopted a number of strategies and legislation to promote resource efficiency and the circular economy in the context of the bioeconomy. For example, the EU has set targets for waste prevention, reuse, recycling and disposal for different waste streams (Resource efficiency and circular economy).

The ability of secondary bioresource processing industries to convert the biomass produced into products in line with market demand is essential for the development of the bioeconomy's primary sectors. The next chapter looks at how biomass can be transformed into new food and non-food products.

3.2. Biomass processing technologies

Looking back in history, it can be assumed that biotechnology is one of the oldest branches of science in human history. As we know, food needs to be produced and stored to be available all year round. This means that as early as 10 000 years ago, people began to select the most useful, productive plants and find ways to process them for long-term storage. It can be concluded that there are 2 stages in biomass processing where biotechnologies are applied, which have not changed over the centuries but have been preserved and developed. First, plants and animals are developed and bred, then cultivation technologies are improved, and next, ways are found to process these plants into the products we need to consume and use them when we need them.

Biotechnology is the improvement of the genetic characteristics of plants and animals and of breeding technologies with the aim of changing the quantitative and qualitative characteristics of biomass for use in final products or processable intermediates. Based on this definition of biotechnology, biotechnology industries can be grouped.

The colour principle is used to group biotechnologies according to their origin (primary industry), the processing technology used and the final products produced. All biotechnologies are divided into eight colour technology groups.

The breakdown of biomass processing technology groups is summarised and described in Table 3.9.

Table 3.9

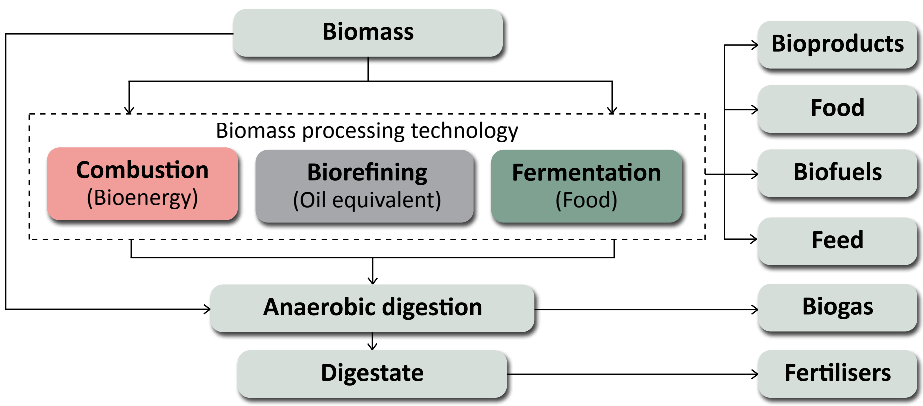
Classification and characteristics of biotechnology colour groups

Designation	Title	Description
	Green biotechnology	Improving the genetic properties of plants used in agriculture and forestry through genetic engineering. Improving cultivation technologies through the development of plant protection products (pesticides, herbicides, insecticides) and growth regulators (fungicides).
	Blue biotechnology	Improving the genetic properties of plants and living organisms used in water and aquaculture through genetic engineering. Improving cultivation technologies through the development of plant protection products and growth regulators.
	Red biotechnology	Using biomass processing to produce medical and veterinary products and medicines (vaccines, antibiotics, food supplements, molecular diagnostics, etc.). Application of genetic engineering technologies to the genetic modification of organisms.
	White biotechnology	Improving the technologies used in biomass processing, with the aim of producing products with less energy consumption and less pollution of the natural environment.
	Yellow biotechnology	Using fermentation technologies in food production, such as cheese, beer and wine production.
	Grey biotechnology	Using micro-organisms to improve and preserve the ecosystem of the natural environment by preventing pollution, e.g. removal of heavy metals in wastewater.
	Gold biotechnology	Using information communication technologies (ICT) for data analysis and process monitoring, control, production and processing of biomass.

Source: compiled by the author, based on Barcelos et al., 2018

In the early stages of civilisation, biomass was mainly used for food and heat energy. The technologies used were relatively simple and subjected the biomass to **biochemical conversion** (fermentation) **or thermochemical** conversion (combustion). In the search for alternatives to fossil fuels, biorefining technology was developed as a result of scientific and practical research. **Biorefining** is a process, which integrates different forms of biomass processing using compatible technological solutions that enable the sequential production of biochemical intermediates, biofuels and bioenergy using biomass. Basically the concept of biorefining is analogous to oil refining technology, the main difference being the use of a renewable feedstock – biomass – in the refining process.

The biomass processing technology, flows and product groups are summarised in Figure 3.4.



Source: compiled by the author

Figure 3.4 **Biomass processing technology, flows and groups of products produced**

Biorefining (bioprocessing) is divided according to technological process into:

- single-phase bioprocessing – this process uses milling of the dry feedstock (grain) to produce ethanol or vegetable oil, with the additional production of some by-products (animal feed, etc.). This type of bioresource processing technology does not meet the definition of biorefining, as it is not technologically feasible to produce a full range of bio-based products;

- two-phase bioprocessing – this process uses "wet" milling technologies for different cereals and can use feedstock depending on the demand for the final product. This technology can produce starch, vegetable fructose syrup, methanol, corn oil and corn gluten feed and flour;
- three-phase bioprocessing – this process uses any type of biomass from agriculture, forestry or fisheries. The processing process can produce a wide range of fuel, chemical and polymer products (Biopol, 2009).

The most commercially successful biomass biorefining technologies that have been developed involve the conversion of biomass into fuels.

The conversion methods are:

- first-generation fuels – biofuels made from cultivated agricultural crops. Examples include bioethanol, which is mainly produced by fermentation from plants with a high sugar or starch content (cereals, sugar cane, sugar beet), and biodiesel, which is produced from vegetable oils (or used cooking oils, including animal fats) by the process of fatty acid transesterification;
- second-generation fuels – biofuels made from wood and organic waste, usually involving the conversion of biomass into liquid fuels. Examples include BTL (biomass-to-liquid), GTL (gas-to-liquid) and CTL (coal-to-liquid) fuels, Fischer-Tropsch biodiesel, lignocellulosic bioethanol, biomethyl ether.

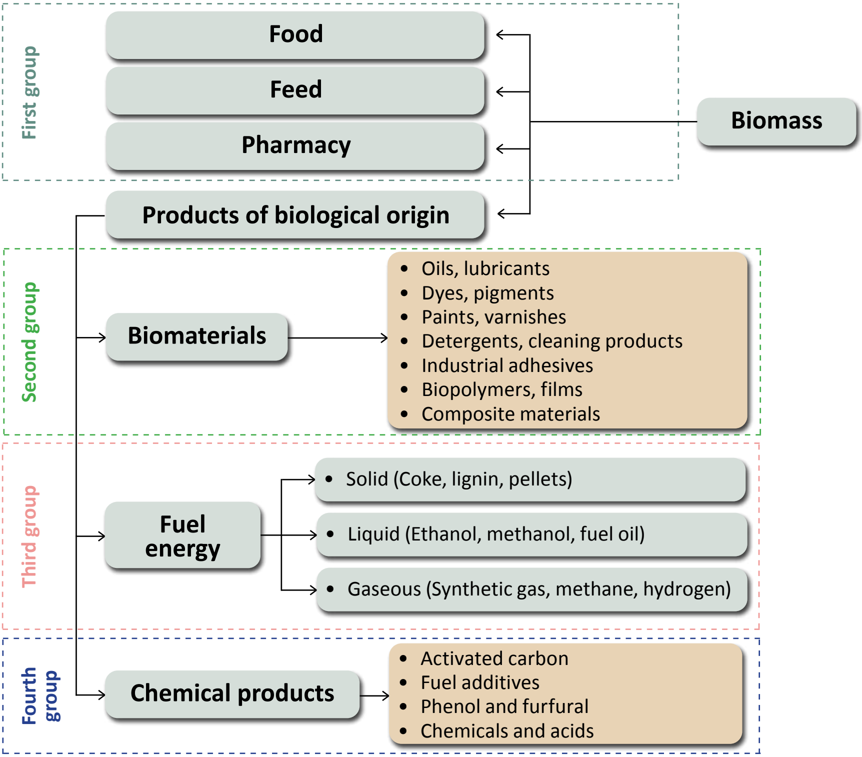
Latvia has started the accession procedure to the **International Energy Agency** (IEA) in 2022. A common **biotechnology classification system** is desirable to ensure interoperability. Depending on the type of biomass used, the technology applied and the final product obtained, the IEA offers its own classification of biomass processing. The classification system is based on:

- the technology used;
- final products produced;
- biomass used;
- biomass conversion process.

According to the classification proposed by the IEA, the biomass processing technology used is called a **processing platform** (Jong et al., 2022), and the classification is based on the qualitative characteristics of the biomass used (Table 3.3) and the product obtained. The main biotechnology platforms are:

- biogas production from anaerobic digestion;
- extraction of synthesis gas by gasification;
- extraction of hydrogen by electrolytic fermentation or steam reforming;
- extraction of glucose, fructose or galactose by fermentation;
- lignin extraction from cellulosic biomass;
- extraction of pyrolysis oil;
- extraction of vegetable and algae oil;
- extraction of heat and electricity.

The **products** from the biomass processing platform are divided into 4 groups (Figure 3.5). The first group includes products used in food, animal feed and pharmaceuticals. The second group consists of different types of biomaterials. The third group of products is used for energy transfer, typically transport fuels, electricity and heat. The fourth group includes chemical products.



Source: compiled by the author, based on Kamm, Kamm, 2004

Figure 3.5 **Classification of bio-based products**

Biomass used in a biotechnology platform is classified according to its origin. The main sources of biomass are agriculture, forestry, fisheries and bio-waste from recycling industries and households.

Depending on the quality of the biomass and the biotechnology platform used, the **processing process results** in the products obtained. The different technologies used in practice can be divided into 4 broad groups depending on the biomass conversion process:

- **biochemical conversion** includes fermentation, anaerobic digestion and composting, where micro-organisms and enzymes are used in the processing;

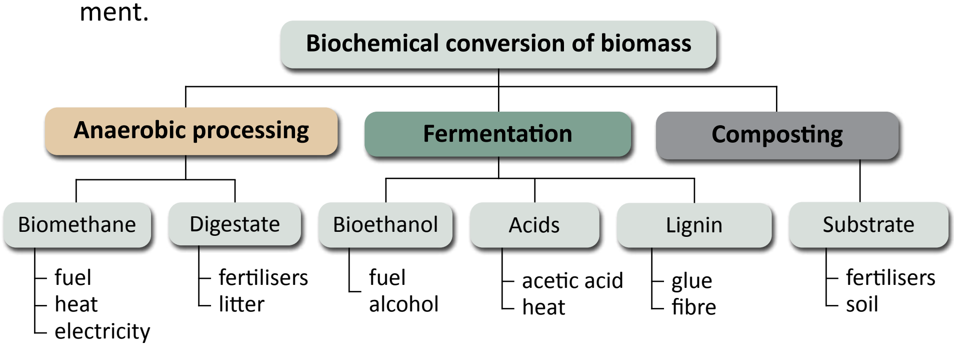
- **thermochemical conversion** involves combustion, gasification, pyrolysis or hydrothermal conversion, where the biomass is exposed to elevated pressure and temperature during the process;
- **mechanical conversion** includes extraction, fibre separation, pressing, mechanical fractionation, distillation and osmosis, which do not change the chemical composition of the biomass during the process, but break down the biomass components into separate defined feedstocks;
- **chemical conversion** includes hydrolysis, transesterification, hydrogenation and oxidation, during which chemical changes occur in the biomass.

3.3. Biomass conversion technology products

Biomass processing results in intermediate or final products obtained by **biochemical, thermochemical, mechanical or chemical conversion** of biomass.

- **Products of biomass biochemical conversion technologies** (Figure 3.6).

Biomass biochemical conversion technology is a biological process in which biodegradable biomass is broken down by micro-organisms, enzymes or bacteria into gaseous or liquid fuels in an oxygen-free environment.



Source: compiled by the author, based on Chen, Wang, 2016

Figure 3.6 **Classification of biomass biochemical conversion technologies**

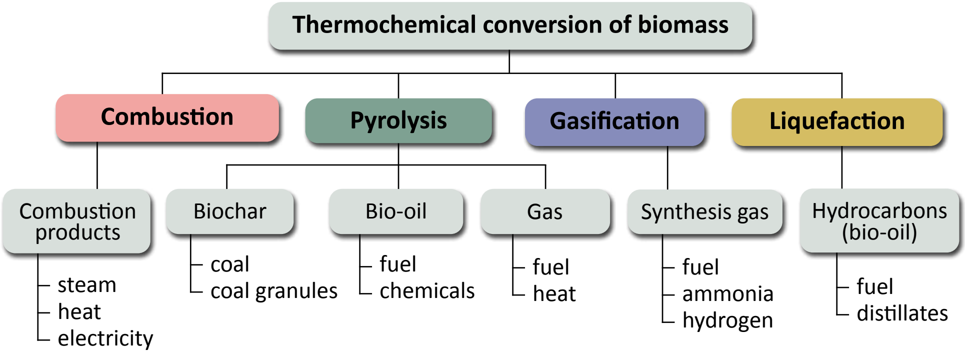
Fermentation is a technology that uses micro-organisms in an oxygen-free environment to convert biodegradable biomass through exposure to low temperatures. Biodegradable biomass of agricultural origin and various types of bio-waste are the most suitable for these conversion technologies. Depending on the qualitative characteristics (sugar, starch, cellulose) of the biomass to be degraded, biochemical conversion technologies can be built on a sugar, starch or cellulose platform.

Anaerobic conversion is a technology that uses bacteria in an oxygen-free environment to convert biodegradable biomass. The conversion produces biogas (methane) and digestate (fertilisers). Biomethane is stored in sealed tanks as biomethane gas. It is used as a fuel for heat production or to power transport. Cogeneration produces electricity and heat. Biodegradable biomass of agricultural origin and various types of bio-waste (manure) containing sufficient carbohydrate, protein and fat quality indicators are the most suitable for these conversion technologies.

Composting technology is a biological process of biomass conversion – the result of activity of micro-organisms; micro-organisms need carbon, nitrogen, oxygen, water (moisture) and nutrients to work successfully. Anaerobic micro-organisms produce methane and carbon dioxide. All types of biodegradable biomass of agricultural origin and various types of bio-waste are suitable for these conversion technologies (Chen, Wang, 2016).

- **Products of biomass thermochemical conversion technologies**

During the thermochemical conversion of biomass, the chemical bonds that make up the biomass structure are broken under elevated temperature and pressure to release the energy that was stored in the biomass during photosynthesis (Jha et al., 2022). The simplest process for the thermochemical creation of biomass is combustion, during which energy is released directly. More complex thermochemical conversion processes include pyrolysis, gasification and liquefaction, which are used to extract further usable intermediate and end products from biomass. The technologies and products of thermochemical conversion of biomass are summarised in Figure 3.7.



Source: compiled by the author, based on Jha et al, 2022

Figure 3.7 **Classification of biomass thermochemical conversion technologies**

The technological biomass **combustion** process is achieved by the use of incinerators, steam turbines or generators of various designs to convert the chemical energy in biomass into heat, mechanical energy or electricity. The technological combustion process produces combustion gases with temperatures up to 1 000 °C. Any type of biomass with a moisture content not exceeding 50% may be used for combustion.

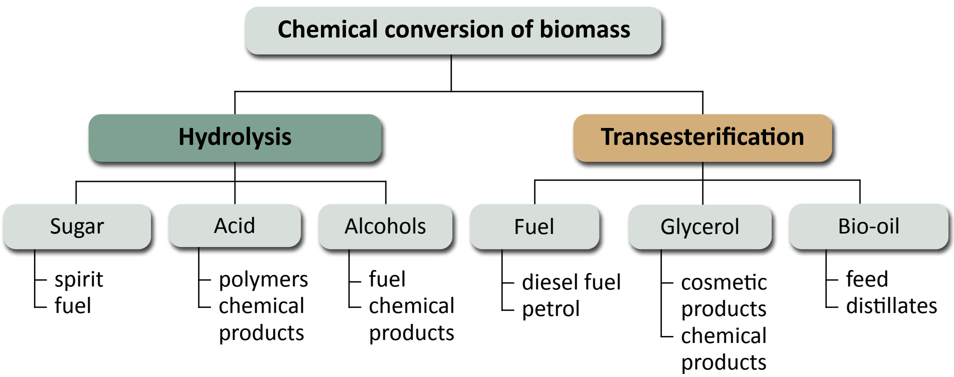
Pyrolysis is a biomass conversion process in which biomass is heated at 500 °C without air supply. Pyrolysis can produce a solid, such as biochar, a liquid, such as bio-oil, or a gaseous substance, synthesis gas, from biomass. Bio-oil, an intermediate product of pyrolysis, is widely used in various sectors of the economy. Bio-oil can be used as a feedstock for the production of various chemicals, including in the food industry. Bio-oil has a wide range of applications in the production of various fuels and its energy is used to generate heat and electricity.

Gasification is a technological biomass conversion process that converts solid biomass into gaseous products by partial oxidation of the biomass at temperatures between 700 and 1 500 °C. The main product of the technological gasification process is synthesis gas, which is used as a fuel.

Liquefaction is a technological biomass conversion process in which solid biomass is converted from a solid to a liquid aggregate at a relatively low temperature of between 500 and 700 °C in an aqueous medium at a high pressure of between 100 and 200 bar in the presence of a sodium carbonate catalyst. Liquefied biomass is the equivalent of oil and this intermediate product can be used in a similar way to fossil oil.

- **Products of biomass chemical conversion technologies**

Chemical conversion of biomass is a broad concept, encompassing any process that changes the molecular content of biomass through a wide range of chemical reactions, thereby converting biomass into chemical products. Biorefining is also one of the chemical biomass conversion technologies, which involves converting biomass into liquid aggregate products such as biodiesel, bioethanol or chemical products (Chen, Wang, 2016). In practice, hydrolysis and transesterification technologies for the chemical conversion of biomass have gained widespread application. Products of conversion technologies are summarised in Figure 3.8.



Source: compiled by the author, based on Jha et al, 2022

Figure 3.8 **Classification of biomass chemical conversion technologies**

Hydrolysis is a chemical conversion technology that uses water to convert biomass into chemical products. Hydrolysis breaks down water molecules to form hydronium ions (H+), which react with biomass molecules to form simpler compounds. The products of the hydrolysis process are listed below.

- Sugar: hydrolysis can be used to convert starches and cellulose into sugars.

  Sugar can be further processed to produce ethanol, bioethanol or other chemical products.

- Acid: hydrolysis can be used to convert cellulose and lignin into acids.

  Acids can be used for further processing to produce biopolymers.

- Alcohol: hydrolysis can be used to convert cellulose and lignin into alcohol.

  Alcohol can be further processed to produce bioethanol or other chemical products.

Esterification technology is a chemical process for converting biomass, in which the reactants alcohol and acid form esters as reaction products. The process takes place at elevated temperature in the presence of concentrated sulphuric acid. Biomass **transesterification** technology is a chemical conversion technology that uses the reaction of fatty acid esters and alcohols to produce biodiesel. In this process, fatty acid ester molecules are replaced by alcohol molecules to form new esters.

The products of the transesterification process are listed below.

- Biodiesel

The product is a liquid fuel that can replace diesel.

- Glycerol

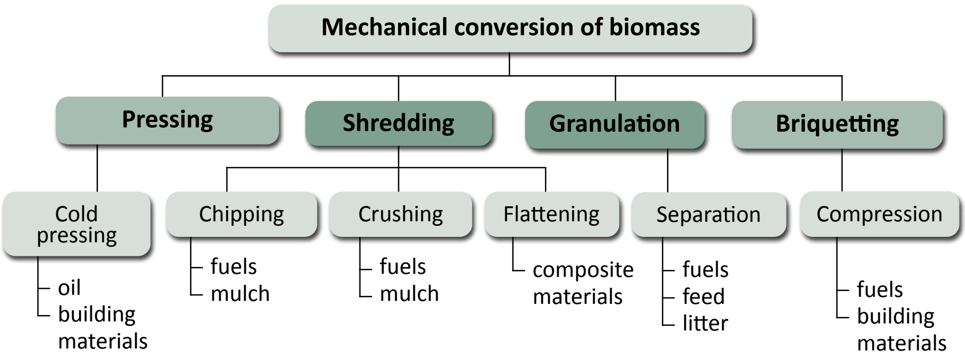
The product is a liquid that can be used as an ingredient in chemicals or cosmetic products.

- Residual oil

The product is the oil that remains at the end of the transesterification process. The residual oil can be used as animal feed or to produce other products.

- **Products of biomass mechanical conversion technologies**

During the process of mechanical conversion of biomass, the shape of the biomass is changed while maintaining its chemical properties. The most common technological processes and the resulting conversion products are summarised in Figure 3.9.



Source: compiled by the author, based on Jha et al, 2022

Figure 3.9 **Classification of biomass mechanical conversion technologies**

Pressing is a biomass mechanical conversion technology where biomass is subjected to mechanical compression to produce vegetable oil or building materials of a particular shape.

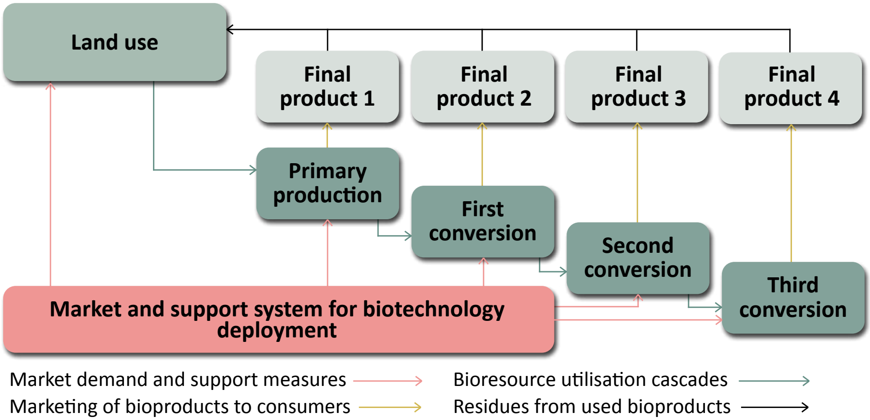
Shredding is a biomass mechanical conversion technology where biomass is subjected to mechanical separation into biomass parts of a particular shape and size. The most common technology is the chipping of woody biomass to produce fuels for heat, steam and electricity.

Granulation is a biomass mechanical conversion technology where the shredded biomass is subjected to mechanical compression in a granulator or separator. Granulated wood biomass is used in automated, low-power heat production plants. **Separation** is a technological process that removes the liquid fraction from wet biomass by mechanical compression. This conversion technology is most commonly used to separate digestate into solid and liquid fractions. The dried solid fraction of digestate is used in livestock farming as bedding in animal sheds.

Briquetting is a biomass mechanical conversion technology where the shredded biomass is subjected to mechanical compression. The fuel product of a technological conversion process in a particular form is wood briquettes or the construction product – building blocks.

3.4. Biotechnologies in agriculture

The use of biotechnologies in agriculture can be divided into two successive stages. **The first stage** is the use of land for primary agricultural production of biomass. **Green biotechnologies** are used in primary agricultural production. The **second stage** involves the conversion of the biomass produced into intermediate or final products through technological processes, the possible types of which are described in the previous section. **White, red, grey, yellow and gold biotechnologies** are used in the biomass conversion step. The extraction of biomass in the primary production stage and the subsequent conversion into intermediate or final products is illustrated in Figure 3.10. A key condition for the deployment of biomass conversion technologies in a real business environment is the market demand for conversion products, as well as a support system for the deployment of product technologies.



Source: by the author

Figure 3.10 **Biomass conversion steps and products**

Biotechnologies in the primary agricultural sector include traditional breeding methods and genetic engineering that modify living organisms or parts of living organisms to produce and modify products, improve plants or animals, or develop micro-organisms for specific agricultural purposes. The use of biotechnologies in agriculture leads to increased production of biological resources and contributes to a sustainable and competitive economy.

Biotechnologies in the primary phase of agriculture include the following research and development areas:

- genetic modification of plants (GMO);

GMO can introduce new traits into plants. The main ones are: resistance to pesticides, diseases and pests; improved nutritional value; resistance to drought and moisture; improved efficiency of the photosynthetic process;

- development of technological tools for plant protection and cultivation;

The development strand involves improving cultivation technologies through the development of plant protection products (pesticides, herbicides, insecticides) and growth regulators (fungicides);

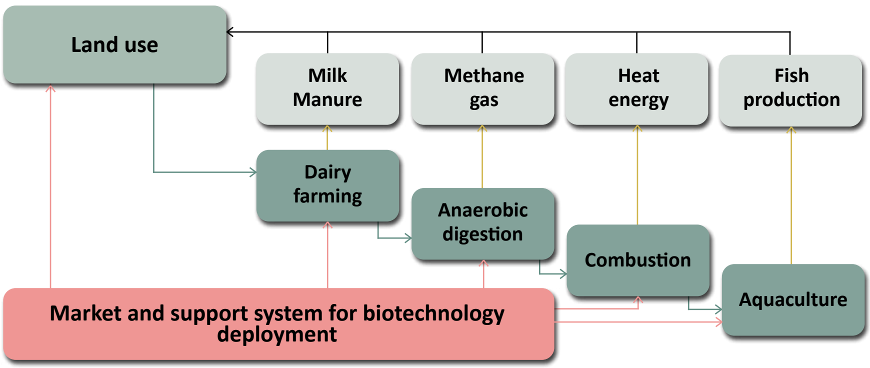
- genetic modification of animals (GMO);

The development strand involves creating new traits in animals to increase productivity, disease resistance and improve the quality of meat, milk, eggs and other livestock products;

- development of technological tools for animal protection and breeding;

The development strand involves development of new vaccines for livestock and the cultivation of plant and animal cells.

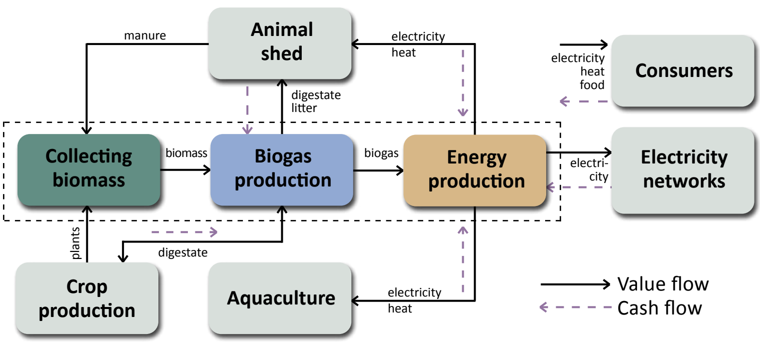
Latvia is one of the first EU countries to adopt a national Bioeconomy Strategy 2030 (LIBRA). It aims to increase the efficiency and added value of bioresources by fostering innovation, cooperation and knowledge exchange between the agriculture, forestry, fisheries, food processing, wood processing, chemical processing and energy sectors. The development of the bioeconomy offers Latvia opportunities to create new rural jobs, diversify rural economic activities, reduce dependence on fossil resources and greenhouse gas emissions, and preserve biodiversity and natural resources (Latvian Bioeconomy Strategy 2030). The development of the bioeconomy and the progress of biotechnology adoption in the **second, processing, stage** of agriculture are illustrated by biogas production, which is widely recognised by the agricultural industry. The biomass production of a dairy farming enterprise and its successive stages of conversion into marketable products are illustrated in Figure 3.11.



Source: by the author

Figure 3.11 **Biomass conversion steps, technologies and products in dairy farming**

With the right biomass conversion technology, it is possible to organise an economically viable biomass use stream. It is important to select a biotechnology for the conversion process to produce a market driven/ demand driven product and to accurately identify the market driven demand that will provide the cash flow towards the biomass converter/ product producer. The value of products and the cash flow generated by demand in the four-step biomass conversion of an agricultural enterprise are illustrated in Figure 3.12.



Source: by the author

Figure 3.12 **Value and cash flows of biomass conversion in a dairy farm**

3.5. Biotechnologies in forestry, fisheries

The development of the bioeconomy and biotechnologies in forestry and fisheries is linked to the sustainable and efficient use of biological resources to produce high value-added products and services and to contribute to a climate-friendly economy.

In forestry, biotechnologies include:

- breeding of forest seeds and seedlings;
- improving the health of the forest:
- valuation of forest ecosystem services;
- processing of wood into chemical, pharmaceutical, textile and construction products.

In fishery, biotechnologies include:

- breeding, conservation and health of fish and marine organisms;
- improvement of aquaculture;
- processing fish into food and feed products;
- extraction of biopolymers and bioactive substances from fish waste.

Latvia's Bioeconomy Strategy 2030 aims to promote the development of the bioeconomy and biotechnologies in forestry and fisheries through innovative solutions, cooperation between sectors and science, quality education and training, as well as by supporting entrepreneurship and exports. The development of bioeconomy and biotechnologies in forestry and fisheries offers opportunities to increase productivity, value added and competitiveness in these sectors, as well as to reduce GHG emissions, pollution and resource consumption (Ivanovs, 2023; RTU scientist..., 2021).

3.5. **Development of alternative production sectors in rural areas**

The growth of the bioeconomy, through the development of rural alternative industries, involves the use of bioresources to produce food, feed, energy, goods and services that are sustainable and competitive, and it also reduces GHG emissions and pollution.

Alternative production sectors in rural areas include:

- biotechnologies in the health sector;
- processing of biomass into chemical, pharmaceutical, textile and construction products;
- extraction of biopolymers and bioactive substances from fish waste;
- biofuels and bioenergy production.

The Latvian Bioeconomy Strategy 2030 aims to promote the development of the bioeconomy and alternative production sectors in rural areas through innovative solutions, cooperation between sectors and science, quality education and training, as well as by supporting entrepreneurship and exports. The development of the bioeconomy and alternative production sectors in rural areas offers opportunities to increase jobs, value added and economic growth in these regions, as well as to preserve natural capital and biodiversity (Latvian Bioeconomy Strategy 2030).

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4. ECOSYSTEM SERVICES

Author: Līga Feldmane

4.1. The concept of ecosystem services and its historical origins

In the context of a sustainable bioeconomy, it is valuable to look at different approaches to assess the attractiveness, value and multiple benefits of the environment for humanity, and to analyse the options for preserving the environment for future generations, one of which is the ecosystem services approach.

Services are the basis of human survival, because everyone has limited resources of time, knowledge and other resources, and people are therefore unable to create and provide all the goods and services they need to meet their basic needs. But what services would we like to receive? The most common answer would be – cheap and good quality, which is a difficult goal to achieve in a market economy. In contrast, under the ecosystem services approach, quality services are continuously provided to us by ecosystems, often free of charge.

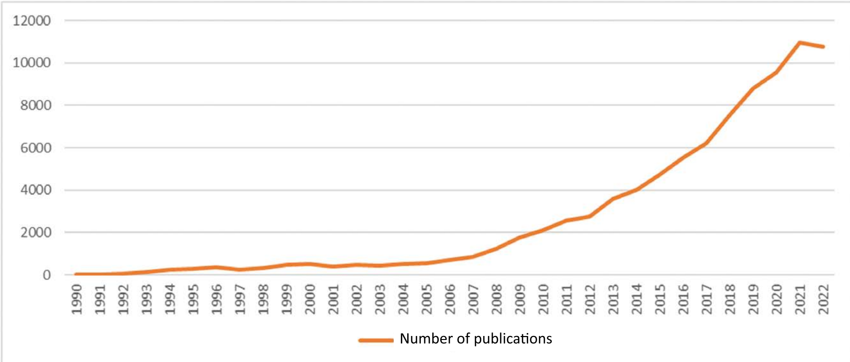
Ecosystem – a set of interacting living and non-living things, whose main function is to ensure the flow of energy between living things and the circulation of substances between living and non-living things.

Without ecosystems, human existence would be impossible, and they also play an important role in ensuring human wellbeing. Ecosystems vary in size; the smallest ecosystems are micro-ecosystems (e.g. a stump where insects live and different plants grow), followed by meso-ecosystems (e.g. grasslands, forests, rivers) and macro-ecosystems (e.g. an ocean). The largest ecosystem is planet Earth, called the biosphere. At the same time, the ecosystem services approach helps to explain to the public that the supply of ecosystem services can be reduced or the quality of services reduced if ecosystems are degraded.

In order to enable the public to understand environmental sustainability issues in a comprehensible way and to oppose society's desire for continued growth, environmental economists have introduced the term "ecosystem services" in the 1980s. They compared nature to limited capital that can provide a limited amount of ecosystem services. In the late 1990s, conservationists and biologists also started to use the term, seeing it as a way of explaining to people the close relationship between nature and people, and thus promoting the idea of the need to protect nature.

Although initially coined as a metaphor, ecosystem services became a popular term among scientists and became one of the central terms used to assess changes in ecosystems. The term became even more popular with the UN Millennium Ecosystem Assessment in the early 2000s. It is an important body of empirical research that has made it possible to assess the state of the environment and existing ecosystem services, and their close links to human wellbeing. According to it, 60% of the ecosystem services analysed have been degraded by human activities, with negative impacts on human wellbeing. For example, it leads to various diseases, sudden changes in water quality, the formation of "dead zones" in coastal waters and contributes to climate change.

Thanks to the Millennium Ecosystem Assessment, the ecosystem services approach has become one of the central approaches in environmental research, policy and management over the last 20 years. The importance of this topic is also reflected in the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), which was established in 2012 and of which Latvia has been a member since 2012. The Panel aims to develop better policies for the conservation and sustainable use of biodiversity, long-term human wellbeing and sustainable development. Despite its popularity, the ecosystem services approach has often been criticised in recent years as too simple to explain the complex interactions between people and the environment. Consequently, there have been attempts to replace the term “ecosystem services” with other equivalent terms, such as “nature’s contributions to people”. However, the term “ecosystem services” is increasingly used in policy planning documents and by scientists, as evidenced by the number of scientific publications that mention it.



Source: by the author based on Web of Science data

Figure 4.1 **Trend in the number of scientific publications mentioning the term “ecosystem services” in the Web of Science database**

The UN Millennium Ecosystem Assessment defines ecosystem services as all the tangible and intangible benefits that people derive from an ecosystem. The European Union Ecosystem Assessment (Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment) highlights that ecosystem services underpin not only human wellbeing, but also economic processes. IPBES (2018) has pointed out that changes in ecosystem services due to land degradation have a particularly negative effect on vulnerable groups such as women, and lower-income populations. In addition, lower-income groups are the ones that depend heavily on ecosystem services. For example, poorer sections of society are more likely to depend on wood for fuel, and access to this ecosystem service can be hampered by adverse conditions such as drought and climate change.

A high quality ecosystem that can benefit people and the environment is often considered to be one with high biodiversity. However, the link between biodiversity and the supply of ecosystem services is not straightforward and may depend on the ecosystem service in question. While an ecosystem composed of a high proportion of living organisms can often provide more diverse ecosystem services, in some cases higher biodiversity can have a negative impact on the provision of ecosystem services, such as the availability of drinking water.

The clarification of the conceptual content of ecosystem services has made it easier for the public to discover the economic importance of the environment, but it has an even greater role to play in raising public awareness of people's relationship with the environment. For example, understanding ecosystem services enables society to understand the importance of the environment in food sourcing education. Understanding ecosystem services also allows society to better understand who benefits and who loses when natural resources are degraded or enhanced.

4.2. Classification of ecosystem services

Ecosystem services can be classified into several groups according to their functions. The Millennium Ecosystem Services Assessment categorises ecosystem services into four broad groups:

- provisioning services;
- regulating services;
- support services;
- cultural or intangible services.

Provisioning services are the material benefits that people obtain from ecosystems and that sustain their existence. Examples include food, drinking water, wood as fuel and building material, genetic material for breeding different animals and plants, various natural textile fibres and medicinal plants. From an ecosystem services approach perspective, all ecosystems provide the conditions for growing, gathering, hunting or harvesting food. Human participation in this process means adding one's own labour to the finished product of the ecosystem to increase the quantity and quality of the product produced. Human life would also not be possible without freshwater, the flow, storage and purification of which play an essential role in ecosystems. Medicinal plants are also an ecosystem service, protecting the plants themselves from unwanted pests and diseases thanks to the various essential oils they contain, and also serving as a tool for improving human health, including through the use of their ingredients in medicinal preparations.

Supply services are characterised by the fact that they are easy to value in monetary terms, as they are products that can be bought on a daily basis in a market or shop and therefore have a known approximate market price. At the same time, the market price does not always reflect the true value of ecosystem services. In many rural areas, households are directly dependent on provisioning services for their livelihoods, so the intrinsic value of an ecosystem service is higher than what a product or commodity can fetch on the market.

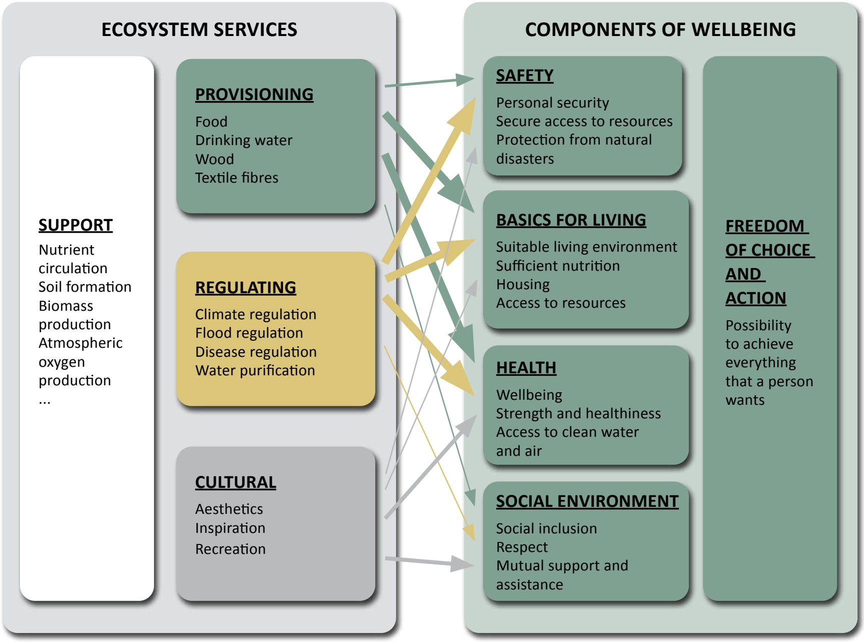
Regulating services are services that people derive as benefits from regulating ecosystem services, reducing environmental pressures or the impacts of natural hazards, which in turn contribute to public safety. Examples include maintaining air quality, climate regulation, erosion control, disease control, pollution abatement, natural decomposition of waste and water purification. Greenery and trees in cities both improve air quality and regulate air temperature. Because these ecosystem services are invisible in everyday life, they tend to be taken for granted. At the same time, regulating services play an important role in human well-being and health, because if an ecosystem's ability to provide a quality regulating service is reduced, this will have a direct negative impact on people. Moreover, if these services are destroyed or damaged, the damage is significant and their restoration is difficult.

Support services are the prerequisites for ecosystem functioning that enable the provision of other ecosystem services, such as soil formation, photosynthesis and nutrient cycling needed for food production, and oxygen production.

Cultural or **intangible services** are the intangible benefits that people derive from ecosystems, and relate to spiritual enrichment, cognitive development, mental health, inspiration, cultural identity, aesthetic enjoyment and recreation in nature. For example, artists are inspired to create artworks by looking at a beautiful landscape. Green spaces – forests, nature parks – also play an important role in maintaining people's physical and mental health. Things in the environment can give an individual a sense of identity and belonging to a place, its history and culture. Animals, plants or landscapes specific to a region are often used not only in coats of arms and flags, but also as objects of worship in various religions (e.g. sacred cows in India, turtles as totem animals in Buddhism).

A similar approach to classifying ecosystem services is used in the European Union, where the Common International Classification of Ecosystem Services (CICES) is used. It identifies three groups of ecosystem services – provisioning, regulating and maintaining, and cultural services. However, the CICES ecosystem classification is based on the final services that people derive from ecosystems, so it does not include a group of supporting services, which are mainly processes of the existing ecosystem that result in other ecosystem services.

As mentioned above, ecosystem services not only sustain human existence, but are also key contributors to human wellbeing. According to the UN Millennium Ecosystem Assessment, each of the ecosystem service groups has an impact on the domains that shape human wellbeing (Figure 4.2).



The thickness of the line indicates the closeness of the link – the wider the line, the closer the link

Source: based on UN Millennium Ecosystem Assessment, 2005

Figure 4.2 **Linking ecosystem services to human wellbeing**

Provisioning services play an important role in meeting people's primary needs, as they provide basic necessities such as food and housing. At the same time, provisioning services can also make an important contribution to maintaining human health, for example by providing safe drinking water and a sense of security in the availability of daily necessities. Regulating services have a significant impact on human health and safety, which can be facilitated by pleasant climatic conditions and a safe environment without climate disasters. Intangible or cultural services not only play an important role in maintaining health, for example through outdoor recreation, but also have a significant impact on the social environment in which we live.

4.3. Ecosystem services valuation

Ecosystem services valuation dates back to around 1987, when the first attempts at ecosystem valuation were made. Today, ecosystem services valuation is widely used in different countries to understand and assess the value of their ecosystems and thus conserve ecosystems. One of the more comprehensive attempts to value ecosystem services was made in 1997 (Costanza et al., 2014), when the ecosystem services provided by the entire world (17 ecosystem services in 16 biomes) were estimated to have an economic value of ~USD 33 trillion per year. Following the UN Millennium Ecosystem Assessment, one of the most important ecosystem assessments was the TEEB project "The Economics of Ecosystem and Biodiversity", which focused on estimating the hidden values of ecosystems, the costs of biodiversity loss, and ecosystem degradation, using experts from the fields of ecology, economics and development.

Ecosystem services valuation is a useful tool when decisions need to be taken to improve the wellbeing of society. Similarly, identifying the value of ecosystem services is useful for their effective management, which in some cases may include economic incentives. Ecosystem services valuation helps:

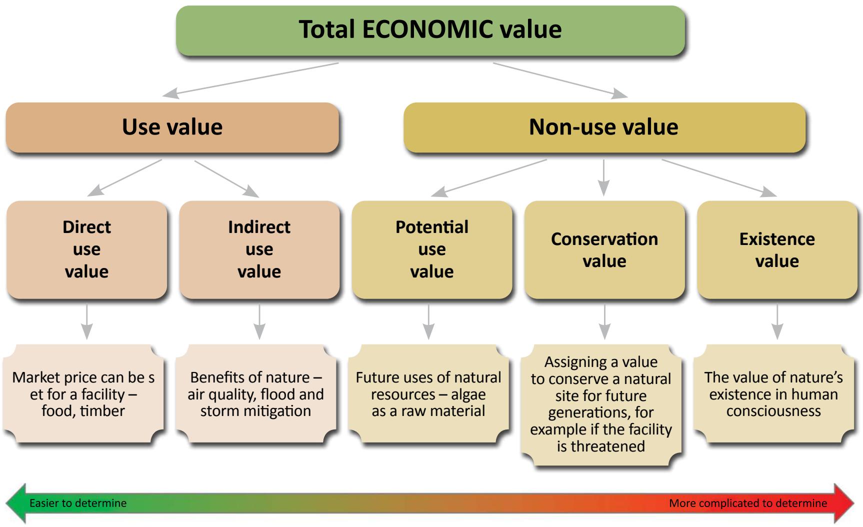
- anticipate future development scenarios for a site;
- calculate the money invested in conservation;
- identify the economic value of nature and its overall contribution to society;
- create understanding of ecosystem services and their links to social and economic wellbeing;
- identify and compare the economic efficiency of different investments in the ecosystem;
- assess different ways of managing the ecosystem, such as land use;
- calculate the costs of environmental damage;
- discuss the importance of nature in a more reasoned way with different groups in society;
- choose the most economically viable and sustainable option for the development of a site.

As ecosystem services valuation is a complex process involving specialists from different fields, biophysical, social and economic valuation methods can be used to value ecosystem services. The **biophysical valuation** leads to the characterisation of ecosystem functions in relation to the provision of ecosystem services. Survey and monitoring data, modelling or expert judgements are used. Biophysical valuation also includes methods such as ecosystem services mapping.

Social valuation is the process of assessing ecosystems to find out what society thinks about a particular ecosystem and its services. Social valuation involves a variety of sociological research methods such as interviews, surveys or focus group discussions.

Economic methods, on the other hand, allow the monetary value of ecosystem services to be assessed using different economic valuation methods. Although economic valuation is expressed in monetary terms, it is considered a relative valuation, as it allows the value of different ecosystem services to be compared, determining which is more valuable, rather than setting an exact price for the service.

All the benefits that people receive from ecosystems can be divided into use and non-use values (Figure 4.3). The use value consists of direct value in use and indirect value in use. Direct use value is goods and services that can be consumed directly by society and for which equivalents are available on the market (e.g. timber, medicinal plants). Indirect use value is goods and services that are not available on the common market, but can contribute to other ecosystem processes (e.g. pollination).



Source: by the author based on Selivanov, Hlaváčková, 2021

Figure 4.3 **Total economic value of ecosystems**

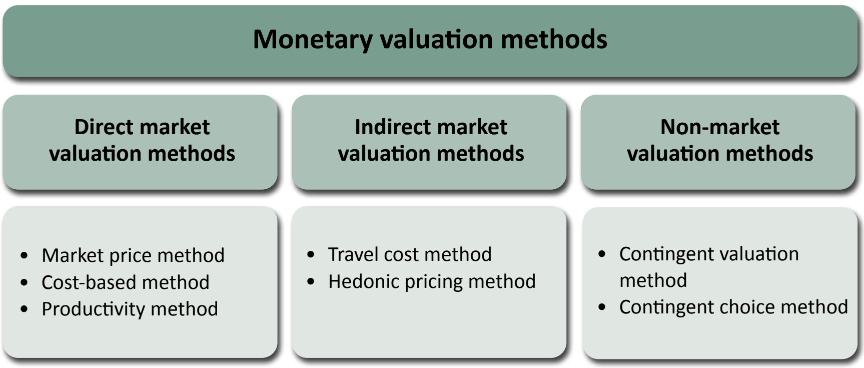
The potential use value is the benefit estimated from the potential future use of a resource if it is not currently used. Conservation value can be defined as the value placed on securing and maintaining the benefits of a resource or ecosystem for future generations, while existence value is the satisfaction derived from knowing that a facility or resource exists. Note that it is easier to calculate the use value of an ecosystem if there are equivalent or comparable products and services on the market, whereas the non-use value is more complex and subjective.

Methods for economic valuation of ecosystems

Economic valuation of ecosystems can be carried out using any of the methods which are divided into three groups.

- **Direct market valuation methods** – methods that use actual market data – the prices of goods and services – as a basis for determining the value of ecosystem services and are subject to market mechanisms such as supply and demand. Direct market valuation methods include the market price method, the cost-based method and the productivity method.

- **Indirect market valuation methods** – used to determine the value of ecosystem services using consumer behaviour or activities in specific markets. These methods use data derived from real markets where actual transactions have taken place. Indirect market valuation methods are the travel cost method and the hedonic pricing method.
- **Non-market valuation methods**, also known as ecosystem services valuation, are based on personal choices and preferences. This approach can be used when market price data are not available and other methods cannot be applied. The preference approach uses the hypothetical preferences indicated by individual respondents to estimate the change in utility associated with an increase in the quality or quantity of a given ecosystem service or services. Non-market valuation methods include the contingent valuation method and the contingent choice method.



Source: by the author based on Selivanov, Hlaváčková, 2021

Figure 4.4 **Monetary valuation methods**

Direct market valuation methods

Market price-based approach. This approach uses the monetary value paid in the common commercial market for equivalent goods or services to determine the value of an ecosystem service. The standard approach to estimating the value of resources traded on the common market is to estimate consumer and producer surpluses using market prices and trade volume data. The total net economic benefit or economic surplus is the sum of consumer surplus and producer surplus. For example, the value of timber production as an ecosystem service can be determined by comparing it with the price of timber on the market.

This method can be used to measure changes in the quantity or quality of a good or service. It uses standard economic methods to estimate the economic benefits of traded goods, based on the quantities that people buy at different prices and the quantities that are delivered at different prices.

Advantages of the method:

- data on market prices, trade volumes and costs of goods and services are relatively easy to access and obtain;
- standard, generally accepted economic methods are applied;
- observational data on actual consumer preferences and behaviour is used.

Disadvantages of the method:

- data available for a limited number of goods and services;
- market prices may not reflect the true value of goods and services;
- seasonality of prices and changes in market supply/demand.

Cost-based valuation method. This method assumes that the value of an ecosystem service can be determined as equivalent to the avoided cost of having that ecosystem service. Cost-based methods do not provide an accurate measure of monetary value based on people's willingness to pay for a product or service, but they do help to determine what costs could be avoided if an ecosystem service were damaged, unable to continue to provide a good quality service, or replaced by an artificial system. For example, storm protection services for coastal wetlands can be evaluated by calculating the cost of constructing protective walls.

Similarly, the erosion protection service of a forest or wetland can be valued in monetary terms by estimating the costs that would be incurred to remove erosion sediments in adjacent areas.

This method is most appropriate where measures to repair damage to ecosystem services have been or will be taken, as it makes it easier to calculate the expected costs.

There are several approaches to applying this method.

- Replacement cost method – calculates the value of an ecosystem service as the cost of replacing it. For example, if a forest stand has to be felled for construction work, the value of the stand will be equivalent to the cost of establishing a new stand.
- Avoided-cost method (also known as the preventive-cost method) – measures the value of an ecosystem service as the cost of potentially avoidable damage that has been prevented as a result of the existence of the ecosystem service. For example, a forest that makes a significant contribution to flood prevention may be valued at the cost of a hypothetical flood if the forest were logged.
- Cost minimisation method – assumes that the cost of the ecosystem service is equal to the expenditure incurred as a result of the negative impacts caused by the degradation of the ecosystem service. For example, the cost of treating water from a contaminated reservoir that provides drinking water. The main difference between this method and the previous one is that in the case of the damage cost method, the damage is hypothetical.

Advantages of the method:

- the method can be used to determine an approximate economic value, taking into account data limitations and the degree of similarity or substitutability of the related goods;
- it is easier to measure the costs of creating an ecosystem service than the benefits we get from it, especially when goods and services are not traded;
- it is less data- and resource-intensive.

Disadvantages of the method:

- cost is not always an accurate measure of the benefits we get from a service;
- information on the degree of substitutability between the market good and the natural resource is needed. Few environmental resources have direct or indirect substitutes on the market;
- The goods or services that are replaced as a result of the degradation of ecosystem services are only part of the full range of ecosystem services provided. The benefits of action to protect or restore an ecological resource may therefore be underestimated.

Productivity method. The method is used to estimate the economic value of ecosystem services that contribute to the provision of other goods or services. It is used when ecosystem services are used together with other inputs to produce a commodity that can generate additional income. For example, the ecosystem service provided by water treatment can be measured in terms of increased revenues from the sale of better quality drinking water, higher agricultural yields or reduced costs of providing clean drinking water. Similarly, the availability of aesthetic recreational space (e.g. walking trails, natural water body) in the neighbourhood can have a positive impact in attracting tourists, leading to job creation and overall increased benefits for the local economy.

The productivity method requires the collection of data on how changes in the quantity or quality of a natural resource affect the cost of producing the final good, the supply and demand for the final good, and the supply and demand for other factors of production. This information is used to relate the impact of changes in the quantity or quality of a resource to changes in consumer surplus and producer surplus, and thus to estimate economic benefits.

Advantages of the method:

- the method is relatively simple;
- the data used for the method is usually readily available, making it relatively cheap to use.

Disadvantages of the method:

- the method is limited to the valuation of resources that can be used as inputs in the production of traded goods;
- when valuing an ecosystem, not all services will be linked to the production of traded goods, so the value of the ecosystem may be underestimated;
- clear modelling of inputs and economic outputs is needed, to make sure that if one variable is affected, the other is affected.

Indirect market valuation methods

Hedonic pricing method. The hedonic pricing method is used to estimate the economic value of ecosystem services that have a direct impact on the market price of a good or service. The method is based on the assumption that people mainly value the characteristics or benefits of a good/service rather than the good/service itself. The market price of a good/service therefore reflects the value of a set of attributes, including the attractiveness of its surroundings, which the consumer considers important when purchasing the good/service.

This method is most commonly used to measure property price fluctuations, as it can statistically model how different ecosystem service indicators affect the market price of a property. This method assesses both the quality of the environment (i.e. air and water pollution, noise levels) and the amenity of the environment (i.e. proximity of natural areas to the property, aesthetically pleasing scenery). Features such as environmental amenities, proximity to water, flood protection increase the value of a property, while nearby pollution reduces it.

Advantages of the method:

- the method is relatively accurate because it is based on actual market prices and relatively easy to measure data;
- it takes into account both internal and external factors to determine the price of the properties under study and is therefore a comprehensive way to determine the price of any property;
- flexibility in that any change in an external environmental fac-

tor can be quickly added to the analysis and its impact on the property price determined;

- if the data needed for the method are available, it is relatively inexpensive to apply.

Disadvantages of the method:

- its use may be limited where the market is distorted, information on environmental conditions is limited and the available data is incomplete;
- the cost of applying the method increases significantly if data are not available and need to be collected and processed using statistical methods that require expertise in the field;
- there is a high degree of subjectivity in the application of the method, as people interpret external environmental factors according to their own perceptions, and it is therefore likely that one external environmental factor can lead to a decrease in the perceived value for one individual and an increase in the perceived value for another;
- not all ecosystem service benefits can be valued using this method.

Example of how the method works. To determine the market price of a property, data on the sales prices of properties in the surrounding area over a certain period of time is first collected. In addition, information is obtained on their location, property characteristics (e.g. area, number of storeys), neighbourhood characteristics (including access to services) and environmental characteristics that affect the price of the property. If there is a green area, public water or a source of environmental pollution in the area, the data can be used to establish a statistical correlation between property prices and their distance to the attractive/polluted environmental area. In this way, the researcher can assess the value of preserving an attractive environment zone by looking at how the average property value changes as the amount of attractive environment in the vicinity changes.

Travel cost method. The travel cost method is most commonly used to estimate the economic value of recreational ecosystem services, to estimate people's willingness to pay for outdoor recreation. It allows to estimate the cost and time spent by households to visit an environmental site or area. The method can be used to estimate the economic benefits or costs that may arise from changes in the cost of access to a recreation site, the removal or creation of an existing recreation site, or changes in the environmental quality of a recreation site.

The main principle of the travel cost method is that the time and travel costs that people incur to visit a recreational site are equal to the cost of accessing that site. Thus, people's willingness to pay to visit a place of recreation can be assessed on the basis of the number of trips they make and the cost of travel.

There are several variants of the travel cost method.

- **Simple zonal travel cost method,** which mainly uses a variety of secondary data originally collected for other purposes (e.g. travel agency data), with only some small amounts of data collected from visitors to the study area. The method is the simplest and relatively cheapest of the travel cost methods. It collects information on the number of visits to the site, taking into account the distance travelled by visitors, and identifies zones. As travel and time costs will increase with distance, this information allows to calculate the number of visits at different costs. This information is used to construct a demand function for the facility and to estimate the consumer surplus or economic benefit from the facility's recreational services.

- **The individual travel cost method,** which is based on obtaining more detailed data through a survey of visitors to the area. It is similar to the simple zonal travel cost method, but the statistical analysis uses individual visitor survey data rather than data for each zone. This method requires more resource-intensive data collection and slightly more sophisticated analysis, but will provide more accurate results as the surveys provide additional data on visitor characteristics.

- **Utility sampling method,** which uses both visitor surveys and other data and statistical analysis techniques to obtain data. This method is the most complex and expensive of the travel cost methods. At the same time, it is the most appropriate approach to use for assessing the benefits not only of a site or facility as a whole, but also of its specific characteristics or changes in its quality. This method is also the most appropriate when there are many other alternative facilities for the facility.

Advantages of the method:

- not only the cost of services at the recreation site (e.g. camping fees), but also the cost of travelling to the site and income foregone is taken into account;
- the method is relatively uncontroversial because it is based on standard empirical methods for measuring economic value, so its results are relatively easy to interpret and explain;
- it is based on information about people's actual behaviour, not on hypothetical scenarios of how people would behave in certain situations;
- it has been widely used, so there has been considerable research into improving the method.

Disadvantages of the method:

- data-intensive data collection, restrictive assumptions about consumer behaviour, sensitive statistical methods;
- the simplest models assume that individuals travel for one purpose, to visit a specific recreational destination. If the trip has more than one destination, the value of the recreation site may be overestimated, as it may be difficult to allocate travel costs between the different destinations;
- the method provides information on the current conditions of the recreation site, but not on the benefits or losses from the predicted changes.

Non-market valuation methods

Contingent valuation method. The contingent valuation method is used when there is no data on the market value of an ecosystem service. The method can be used to estimate both use and non-use values. The method is based on surveys or interviews that measure people's willingness to pay a certain amount to maintain or restore a specific ecosystem service. They are also sometimes asked for their views on the amount of compensation they would be willing to accept to give up certain ecosystem services.

The contingent valuation method has four variations:

- willingness to pay – this method assesses the value of an ecosystem service by asking people directly how much they would be willing to pay for improvements and services provided by the ecosystem;
- willingness to accept – this method asks people how much money they are willing to accept as compensation for losses caused by the degradation of the ecosystem and the services it provides;
- willingness to sell – a method to find out how much people would be willing to sell an ecosystem service for, or how much another stakeholder would be willing to pay for that ecosystem service;
- inferred valuation method – to obtain a more objective valuation, the method asks people to predict the value that others will place on an ecosystem service, rather than expressing the respondent's personal valuation of the ecosystem service.

Advantages of the method:

- the only method that can measure the potential use value and existence value of an ecosystem service and give a true total economic value;
- the flexibility of the method, which allows it to be applied to

measure the economic value of almost any ecosystem service;
- wide use of the method, which has contributed to the improvement of its methodology.

Disadvantages of the method:

- although the method is widely used, there are differences of opinion among researchers as to whether the method adequately captures people's willingness to pay for ecosystem services;
- it is not always easy for respondents to assign a monetary value to ecosystem services, which can lead to discrepancies in the value assigned;
- the method can be time-consuming and relatively expensive to apply.

Contingent choice method. Like the contingent valuation method, the contingent choice method can be used to determine the economic value of almost any ecosystem and the service it provides. The difference is that the contingent choice method does not ask respondents to name their monetary value for a given ecosystem service, but is inferred from hypothetical choices or alternatives that people make. For example, respondents are asked to choose one of the ecosystem services or indicators offered, or to rank the importance of different ecosystem services. Once the data is collected, statistical methods are used to determine the relationship between the characteristics and the individual's preferences. Given that the method is based on trade-offs and people's choices between different ecosystem services, it can be successfully used as a tool for policy decision making where different potential scenarios of action may have impacts on environmental resources and ecosystem services.

Advantages of the method:

- this method allows respondents to think about trade-offs, which can be easier than directly naming the value of an ecosystem service;

- unlike the contingent valuation method, this method reduces the possibility of unrealistic values being obtained from the survey;
- the method results in a relative ecosystem service value that can potentially be used for decision making on action alternatives and their environmental impacts.

Disadvantages of the method:

- respondents may find it difficult to evaluate the different alternatives if they are not familiar with them;
- providing a limited number of responses may lead respondents to make choices that they would not voluntarily make, which may therefore bias the results;
- researcher opinions on the reliability and suitability of the method for valuing ecosystem services differ.

Further reading

- **UN Millennium Ecosystem Assessment** – an ecosystem assessment prepared by the UN between 2001 and 2005, involving more than 1 360 scientists from around the world, to assess the impact of changes in the world's ecosystems on human wellbeing, as well as to identify the way forward to improve the conservation of ecosystems for future generations, ensure sustainable use of ecosystems, and bring back benefits to humanity. The results of the assessment provided a scientific assessment of the status and trends of the world's ecosystems, the services they provide, their controls and the opportunities to restore, maintain or improve their sustainable use. **Available at:** https://www.millenniumassessment.org/en/Global.html

- **Intergovernmental Platform on Biodiversity and Ecosystem Services –**
Available at: https://www.ipbes.net/

- *LIFE +* programme "Environment Policy and Governance" **project "Assessment of ecosystems and their services for nature biodiversity conservation and management"** – project implemented

in the period 2014-2020, during which ecosystem services were identified, mapped and assessed in the coastal areas of Engure and Saulkrasti.
Available at: https://ekosistemas.daba.gov.lv/public/lat/

- The **European Union Ecosystem Assessment** (Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment) is a report by the European Commission's Joint Research Centre on the state of ecosystems in the European Union, covering its terrestrial and marine areas. The report aims to provide evidence-based scientific support to the European policy making process, as well as to raise awareness of the ecosystem services approach among EU Member States. **Available at:** https://publications.jrc.ec.europa.eu/repository/handle/JRC120383

- **The Common International Classification of Ecosystem Services (CICES)** – an international hierarchical system adopted by the European Union designed to allow the measurement, accounting and valuation of ecosystem services.
Available at: https://cices.eu/

- **The Economics of Ecosystems and Biodiversity (TEEB), an international study** on biodiversity loss and ecosystem degradation and their economic value, produced under UN Environment Programme in 2010.
Available at: https://teebweb.org/publications/teeb-for/synthesis/

- **Examples of methods for valuation of ecosystem services** Provides a detailed description of the different monetary valuation methods for ecosystems, with practical examples.
Available at: https://www.ecosystemvaluation.org/

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5. BIOECONOMY PROFILE OF THE EUROPEAN UNION AND LATVIA

Authors: Sandija Zēverte-Rivža, Vineta Tetere, Dina Popluga, and Aina Muška

The Council of the European Union has concluded that a sustainable circular bioeconomy is crucial to achieving a climate neutral Europe by 2050, guaranteeing food and nutrition security, sustainable biomass production and use, reducing food waste, restoring and improving ecosystem functioning and biodiversity. In Latvia, the bioeconomy is also seen as the basis for the country's economic development. The Ministry of Agriculture (MoA) of the Republic of Latvia points out that bioeconomy sectors strengthen the viability of the Latvia's territory and have a high growth potential in terms of creating well-paid jobs. The bioeconomy is the part of the economy where renewable natural resources (plants, animals, micro-organisms, etc.) are used in a sustainable and intelligent way to produce food and feed, industrial products and energy.

5.1. Bioeconomy indicators

The Latvian Bioeconomy Strategy identifies a number of indicators that can be analysed to assess the profile of Latvia's bioeconomy sectors. Similar indicators are used in the EU Bioeconomy Strategy and in the strategies of other EU Member States to analyse this area. Key indicators are turnover in bioeconomy sectors, value added and number of employees. A more detailed analysis can look at bioresource flows within the EU and Member States. These can be looked at within individual sectors of the bioeconomy, as well as analysing flows between sectors. In addition, foreign trade in bioeconomy sectors and the main importing countries of bioeconomy products can be analysed, as well as the main export markets for products produced in Latvia.

Overall, turnover in the bioeconomy in the EU in 2020 was worth EUR 2.3 trillion, while in Latvia – EUR 8.4 billion. Comparing the EU bioeconomy indicators with Latvia, an analysis of the sectoral structure shows that the largest bioeconomy sector in the EU as a whole is food, beverages and tobacco, with a turnover of EUR 1.14 trillion, followed by agriculture and bio-based chemicals, pharmaceuticals, plastics and rubber production.

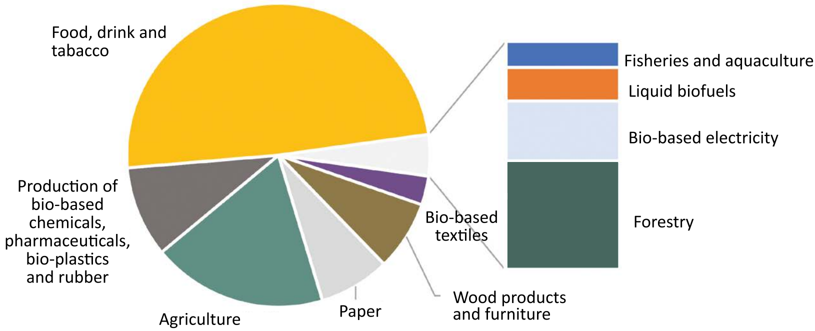

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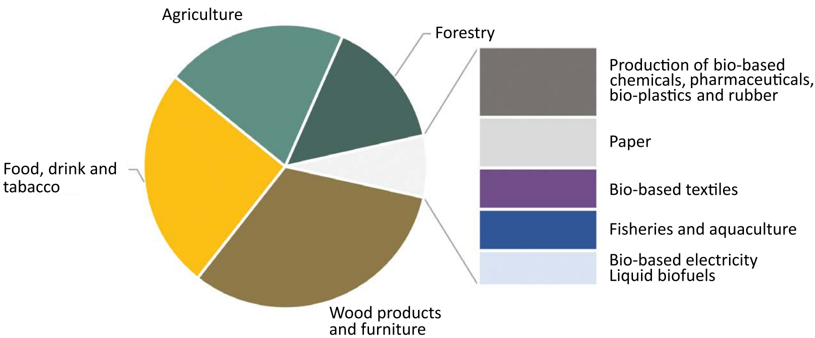
Figure 5.1 **Turnover in bioeconomy sectors in the EU in 2020, billion.**

Forestry, wood processing and wood products manufacturing are the dominant sectors in Latvia, with a total turnover of EUR 5.4 billion in 2020. These sectors are followed by food, drink and tobacco, and agriculture.

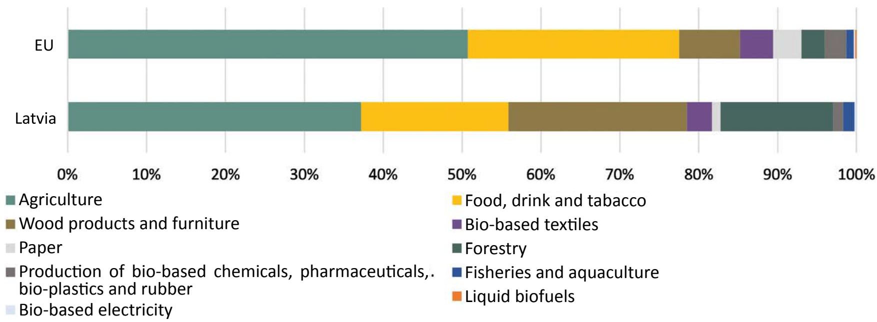


Source: authors using data from DataM, 2023

Figure 5.2 **Turnover in bioeconomy sectors in Latvia in 2020, billion.**

These differences between the EU average sectoral distribution and the dominant sectors in the Member States are due to the different distribution of natural resources between the EU Member States, e.g. in Latvia and Finland it is forest resources that dominate and, consequently, forest-based industries. The sectoral breakdown is also influenced by regional specialisation and demand.

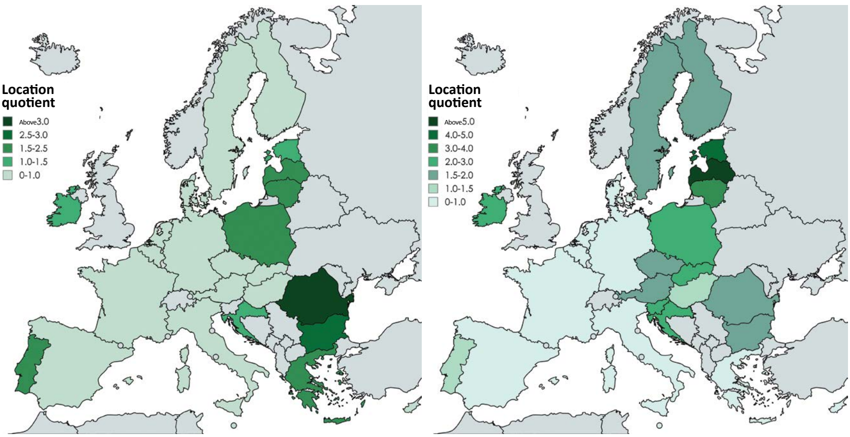
Overall, 17.16 million EU citizens were employed in the bioeconomy in 2020, compared to 124.58 thousand, in Latvia, or 6.5% of the total population of Latvia, or 11% of the total population in employment in Latvia. This represents 3.8% of the total EU population and 8.7% of the EU population in employment, respectively. Analysing data on the number of people employed in the bioeconomy sectors in the EU and Latvia, it can be observed that it is on average proportional to the turnover in these sectors, and although agriculture has the highest number of employees in the EU and Latvia, it is not the largest sector in terms of turnover in either the EU or Latvia. Agriculture employs 46.3 thousand people in Latvia, or 37.2% of all those working in the bioeconomy. The next largest sector in terms of employment is food, beverages and tobacco, which employs 23.3 thousand people in Latvia, or 18.7% of all those working in the bioeconomy.



Source: authors using data from DataM, 2023

Figure 5.3 **Employment in bioeconomy in the EU and Latvia in 2020, % of total employment in the bioeconomy**

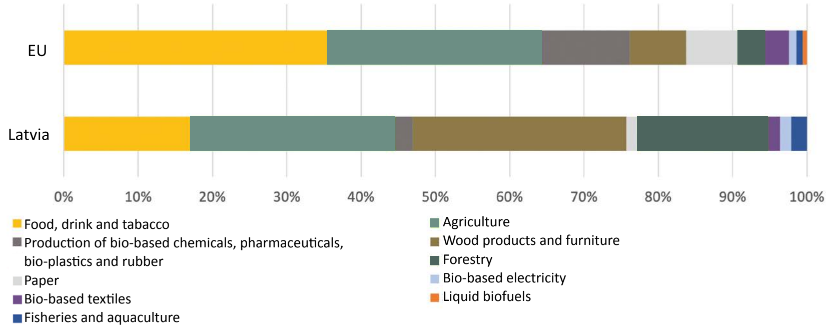
Another indicator that reflects the employment intensity of a bioeconomy sector compared to the rest of the EU is the location quotient (LQ). This is an analytical statistic that measures the specialisation of a region in relation to a larger geographical unit, in this case it shows the share of employment in a Member State's total bioeconomy or in some of its sectors in relation to the share of employment in the EU bioeconomy. As shown in Figure 5.4, Romania and Bulgaria have the highest location quotients in the EU in 2020, due to the large number of people employed in agriculture in these countries. In Latvia, the location quotient is 5.91 in the dominant forestry and wood processing sector, but in forestry alone it is as high as 8.91, which is much higher than the location quotients in these sectors in other countries. As mentioned above, this may indicate both the country's specialisation in certain sectors, using local resources, which in the case of Latvia would be forests, although in the case of Romania, for example, it could also indicate labour-intensive farming methods in the sector and the need to restructure the sector in order to intensify it.



Source: authors using data from DataM, 2023

Figure 5.4 **Location quotient for bioeconomy sectors in the EU in 2020 (left) and for forestry and wood processing sectors (right)**

Another indicator to analyse in the context of the bioeconomy's sectoral profile is value added: in the EU, in the bioeconomy's sectors such as food, beverages and tobacco it is the highest, while in Latvia it is wood products and furniture. In both the EU and Latvia, agriculture is the second largest sector with the highest value added, followed by bio-based chemicals, pharmaceuticals, bioplastics and rubber in the EU and forestry in Latvia in the third place, and the EU's dominant food, beverages and tobacco in the fourth place.



Source: authors using data from DataM, 2023

Figure 5.5 **Value added in bioeconomy sectors in the EU and Latvia in 2020, % of total bioeconomy value added**

As regards imports and exports, Latvia had a negative external trade balance in 2022, i.e. the export volume (EUR 21 billion) was lower than the import volume (EUR 26.5 billion). Of the total exports, goods attributable to the bioeconomy accounted for EUR 7.8 billion or 36.91% of total exports. Compared to 2021, the total value of exports of all goods, including those produced by the bioeconomy, has increased, but the share of bioeconomy products in total exports has slightly decreased from 39.44% in 2021 to 36.91% in 2022. In 2022, the most important export partner countries for Latvian bioeconomy exports were Lithuania, Estonia and Russia for food and beverages; the UK, Sweden, Germany and Estonia for wood and wood products; Nigeria and Spain for vegetable (grain) exports; and Lithuania for animal and livestock exports.

Looking at the dynamics of imports, the share of production attributable to bio-based industries has slightly decreased overall, from an average of 12–14% in previous years to 11% in 2022. The decline is observed both in monetary value and in the weight of imported products. The main groups of imported bio-economy products are clothing (total knitted and non-knitted – EUR 480 million); paper and paperboard (EUR 412 million); as well as milk and milk products (EUR 270 billion).

Analysis of trade data is complicated by the separation of biomass in sectors that use both bio and non-biobased products, such as pharmaceuticals. It is therefore currently excluded from the analysis of imports and exports, even though some of the raw materials used are attributable to the bioeconomy.

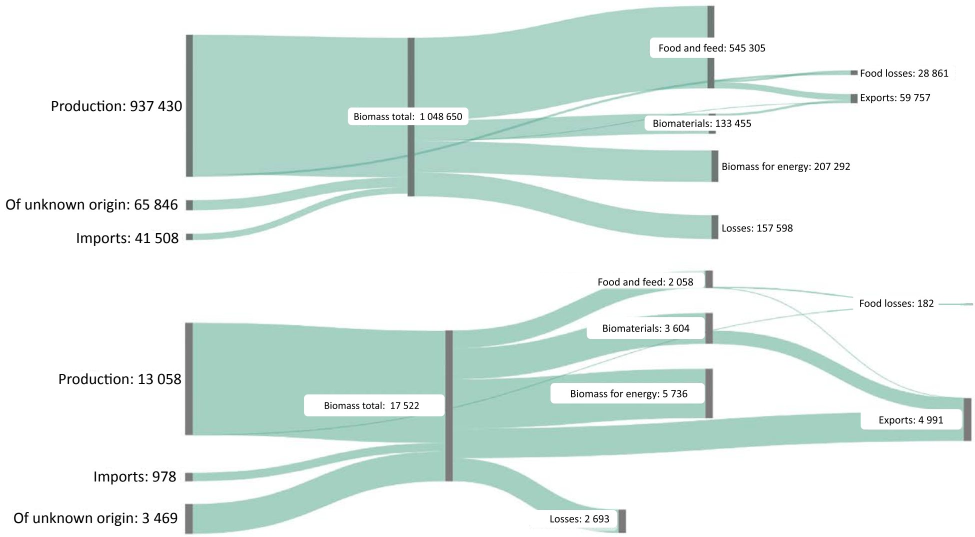
As awareness of the importance of a sustainable bioeconomy in Europe grows, so does the need to increase the availability and quality of statistics, but several key aspects are still missing at EU level, including (i) comprehensive databases and statistics on bioeconomy sectors; (ii) transparent methodologies for collecting bioeconomy data; (iii) integrated value chain data and indicators illustrating the flows of different bioeconomy commodities.

To address these challenges, the Horizon 2020 project "Biomonitor" developed the Material Flow Monitor (MFM) methodology. This methodology describes the physical flows of materials (including biomass) in the economy using supply and use tables and data from the BioSAM database for specific commodities and sectors. The data in this database is updated every five years. BioSAM is the database that provides the most complete picture of the bioeconomy's sectors and details how they relate to other sectors. The BioSAM database has the highest level of commodity and sector disaggregation to measure the importance of the bioeconomy in Latvia and other European countries. Although the volume of bio-based raw materials and products is increasing, it remains difficult to measure and monitor the development of the bioeconomy. This is because bio-based raw materials and products are increasingly used to replace petrochemicals, for example, but are not separately identified in the statistical classification. One possibility is to use biomass factors to determine the share of bio-based origin for each product category, which is the best available method for determining the share of bio-based products, but such factors are not precise enough to reliably reflect small changes.

To visualise biomass flows in the EU, the European Commission's (EC)

Joint Research Centre (JRC) has developed biomass flow diagrams that show biomass flows in the EU and its Member States. In this case, biomass flows are represented as tonnes of dry matter, without conversion into monetary units such as euros.

The analysis of bioresource flows shows that Latvia has a higher share of biomass exports compared to the EU (although these are mostly to other EU countries): more biomass is used for energy production (mostly as fuel), while a smaller share of the total biomass is used for food and



Source: authors using data from DataM, 2023

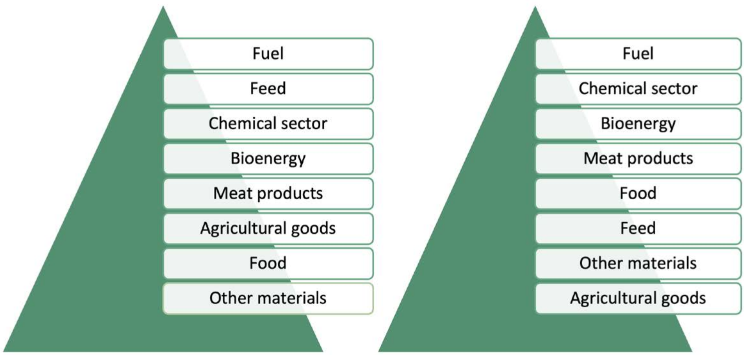
Figure 5.6 **Biomass flows in the EU (top figure) and Latvia (bottom figure) in 2020, 1000 t DM net.**

Statistics Netherlands has developed a Material Flow Monitoring Methodology (MFM), which describes the physical material flows in the Dutch economy, measured in millions of kilograms. Physical flows also include detailed imports and exports of goods. The MFM is derived from the accounting statistics on money supply and use published in the national accounts, which are converted into physical material flows. The level of detail achieved with these material flows makes it possible to estimate the size of the bioeconomy in physical terms for the whole Dutch economy, thus excluding monetary fluctuations and increasing the accuracy of the resulting data. It also allows to distinguish between different material streams, such as bio-based and non-biobased material streams in different sectors. Currently, this methodology is only used in the Netherlands.

The bioeconomy framework defined in the Latvian Bioeconomy Strategy is one way to analyse the Latvian bioeconomy. It is expressed in monetary values, and price volatility can lead to biased assessments of these values. It is therefore advisable to use physical volumes to provide a perspective for an objective assessment of the bioeconomy sectors.

The application of the MFM methodology to the Latvian bioeconomy allows to assess the contribution of biomaterial flows to the bioeconomy, distinguishing between flows of bio and non-bio origin in the sectors.

There are sectors that are not included in the Latvian Bioeconomy Strategy, but they are included in the BioSAM database. This database, together with the MFM methodology, allows a comparison of the commonalities and differences between approaches to bio-economic analysis. In order to combine monetary and non-monetary analytical approaches, Bos et al. (2014) created a value pyramid to reflect the monetary value of biomass use. Each product is categorised regardless of the sector in which it is used. Using the Bos et al. methodology and data from the BioSAM tables, it is possible to represent Latvian biomass flows in a pyramid of values, both in monetary terms and in volume units.



Source: by the authors

Figure 5.7 **Biomass monetary value pyramid (left) and biomass volume value pyramid (right)**

Comparing the two pyramids, it can be seen that the share of the volume of goods in the bioeconomy is different from the monetary value. The biomass of agricultural commodities is three times higher in weight than its monetary value. At the same time, food processing accounts for only 2.6% of all biomass, even though it has a monetary value of 29% of all biomass.

5.2. Concentration and structure of bioeconomy companies in Latvian regions

Latvia's overall bioeconomy performance is promising and shows that bio-based industries play an important role in the country's economy. However, for future growth in the bioeconomy to be sustainable, it is necessary to identify whether growth and bioeconomy capacity in terms of the number of enterprises is balanced across the country.

Various indicators are used to describe the performance and trends, social and economic importance of the bioeconomy: number of people employed, turnover, value added, productivity (in terms of turnover per person employed), exports, domestic sales, contribution to GDP, investment. This subchapter uses the indicator "number of economically active enterprises in the market sector" – an indicator used to characterise business activity – to assess the performance of the bioeconomy, highlighting the concentration and structure of bioeconomy enterprises in a given territorial unit. In order to identify the concentration and structure of bioeconomy enterprises, this subchapter follows the most common understanding of the bioeconomy in the EU and Member States (described in subchapter 1.3 "Bioeconomy sector classification"): the bioeconomy includes all economic activities related to the production and processing of biomass.

In order to show the diversity of the bioeconomy in the Latvian municipalities, two differentiation criteria are used:

- bioeconomy location quotient (LQ);
- the share of bio-based primary production enterprises (sectors A01, A02 and A03) in the total number of enterprises in the bioeconomy.

Bioeconomy location quotient

Location quotient is a widely used indicator to assess the concentration of industry in an area and is very important to identify the specific strengths and weaknesses of an area. The study used location quotients to determine the concentration and structure of bioeconomy enterprises in a given municipality. This helps to show what makes a particular municipality "unique" compared to other municipalities and the national average.

The bioeconomy location quotient (LQ) is calculated using the following formula:

$$LQ_{i,l} = \frac{\dfrac{EB_{nov\ i,l}}{ET_{nov\ i,l}}}{\dfrac{EB_{LV}}{ET_{LV}}}, \quad (1.)$$

where

$EB_{nov\ i,l}$ is the number of bioeconomy enterprises economically active in the market sector in the i-th region of Latvia in the i-th year;

$ET_{nov\ i,l}$ is the total number of enterprises economically active in the market sector in the i-th region of Latvia in the i-th year;

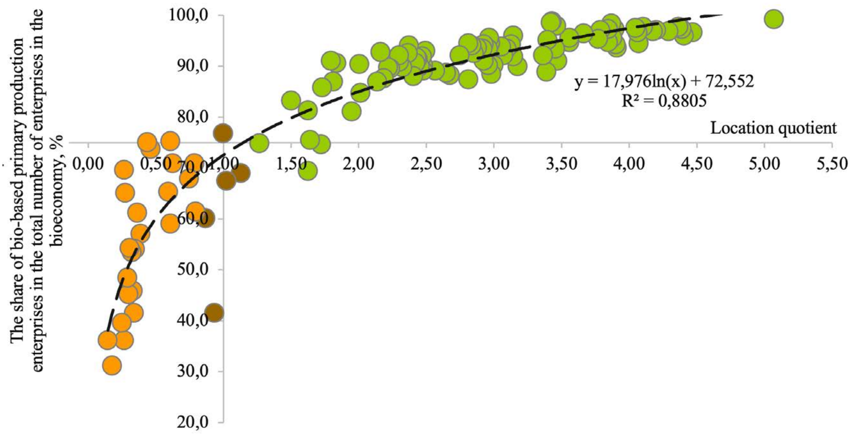
EB_{LV} is the number of bioeconomy enterprises economically active in the market sector in Latvia in the i-th year;

ET_{LV} is the total number of enterprises economically active in the market sector in Latvia in the i-th year.

The following interpretations of the ranges of LQ values are used to estimate the degree of concentration:

- an LQ value > 1 means a higher concentration of the characteristic being analysed than the Latvian average;
- an LQ value < 1 means a potential deficiency of the characteristic being analysed;
- an LQ value = 1 (± 0.15) means that the distribution f the variable being analysed is similar to the distribution of that variable in the reference area.

Further information on the methodology for calculating the location quotient of the bioeconomy is available in a publication prepared by scientists at the Latvia University of Life Sciences and Technologies (Muska et al., 2023):



Source: Musk et al., 2023

Figure 5.8 **Scatter chart of the location of Latvian administrative territories between the bioeconomy location quotient, and the share of bio-resources primary production enterprises in the total number of bioeconomy enterprises (%) in 2019, Latvia**

According to these two criteria, three main groups A, B and C were identified (Table 5.1):

- group A: higher concentration of bio-economy than the Latvian average and bio-resources primary production enterprises account for more than 75% of total bio-economy enterprises;
- group B: the concentration of bio-economy is the same as the Latvian average and bio-resources primary production enterprises account for less than 75% of total bio-economy enterprises;
- group C: a potential deficit of bio-economy and bio-resources primary production enterprises account for less than 75% of total bio-economy enterprises.

Table 5.1

Groups of municipalities with different levels of bioeconomy concentration in Latvia, 2019

Group of municipalities	Municipalities		Location quotient (LQ)			TOP bioeconomy industries (NACE)
	Number (n)	*Share (%)*	*Min.*	*Max.*	*Average*	
Group A: municipalities with a higher concentration of bioeconomy than the national average	89	75	1.15	5.07	2.98	Crop and animal production, hunting and related service activities (A01) Forestry and logging (A02)
Group B: municipalities with the same concentration of bioeconomy as the national average	5	4	0.87	1.13	0.99	Manufacture of food products (C10) Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (C16)
Group C: municipalities with a potential bioeconomy deficit	25	21	0.15	0.79	0.42	Manufacture of food products (C10) Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (C16)

Source: Musk et al., 2023

Group A: higher concentration of bio-economy than the Latvian average and bio-resources primary production enterprises account for more than 75% of total bio-economy enterprises.

Group A includes the majority of Latvia's municipalities (89 municipalities or 81%). In the municipalities belonging to this group, the bioeconomy concentration index ranges from 1.15 to over 5, and most of the economically active enterprises in the market sector are active in the primary production of bio-resources (mainly in sectors A01, A02). Consequently, the primary bio-resources production sectors are the dominant sectors in these municipalities. In municipalities with LQ greater than 3, the number of enterprises in the bio-resources primary production sectors exceeds half of all enterprises. In nine regions (Vārkava, Rugāji, Riebiņi, Baltinava, Jēkabpils, Priekule, Durbe, Aknīste, and Dagda) the share of the number of enterprises in sector A exceeds 70%.

A more detailed study of the data for the municipalities (32 in total) where the share of bio-resources primary production enterprises is below 40% showed that the TOP 5 sectors by the number of economically active enterprises in the market sector (according to NACE Rev.2 classification) are:

1. agriculture, forestry and fishing (A sectors)
2. wholesale and retail trade, repair of motor vehicles and motorcycles (G sectors);
3. processing industry (C sectors);
4. professional, scientific and technical services (M sectors);
5. real estate operations (L sectors).

As some of the processing industry sectors are bio-based, the study classified the processing industry sectors into two groups:

1. bio-resources processing sectors (i.e. sectors C10, C11, C12, C15, C16 and C17, and the bio-based part of sectors C13, C14, C20, C21, C22, and C31);
2. other C sectors (i.e. the non-biobased part of sectors C13, C14, C20, C21, C22, C31 and C3511 and other C sectors C18, C19, C23-C30, C32, and C33).

The analysis of the structure of processing industry shows that:

- bio-resource processing sectors (mainly C10 and C16) dominate by number (more than half of the total number of C sector enterprises) in most (24 out of 32) of the municipalities analysed;
- in Bauska, Brocēni, Burtnieki, Iecava, Kocēni, Lubāna, Saldus and Strenči municipalities, other C sectors dominate (accounting for more than half of the total number of C sector enterprises).

Group B: the concentration of bio-economy is the same as the national average and bio-resources primary production enterprises account for less than 75% of total bio-economy enterprises.

This group includes five municipalities: Mērsrags, Lielvārde, Ozolnieki, Ropaži and Ogre municipalities.

The TOP 5 sectors in the municipalities in group B are:

1. wholesale and retail trade, repair of motor vehicles and motorcycles (G sectors);

2. processing industry (C sectors);
3. professional, scientific and technical services (M sectors);
4. construction (F sectors);
5. an then – agriculture, forestry and fishing (A sectors).

Source: Musk et al., 2023

Figure 5.9 **Sectoral breakdown (NACE Rev.2) by number of economically active enterprises in the market sector in the municipalities in group B in 2019, %**

The share of A sectors ranges from 7% (Mērsrags municipality) to 14% (Lielvārde municipality), while the share of processing industry sectors ranges from 9% (Ogre municipality) to 11% (other municipalities).

The analysis of data on the processing industry sectors shows that:

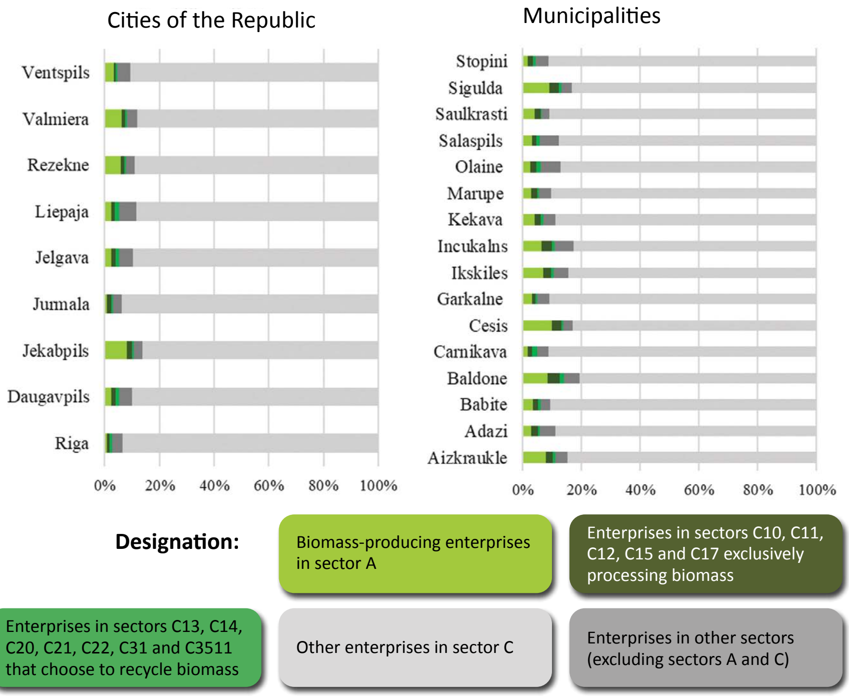
- bioresources processing sectors (mainly C10 and C16) dominate in Mērsrags municipality, accounting for more than 88% of the total number of enterprises in C sectors;
- in Lielvārde, Ozolnieki and Ropaži municipalities, the bioresources processing sectors (mainly C10 and C16) have a slight

predominance (55%) over the other C sectors (around 45%);

- in Ogre municipality, the other C sectors (54%) slightly outnumber the bioresources processing sectors (mainly C10 and C16) (46%).

Group C: a potential deficit of bio-economy and bio-resources primary production enterprises account for less than 75% of total bio-economy enterprises.

This group includes 16 Latvian municipalities and all (nine) cities of the republic. Most of the areas in this group are municipalities adjacent to the capital of the state.



Source: Musk et al., 2023

Figure 5.10 **Structure of sectors (according to NACE Rev. 2 classification) by number of economically active enterprises in the market sector in group C in administrative areas in 2019, %**

The share of the economically active enterprises in the bioeconomy in the market sector in the total number ranges from 2.6% in the national capital Riga to 14.0% in Baldone municipality.

This group is characterised by a higher share (above the national average) of enterprises operating in the bioresource processing sectors compared to groups A and B. Bioeconomy sectors are not the dominant sectors in these municipalities.

In the cities of the Republic in group C, the TOP 5 sectors are:

1. wholesale and retail trade, repair of motor vehicles and motorcycles (G sectors);
2. real estate operations (L sectors);
3. professional, scientific and technical services (M sectors);
4. construction (F sectors);
5. TOP 5 is concluded by processing industry (C sectors).

In the municipalities in group C, the TOP 5 sectors are:

1. wholesale and retail trade, repair of motor vehicles and motorcycles (G sectors);
2. construction (F sectors);
3. professional, scientific and technical services (M sectors);
4. processing industry (C sectors);
5. real estate operations (L sectors).

Analysing the data on the number of enterprises by cross-section of processing industry sectors, it was found that:

- in Baldone municipality, the bioresources processing sectors (mainly C10 and C16) and the other C sectors are equally developed (50/50);
- in Cēsis and Sigulda municipalities, the bioresources processing sectors (mainly C10 and C16) slightly dominate the other C sectors;
- in Jēkabpils, Saulkrasti and Babīte municipalities, the other C sectors slightly outnumber the bioresources processing sectors (mainly C10 and C16);

- other C sectors dominate in other municipalities and cities.

In its study, the Employers' Confederation of Latvia (LDDK) has also concluded that most companies in Latvia operate in the areas of crop and livestock production, hunting, retail trade, personal services, real estate and wholesale trade. The number of companies representing other fields is limited to 5% each. Although these sectors are almost equally represented in all regions, there are some regional differences. In the Riga region, crop and livestock farmers, and those active in the field of hunting represent a much smaller share of the total number of enterprises than in other regions, while wholesalers represent a larger share than in other regions. The share of forestry and logging enterprises is higher in Vidzeme, Kurzeme and Latgale than in other regions. Zemgale has traditionally been considered an agricultural region, as well as an industrial one.

When studying the competitiveness of entrepreneurs in Latvian municipalities, the LDDK has concluded that there are differences between Latvian regions and that most of the regional differences can be attributed to the factor of geographical location – distance from the capital city, proximity to the sea, proximity to road junctions, availability of natural resources, etc. The authors of this chapter also consider that the availability of natural resources is a crucial factor for the development of the bioeconomy, especially the bioresources primary production (mainly agriculture and forestry) sectors throughout the country. This is also confirmed by the authors' correlation analysis, which showed a strong non-linear relationship ($r = 0.9383$) between the *location quotient* of the bioeconomy and the share of bioresource primary production enterprises in the total number of bioeconomy enterprises.

The Employers' Confederation of Latvia analysed the sustainable development strategies and implementation plans of Latvian cities and municipalities to gather information on how Latvian municipalities want to specialise in terms of business and economic development. Conclusion: a large number of municipalities attribute their territorial specialisation to natural capital – 27% primarily view nature as a resource and 6% as something to be protected and preserved. The authors of the chapter assume that there is insufficient understanding of the role of local governments in promoting and developing entrepreneurship in their territory. In the sustainable development strategies and implementation plans of Latvian cities and municipalities, the objectives set by local authorities for entrepreneurship and economic development are often limited to developing existing activities and are not ambitious, so incentives and tools are needed to educate local governments in this area.

In the document “Regional Policy Guidelines 2021-2027” the Ministry of Environmental Protection and Regional Development of the Republic of Latvia (MoEPRD) has pointed out that the planning capacity of local governments is one of the major challenges and investment needs after 2020. The need for capacity building in development planning has also been pointed out by the State Audit Office (VK) of the Republic of Latvia, which in its audit has found that 47 municipalities did not have a spatial development planning specialist with basic responsibilities. Also, in some cases, outsourcing is used in the preparation of municipal spatial development documents, which does not always ensure full contact with citizens on development planning issues. The practice of developing spatial development planning documents in a participatory manner should therefore be improved. According to the data available to MoEPRD, 30 municipalities do not have a specialist specifically responsible for entrepreneurship issues, even though this is one of the municipality’s functions. Nor is it the only responsibility of a number of business specialists (in 50 municipalities it is the main responsibility of the specialist).

In order to increase the capacity of planning regions and municipalities’ specialists, the MoEPRD in cooperation with sectoral ministries as well as other stakeholders (higher education institutions in the regions, civil society groups, etc.) plans to provide methodological guidance to planning regions and municipalities for the elaboration of spatial development planning documents, as well as to organise capacity-building events in various formats (attraction of specialists, seminars, conferences, summer schools – camps, experience exchange visits, etc.).

In general, it can be concluded that Latvian administrative territories are dominated by companies operating in traditional bioeconomy sectors, which are oriented towards primary production of bioresources (mainly agriculture and forestry). Although Latvia is located on the Baltic Sea (the total length of the Latvian coastline is 497 km), the number of companies involved in fisheries and aquaculture is small.

Among the bioresources processing sectors in Latvian regions, food production (sector C10) and wood, timber and cork production (sector C16) dominate . These two sectors of the bioeconomy generated a turnover of EUR 3.8 billion (47% of the total turnover in the bioeconomy) in 2019, employing more than 40 thousand people (17% and 16% respectively), and added value of EUR 0.95 billion.

Biomass feedstock processing industries (bio-based chemicals, bio-based pharmaceuticals, plastics and rubber, textiles and electricity) make a small contribution to employment, turnover and value added in Latvia.

Industries are divided into several groups according to the technologies they use. One of the most widely used breakdowns is high-tech (bioresources processing sector C21), medium-high-tech (bioresources processing sector C20), medium-low (bioresources processing sector C22), and low-tech (bioresources processing sectors C10-C17 and C31) sectors. Based on this breakdown, it can be concluded that in Latvia the bioresources processing sectors are dominated by **low-tech sectors**, i.e. the *manufacture of food products* (sector C10) and the production *of wood and products of wood and cork* (sector C16), therefore incentives and instruments are needed for both local authorities and entrepreneurs to facilitate the transition from low-tech to medium-high-tech (C20) and high-tech (C21) sectors. This will ensure a more sustainable development of the bioeconomy and national growth.

Latvia's "National Industrial Policy Guidelines 2021-2027" emphasise the need to stimulate more innovation in the bioeconomy, targeting the mass production of higher value-added products to boost productivity and innovation, and productivity-led exports. Moreover, given the challenges posed by climate change, it is essential to target the development of research (human capital) expertise and innovation capacity for climate change adaptation in forestry and agriculture now. Given the significant impact of the sector on export performance, as well as its overall impact on the development of sustainable thinking in society, the effective dissemination, accumulation, transformation and transfer of knowledge to future generations is of paramount importance.

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6. INNOVATION IN THE BIOECONOMY

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Knowledge is the most important factor of production today, and even more so: knowledge is the most important factor of change, both change that creates unwanted side effects (externalities) and change that can address them, creating the potential for a more sustainable and efficient economy. While the economy was built on increasingly diverse and cheap natural resources in the 19th century, and on investment and product diversification and globalisation in the 20th century, today it is data, information and knowledge that are crucial for innovation and economic growth.

Innovation plays a much more important role in the bioeconomy than in the economy as a whole, even though it is key to increasing economic potential, rebooting the business cycle and improving quality of life. Bioeconomy sectors provide most of raw materials and almost all of food. The World Resources Institute estimates that food production has tripled since 1960, with inevitable impacts on drinking water consumption, availability of ecosystem services and climate change. At the same time, the world's human population continues to grow, with 9.8 billion people projected to consume humanity's ecosystem services by 2050, requiring 70% more food than today. This requires changes and new solutions along the food chain, starting with more sustainable farming, more efficient processing, fairer distribution and more conscious consumption.

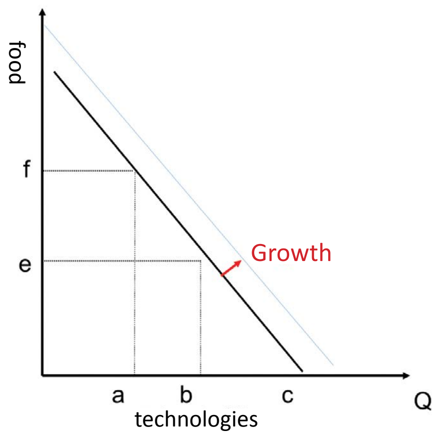
We love new technologies that celebrate human creativity while at the same time mimicking the power of evolution, without taking into account the multiple side effects that are created in the process. G. Herrington asks "Why should we use our capacity for innovation to invent pollinators to replace bees when we have the potential to develop agricultural practices that do not have the side effects of insecticide use?". In his study, G. Herrington shows that humanity can be saved by a combination of extraordinary technological advances and their rapid adoption, and changes in societal values and priorities (Herrington, 2021). Changes in societal values and the interaction between social and ecological systems are the discussed in more detail in Chapter 2; this chapter is devoted to the development of innovation in the bioeconomy. This chapter examines the concept of innovation and its role in the bioeconomy, the role of the innovation ecosystem and the drivers and functioning of the innovation system.

6.1. The role of innovation and knowledge in the bioeconomy

The concept and notion of innovation is becoming more and more embedded in business practice. As P. Drucker (1954) has noted, "Entrepreneurship has only two basic functions: marketing and innovation. Marketing and innovation produce results, all the rest are costs". The slogan "innovate or die", so popular in business today, applies not only to individual companies, but also to the economy as a whole. If we fail to find solutions that reduce humanity's impact on the ecosystem, promote resource efficiency and socially responsible consumption, it will be impossible to avoid the Malthusian catastrophe mentioned in the previous chapters – a total human decline due to resource scarcity and social tensions. On the other hand, there is still technological optimism, and so far it has been possible to "postpone the end date" ever further. Surprising as it may seem, this is in line with the basic postulates of the prevailing view of capitalist economics. Almost 100 years ago, J. Schumpeter pointed out: "The process of creative destruction is an important feature of capitalism. This is why capitalism exists and why it matters." (J. Schumpeter, 1942).

Creative destruction is essentially a natural process of a market economy, where less efficient technologies, products and companies are replaced by more efficient ones. In other words, innovation is an essential economic function that determines growth and overcomes the stagnation or crises caused by capital growth and concentration due to diminishing returns. In the context of climate change and resource scarcity, bioeconomy industries have not only the opportunity, but the challenge to become innovation drivers in a context of creative destruction.

The most popular definition of innovation in Latvia stipulates that innovation is a process in which new scientific, technical, social, cultural and other field ideas, developments and technologies are implemented in a market demanded and competitive product or service (Guidelines for Science, Technology Development, and Innovation 2021–2027). It is all based on the competitive market model that determines the viability of a new technology or idea, and if it exists in the market and meets the needs of a section of society, it is innovation. The simplified approach would be to consider that innovation is a commercialised idea or money earned. This is certainly true at company level, but in the economy, innovation plays a broader and more strategic role, resulting in faster growth.



Source: compiled by the author

Figure 6.1 **The equal opportunities curve and growth**

Growth is the excess of economic potential over which more can be produced with existing resources (Figure 6.1). Exceeding economic potential may sound ambiguous, because how can potential be exceeded? The answer is: innovation that allows technological and human capital development, which is often difficult to predict accurately. On the other hand, it is difficult to explain economic growth without these factors, because once economic potential is reached, the economy must enter a crisis that can only be overcome by increasing the availability of labour in the first place and other resources in the economy in the second place. But many countries are experiencing economic growth in a context of declining labour availability, including Latvia.

In fact, knowledge has become the most important factor for development, creating a new paradigm of economic development called the knowledge-based economy. The concept has its origins at the turn of the century and has been defined by the OECD as a concept designed to describe trends in advanced economies. They need to become more dependent on knowledge, information and high levels of skills, and to meet the growing need of business and the public sector for easy access to all this (OECD, 1996). Economic development, which traditionally starts with resource exploitation and focuses on the use of cheap raw materials and resources to produce standardised mass products, is being transformed into a more industrial one: it focuses on investment in imported innovation (exnovation) to produce high value differentiated products, which leads to the need to develop technology and build an indigenous knowledge (science) base, to become an endogenous factor of growth, and this stimulates investment in R&D not only to produce high value complex products, but to create completely new product and service groups, making full use of resources (Dahlman et al., 2006). This means that the bioeconomy is not a concept about the use of bio-based resources, which is essentially part of the natural resource economy, but about the sustainable and intelligent use of bio-based resources to meet the needs of society.

Knowledge is crucial for transforming the natural resource economy into a bioeconomy. At the same time, if one wants to emphasise the role of knowledge in the development of the bioeconomy, the knowledge-intensive economy can be defined as the development of traditional sectors that use natural resources, agriculture, forestry and fisheries, food and beverage production through research-based technological and social innovations with the aim of increasing the productivity of these sectors, efficient use of resources and competitiveness at regional and international level (MoES, 2020). It should be stressed that the above definition of a knowledge-intensive bioeconomy has a political context related to the implementation of the Latvian Smart Specialisation Strategy (RIS 3), where the knowledge-intensive bioeconomy is one of the specialisation areas.

According to the World Bank Institute (Chen, Dahlman, 2006), there are four essential preconditions for a knowledge-based economy, which are equally important for the development of the bioeconomy:

- **Economic incentives and institutional arrangements** that ensure good economic policies, and institutions that allow for efficient mobilisation and allocation of resources, stimulate creativity and efforts to create, disseminate and use existing knowledge efficiently.
- **Educated and skilled workers** who can continuously improve and effectively adapt their skills to create and use knowledge.
- **Efficient innovation system** for firms, research centres, universities, consultants and other organisations that can keep pace with the knowledge revolution and harness, assimilate and adapt growing global knowledge to local needs.
- **A modern and adequate information infrastructure** that can facilitate effective communication, dissemination and processing of information and knowledge.

In essence, the prerequisites are to build innovation systems that include human capital development measures, digitisation and infrastructure development and support policies. At the same time, these themes cut across fiscal, regional, education and science policies, which means that the development of bioeconomy innovation requires the creation of specific strategic documents.

The Bioeconomy Strategy (EU Bioeconomy Strategy, 2018) is part of the EU's policy to promote knowledge, with three priorities:

1. strengthen and expand bioresources industries, stimulating

investment and market development;
2. stimulate local bioeconomies across Europe;
3. understand the ecological constraints to bioeconomy development.

Although this strategy paper has no legal implications, it is an initiative document whose principles have found their way into other EU policies and have inspired the creation of national bioeconomy strategies in at least 12 Member States, with several more in the pipeline. Latvia was one of the first countries to develop its Bioeconomy Strategy (Latvian Bioeconomy Strategy 2030) with active involvement from LBTU, which includes three strategic goals:

1. ensure that employment in the traditional sectors of bioeconomy in 2030 would remain at the level of 2015, i.e. 128 thousand people;
2. increase the value of exported goods from EUR 4.25 billion in 2016 to at least EUR 9 billion in 2030;
3. increase the added value in traditional bioeconomy sectors from EUR 2.33 billion in 2016 to EUR 3.8 billion in 2030.

The Strategy also underlines that research excellence of the traditional bioeconomy sectors and efficient transfer of knowledge are preconditions for the achievement of the strategic objectives for the development of bioeconomy. In summary, developing innovation in the bioeconomy has the same conceptual basis as innovation in general. This is: meeting society's growing needs for goods and services through new technologies and ideas, which in turn contribute to market development and the renewal of the economic cycle in line with society's changing development challenges. Targeted development of bioeconomy innovation and the creation of an appropriate ecosystem is one of the challenges of the economic transformation towards a sustainable economy.

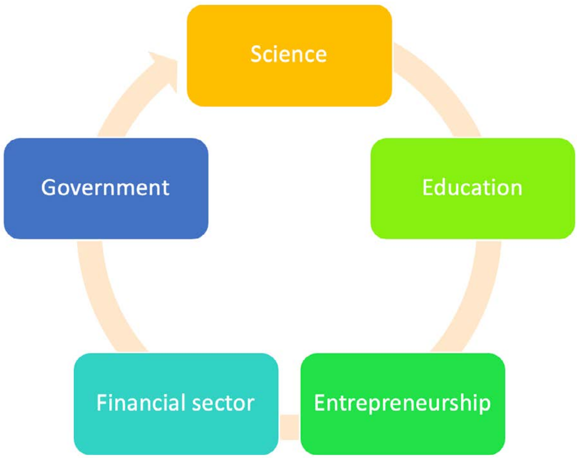
6.2. Developing innovation in the bioeconomy and building its ecosystem

Bioeconomy innovation cannot be seen as a technological development in the bioeconomy, but as a paradigm shift in the economy. Haen et al.

(2012) point out that the transition from petrochemicals to bio-based chemistry is a paradigm shift across the chemical industry, requiring a strong emphasis on interdisciplinary research and education. This vision can be applied to all sectors of the bioeconomy. The bioeconomy is characterised by three essential features: creativity, which provides original solutions to existing complex problems; innovation as the ability to implement these ideas, the ability to adapt to continuous technological change in the infrastructure of the economy; and this is not possible without an innovation system that ensures the continuity and viability of the innovation process. Such a system consists of components, relationships and attributes. Components are the working parts of any system, relationships are the links between components and attributes are the properties of components and relationships that characterise the system. This means that if we want to understand and manage complex systems, such as an economy or an innovation system, it is not just the components that matter, but the ability to qualitatively develop and interact between them. This will ensure the desired result: an increase in GDP for the economy, export potential in the case of innovation, and value added.

Creativity, big ideas and new technological solutions in the economy depend directly on a strong science sector. Scientific progress has led to a huge amount of new scientific knowledge. Around 5 million new scientific publications are published every year, with a 22% increase in the last five years (as of 2018) (Curcic, 2023). This is a vast amount of new and socially relevant information in all areas of importance to humanity, including politics and economics. At the same time, scientific ideas alone do not guarantee the development of society and technological progress in the economy. In the 1990s, attention was drawn to a phenomenon that has been called the European paradox. In particular, the European science space has long been characterised by a high number of internationally relevant publications and conferences, but at the same time a relatively low number of patents and limited high-tech trade (Rodriguez-Navarro et al., 2018). The focus of policy makers on the science sector does not yet imply a linear model of innovation between science and business. Strengthening the links between these sectors is also important.

Making scientific developments a factor of production requires that science focuses not only on fundamental discoveries, but also on applied and marketable discoveries. There are many different definitions of a national innovation system, such as: "... a network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987); "... elements and relationships that interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state." (Lundvall, 1992); "... a set of institutions whose interactions determine the innovative performance ...of national firms" (Nelson, 1993). Common to all definitions is the set of institutions (elements) that ensure the dissemination and use of economically relevant knowledge.



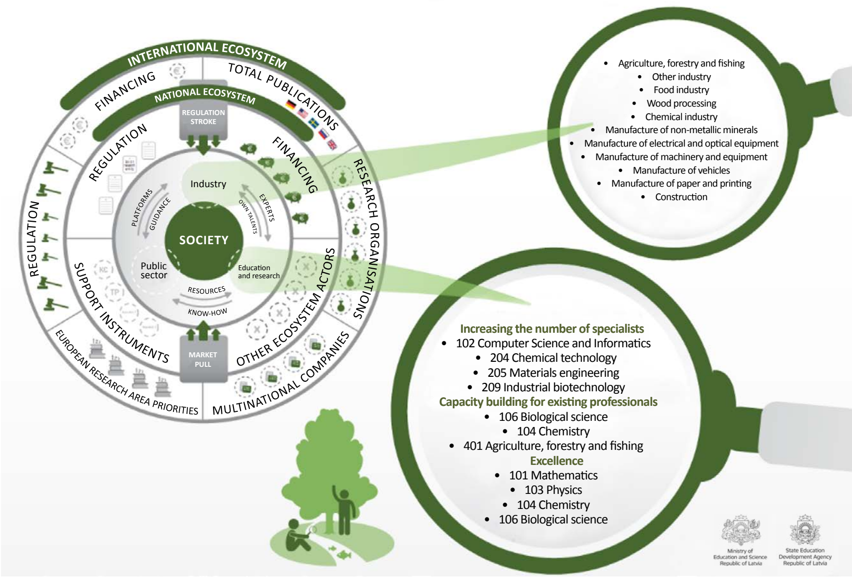
Source: by the authors.

Figure 6.2 **National innovation system**

At both micro and macro level, economic success is important, as it can be counted as additional added value that creates a comparative advantage for economic development. At the same time, these two key elements are unthinkable without an education sector that ensures the generation and exploitation of scientific ideas; financial services that support venture capitalists, because innovation is a complex process with many uncertainties that are difficult to predict; and a state that can integrate these elements into a single workable system. Technological change has had a major impact on the ability to generate and exchange data, which inevitably affects the flow of knowledge in the economy. At present, it is not possible to speak of a linear innovation system, where knowledge generated in research institutions is further commercialised in the business sector. Today, innovation can come from many different sources, which is why we can speak of an interactive innovation model.

The interactive innovation model requires a real relationship with industry to identify needs. The linear model requires communication and marketing work after the study. The inefficiency of this process has led to linear models being replaced by spiral or triple helix models and open innovation models, in which coordination between the actors in the system (researchers, companies, government, coordinators) becomes crucial. In the context of the bioeconomy, there is a need for various coordination councils and cooperation groups to facilitate collaboration between primary producers, processors, traders and government. The very strong political context due to the global challenges means that NGOs, lobbies and policy makers play an important role, and it is the latter that is essential for the functioning of a national innovation system.

An innovation ecosystem is a dynamic system made up of actors exchanging knowledge made possible by formal links. In essence, it is similar to an ecosystem based on the flow of energy, as opposed to an innovation system that exchanges knowledge. This is why, using the taxonomy of the natural sciences, we speak of an innovation ecosystem. It is necessary to combine technology with an understanding of complex systems and to make a major effort to integrate social and human aspects. In this way, transdisciplinary research integrating sustainability science, climate research, ecology, biology, agriculture, forestry, economics, sociology, political science, psychology, human health and epidemiology, and many other fields of science are much needed.



Source: Ministry of Education and Science of the Republic of Latvia, 2015

Figure 6.3 **Knowledge-intensive bioeconomy and the ecosystem that supports its creation**

The Knowledge-intensive bioeconomy is the development of traditional sectors that use natural resources, agriculture, forestry and fisheries, food and beverage production through research-based technological and social innovations with the aim of increasing the productivity of these sectors, the efficient use of resources and competitiveness at regional and international level. Innovation in the bioeconomy includes not only research and creation of new products and services, but also the finding of solutions for more efficient use of resources and optimisation and quality improvement of processing processes, as well as non-technological innovations for the creation of higher added value products and services. The concept of bioeconomy provides for the gradual replacement of fossil fuels by bio-based and renewable resources, and the increasing adoption of circular economy principles. Latvia has developed a Smart Specialisation Field "Knowledge-intensive Bioeconomy" Strategy 2022-2027, which, taking into account the objectives of LIBRA (Latvian Bioeconomy Strategy), has defined a mission to achieve sustainable, knowledge and innovation-led growth of the bioeconomy sector, which will contribute to economic development, social empowerment and the achievement of climate and environmental goals, in order to move towards the objectives set by the European Green Deal. The strategy outlines development pathways: innovation in bioeconomy education, agriculture, bioenergy, food, forestry, water management, materials from renewable resources, and highlights the importance of funding for ecosystem investments to boost export capacity and investments in research and development.

6.3. Types of innovation in the bioeconomy

While the bioeconomy is growing rapidly, it is considered an early-stage sector and needs innovation to build strength and increase value. Many authors argue that making the bioeconomy more competitive requires more investment in research, new products and services, or more policy incentives. While innovation is often mentioned in bioeconomy strategies and considered as one of the most important drivers of the bioeconomy, current research on innovation focuses more on a classical approach, explaining the difference between product and process innovation, but does not take into account the specificities that are important for scaling up and accelerating the transition to a bioeconomy. There is also a lack of a concise conceptual framework to distinguish between different types of innovation, in particular those that enable a shift towards new thinking, new economic processes, new behaviours, new business models.

Overall, the objectives of bioeconomy innovation are to reduce societal problems and promote environmental benefits. It is usually a radical innovation, with the main difficulty being market entry, as the main barrier is the traditional fossil-based economic system and mindset that exists and is ingrained in the public consciousness. Bioeconomy innovation is also cost and risk intensive, so the policy framework requires forward-looking and sophisticated strategic leadership that ensures the strategic renewal of economic systems.

In this subchapter, the authors provide an overview of the typical types of bioeconomy innovation found in practice and contributing to bioeconomy competitiveness (Table 6.1).

Table 6.1

Types and description of innovation in the bioeconomy

Type of innovation	Description	Example
Replacement products	Innovation that helps replace fossil resources in products with renewable energy and plant-based resources.	Cotton packaging bag
New processes	Innovation that occurs in a bio-based production process and leads to incremental change, improving the performance of an established process, or is disruptive, resulting in a new value chain, new processing options.	Algae biorefinery
New products	Innovation that creates new products made from bio-based materials with new functions.	Biodegradable stents for medical manipulation
New behaviours	Innovations that require a new way of doing things, or are driven by a new way of behaving.	A company wants to optimise a product's ecological footprint

Source: compiled by the authors, based on Bröring et al., 2020

Replacement products

One of the most talked-about challenges of the bioeconomy is the replacement of fossil fuels such as petrol with renewable and plant-based resources. This type of bioeconomy innovation fulfils this role and is one of the most popular and easily understood types of bioeconomy innovation today. Replacement products of organic origin generally have a wide range of uses that can be easily incorporated into existing value chains. The replacement product is new, but does not offer any new functions and is produced using bioresources. For every replacement product offered by the bioeconomy, a similar product can be found in a fossil-based economy (Table 6.2).

Table 6.2

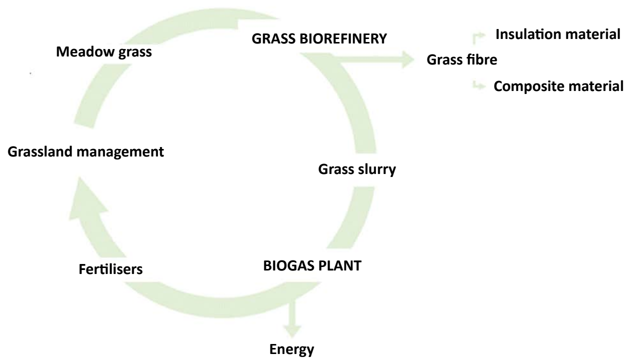
Examples of a type of bioeconomy innovation – a replacement product

Product from a fossil-based economy	Replacement product from the bioeconomy
Polypropylene (PP), polyethylene (PE) or polystyrene (PS)	Polylactic acid (PLA)
Oil	Bioethanol from lignocellulose
Oil	Bioethanol from microalgae

Source: by the authors

New processes

New processes include all innovations in bio-based production and value chains that are either incremental, improving the performance of a process, or disruptive, resulting in new value chain connections and new processing options. With radical process innovation, entirely new value chains can develop. The most typical example of this type of innovation is new biorefineries.



Source: compiled by the authors, based on Zörb et al., 2017

Figure 6.4 **Example of grass biorefinery**

Biorefinery is based on the principle of feedstock cascading, which ensures the efficient use of bioresources to produce new materials. Figure 6.4 gives an example of a grass biorefinery, where new materials and products are extracted from grass – insulation material, composite material, energy.

Grass biorefinery

Based on the biorefinery concept, the Swiss-German company Biowert Industrie GmbH was founded in 2000 and the first Biowert grass processing plant, located in Brensbach, Germany, became operational in 2007.

The main products derived from pasture grass are grass fibre insulation material (AgriCellBW), grass fibre reinforced plastic (AgriPlastBW) and fertiliser made from digestate (AgriFerBW).

The annual throughput of the plant is approximately 2 000 t of dry matter, which is equivalent to 8 000 t of grass per year with a dry matter content of 25–30%. The integrated biogas plant produces an average of 1.3 million m3of biogas per year, which is used in a combined heat and power plant that produces an average of 5.2 GWh of electricity.

More information on this grass biorefinery can be found in the material produced by the IEA Bioenergy

New products

This type of bioeconomy innovation could lead to the development of products with unforeseen applications or create entirely new value chains. These products have radically new functionalities or set new technological standards.

Examples of this type of innovation:

- biodegradable stents for medical manipulation;
- building material with low emissions, temperature efficiency and antimicrobial properties;
- new biological parts created by synthetic biology for a specific purpose.

New behaviours

The focus is on the concept and intent of the bioeconomy, such as the cascading use of feedstocks. It is a new way of organising business, based on the desire to change towards sustainable production. The will to change can come either from customers, through increased demand for organic products, or from users, through the development of sharing concepts and so on.

Often new behaviours evolve through servitisation, a transformation process in which a company moves from a product-oriented to a service-oriented business model and logic. This type of bioeconomy innovation can also be a new type of collaboration with stakeholders, in particular with secondary stakeholders such as higher education institutions or public authorities.

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7. ROLE OF DIGITALISATION IN PROMOTING THE DEVELOPMENT OF THE BIOECONOMY

Authors: Dina Popluga, Sandija Zēverte-Rivža

This chapter is based on examples of how digitalisation and biotechnology together can provide solutions to key bioeconomy policy objectives that could not be achieved in each area alone. Digitalising the bioeconomy involves combining different technologies to solve problems, optimise production and use available resources more efficiently. The combination of digital and bio-based transformation can significantly change the production process and even create new business models. While the digitalisation of the bioeconomy is seen as a future direction, it is in fact already underway, and this chapter looks at its various aspects and gives examples.

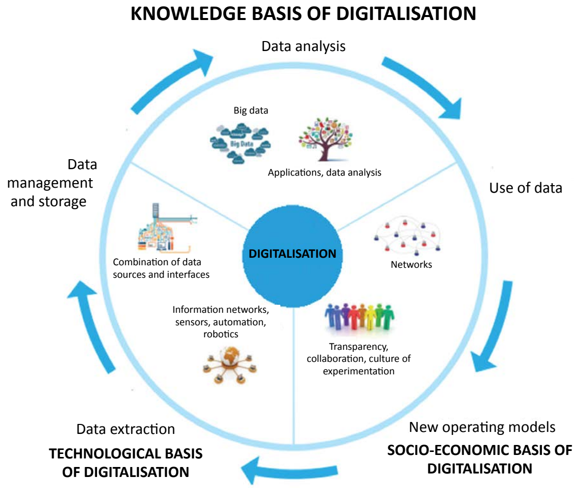
7.1. Basis and barriers to the digitalisation of the bioeconomy

The conceptual content of the bioeconomy cannot be separated from natural resource management, the promotion of renewable resources, climate change mitigation and food security. Digitalisation has become an important feature of the bioeconomy in recent years. In the context of the bioeconomy, digitisation encompasses a range of different activities, typically related to data collection, electronic processing, data exchange and data management. This is why both the bioeconomy and the digital economy are described as two future trends that are driving and leading the transformation of the economy of today. From a bioeconomy perspective, there are measurable benefits from using new technologies. For example, new technologies can help employees make operational decisions based on bioeconomy principles and improve the economic and environmental sustainability of products through resource efficiency.

The debate on the digitalisation of the bioeconomy cannot be just about technological change. Digitalisation is changing the role of information and is a kind of enabler of business efficiency. This implies a fundamental change in the way business as usual is conducted, with digital solutions being widely used in the activities of individuals, organisations and society. In this context, the digitisation wheel (Figure 7.1) developed by Finnish researchers gives a good idea of the scope of digitalisation, showing that technological advances contribute to the emergence of new business models, which in turn require new technological and organisational solutions.

The technological basis of digitalisation is the integration of digital technologies, automation, data exchange and intelligent systems. These advances also make it possible to collect measurement data from sites that were previously impossible to monitor technologically. In terms of the use of data, it is important to develop its management and storage, for example through cloud-based services for data storage and the integrated use of different combinations of data sources. It is important to stress that data will not create new added value in itself. Only through analysis and interpretation can the data become information that can inform the development of new activities or the optimisation of existing ones. This is one of the main reasons why digitalisation also depends on the development of data analysis solutions and applications. In addition, effective data analysis requires data of sufficient quality and accuracy.

The socio-economic basis of digitalisation is the use of data and the way it is organised. The most typical patterns of action that digitalisation has initiated are the emergence of different types of networks or collaborations, with a greater focus on transparency of process or on fostering a culture of experimentation. The role of people in the further development of digitalisation is also being given greater emphasis in the context of Industry 5.0, the next stage after Industry 4.0. Technological innovation and its exploitation is a key feature, while Industry 5.0 is seen as a potential phase where humans and machines work more closely together, emphasising human skills alongside technological advances.



Source: adapted from VTT, 2017

Figure 7.1 **Digitisation wheel and its main operating conditions**

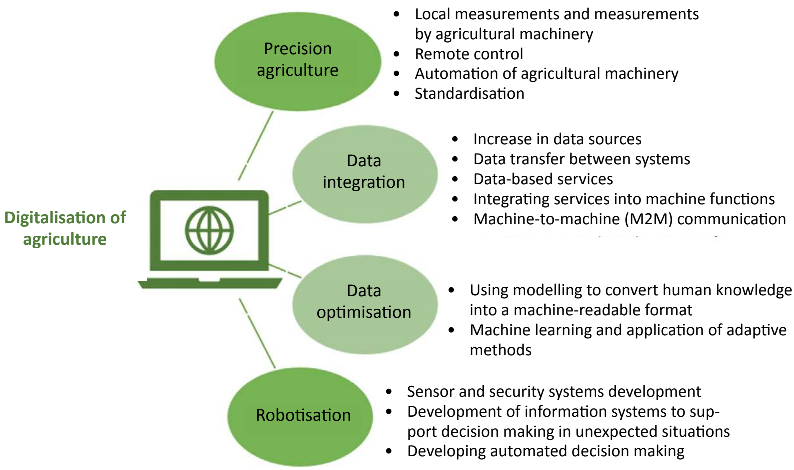
How can digitalisation boost the bioeconomy? More broadly, digitalisation is about progress, efficiency and speed of processing. New digital tools for information use and communication technologies for identification, monitoring, analysis and representation are widely applicable in all sectors of the bioeconomy. But certain sectors, such as the bio-resource producing sectors – agriculture, forestry, and fisheries – are making their business operations more efficient by introducing digital technologies into their daily processes, as many of the benefits of digitalisation are linked to increased efficiency through precision mechanisation, automation and improved decision-making. Agriculture is expected to play an important role in driving digital progress, which focuses on advances in smart or (initially) precision agriculture.

What is Industry 4.0?

Industry 4.0, also known as the Fourth Industrial Revolution, reflects the integration of digital technologies, automation, data exchange and intelligent systems in the manufacturing and industrial sectors. The key features of Industry 4.0 are:

- Internet of Things (IoT): devices and machines are connected to each other, allowing them to communicate and share data; big data and analysis: collecting and analysing large amounts of data to make informed decisions and optimise processes;
- artificial intelligence (AI) and machine learning: using algorithms to improve automation and decision making;
- robotics and automation: the use of robots and automated systems for repetitive or complex tasks;
- cyber-physical systems: integration of physical equipment with digital systems to optimise operations.

An analysis of the digitalisation process in agriculture shows that there are several phases: precision farming, data integration, data optimisation and robotics (Figure 7.2). Of these stages, ***precision farming*** is considered to be the first stage of the digitalisation process. Precision farming focuses on the precise and targeted application of fertilisers and crop protection products, tailored to the needs of each crop. These needs are determined on the basis of measurements made by appropriate equipment, remote sensing data and analyses carried out. Technical advances in precision technologies, the integration of Internet of Things (IoT) technologies and the falling cost of sensors have led to greater availability and increased use of these technologies in agriculture. More and more accurate information is being obtained on different parts of crops, at different stages of their growth, and on the health status of livestock on the farm. Advances in precision technologies make it possible, for example, to collect accurate data and thus increase the accuracy of crop growth modelling and forecasting, further facilitating automated decision making.



Source: compiled by the authors, based on VTT, 2017

Figure 7.2 **Types of digitalisation of agriculture**

The second stage of digitising agriculture is ***data integration***. The integration of different systems allows a greater degree of automation in precision farming and more control over the production process. The data integration process involves the transfer of planning, quality and measurement data between systems before any physical operations are carried out, ensuring traceability and control of processing.

The third stage, linked to the development of digitalisation and the growth of data and knowledge, is ***data optimisation***. Data optimisation is about finding the best alternative and is always performed against a desired criterion; for example, a production line can be “trained” using machine learning to identify production defects based on a database of defects in previously manufactured products and thus use the previously extracted and accumulated data to build a quality control system. This would replace a staff member who would have to build up this experience in the course of their work, and would have to be rebuilt several times as staff changed. In agriculture, this means optimising the whole farming process, not just controlling machinery more efficiently or optimising a narrowly specific process.

In the current understanding, the latest or fourth stage of the digitalisation of agriculture is ***robotisation***. The difference between an automaton and a robot: an automaton will always perform one specific task, while a robot's tasks can be varied. Technologies that allow robotic operations are already available and used in agriculture. In the context of the evolution of robotisation, the ability of robots to cope with complex and unexpected situations is a topical issue, where data integration and optimisation play an important role. As the integration of these technologies develops, precision farming is transforming into Agriculture 4.0 and further into Agriculture 5.0.

As regards the digitalisation of the bioeconomy, it is important to understand that the digital revolution and the transition to a bioeconomy is a process of change that can radically transform existing economic structures and stakeholder relations. As is typical of systemic change, the digitalisation of the bioeconomy can mean winners and losers. In addition to new technological solutions, digitalisation creates new expectations for bioeconomy actors. The development of the bioeconomy and the digitalisation process require additional resources from companies to better prepare and meet customer expectations in terms of ethics, the environment and the impact of production on well-being. One of the manifestations of digitisation – the increased volume of information and the spread of surveillance technologies in everyday life – is already increasing the pressure on companies to ensure transparent production processes. In addition, the growing volume of information increases and will continue to increase the risk of data misuse and will lead to increasing concerns about privacy and ownership of information.

Digital transformation unfortunately does not only bring benefits, but also various political, economic, social and technological barriers. These barriers are summarised in Table 7.1 according to the PEST analysis criteria.

Table 7.1

Barriers to digital transformation in the bioeconomy according to the PEST criteria

PEST criterion	Barrier
Political	Uncertainty about data regulation methods, data protection issues
	Lack of identification of digitalisation as a strategic priority
	Fragmented support for digitalisation
	Insufficient integration of publicly owned data systems, e.g. systems collecting agricultural data, meteorological data
	Lack of transparency on the use of the requested data
Economic	High investment costs
	Limited monetisation of generated data
	Cost-effectiveness of introducing new technologies
Social	Digital skills of entrepreneurs and employees
	Other supply chain and market readiness, limited data integration, lack of digital skills of customers
	Willingness to learn and change practice
	Fear of using new technologies, uncertainty about cybercrime, security threats and concerns about data sharing
	Potential negative consumer and public perceptions of digital tools compared to traditional practices, business as usual
Technological	Poor data quality, data gaps
	Systems, technology and data integration challenges
	Data and cyber security threats
	Limited availability of technology
	Problems with the stability, speed and reliability of internet connection
	Limited availability of service, parts and technical support

Source: authors' compilation based on Fielke et al., 2020; Eastwood et al., 2023; Goller et al., 2021, Zeverte-Rivza et al., 2023.

An analysis of the barriers faced by agricultural businesses in adopting digital applications shows that the most significant challenges relate to technological issues: data quality, reliability, security and integration of data with different systems. In addition, digital transformation entails high investment costs in new technologies, making it feasible mainly for large and profitable agricultural businesses. In this context, it should also be highlighted that public authorities are often lagging behind in digitising their systems, resulting in inadequacy of existing digital infrastructure and hindering the introduction of new digital solutions. The lack of skilled staff in rural areas is also affecting the wider adoption of digital technologies. Cooperation between public authorities, consultants, researchers and businesses in the field of digital skills development is essential to address these challenges.

Overall, it is important to recognise the various barriers to digitalisation in the bioeconomy and to find ways to overcome or reduce them in order to enable digitalisation processes to flourish. At the national level, it is also important to clearly prioritise digital transformation policies, building an integrated digital infrastructure and putting in place smart digitalisation support measures for businesses.

7.2. Using artificial intelligence to digitise the bioeconomy

In the context of the bioeconomy, big data and artificial intelligence have the potential to sustainably contribute to more efficient biomass production in agriculture, forestry and fisheries. To this end, data is collected in several ways: from satellites, aircraft and drones; from sensors in the field, in the air and in the ocean; and from sensors in agricultural machinery, forestry machinery and fishing vessels. In addition, there are other data, such as metrological data and data on market and input prices, which can be used to plan and forecast the development of the bioeconomy. When all these data sources are integrated, analysed with different models and visualised, there are huge opportunities to create different solutions. These solutions can support end-users – farmers, forest owners, fishermen and other stakeholders – in their decision making and thus increase biomass production and reduce costs and environmental burdens.

One of the areas that is making a significant contribution to the bioeconomy is the development of precision agriculture. It is a data-driven approach to farm management that can improve productivity and yields, thereby increasing the overall profitability of farming. This approach also helps reduce the need for inputs such as water, synthetic fertilisers and pesticides, thus reducing the environmental impact of farming. Advances in digital technologies and their wider spread, such as mobile devices, remote sensing using satellite data, drones, the Internet of Things, artificial intelligence and cloud computing, as well as their increasing availability, make precision agriculture applications accessible not only to large farms but also to small farms at different stages of the agricultural production, processing, supply and/or marketing chain. Agriculture 4.0 and 5.0 approaches analyse the data by integrating several systems, for example animal activity data is viewed in the context of feeding and milk yield data, which can lead to adjustments in feed intake. In vegetable production, data collected by field sensors is integrated with weather station data and, if necessary, irrigation is automatically initiated through machine-to-machine (M2M) communication between the systems. This is particularly useful in spring, when starting watering early, as frost approaches, can protect plants during flowering.

This data is complemented by economic data on output (volume, seasonality of demand, prices) and input prices, providing a wide range of options for data analysis and improving both production efficiency and the ability to plan and forecast more accurately the future development of enterprises and industries.

What can a farm collect and analyse big data on?

In crop farming on:

- plants (growth progress, plant colour);
- soil (temperature, humidity, pH, N and contents of other elements by mapping – suitability for growing specific crops, forecast yields, identify the need for additional actions);
- the spread of pests and diseases;
- meteorological conditions;
- application of fertilisers and plant protection products;
- the yields obtained.

In livestock farming on:

- animal health (temperature, activity level, noise level in the shed);
- feeding and water consumption;
- productivity (milk yield, liveweight gain);
- animal diseases and treatment (spread in the herd, use of antibiotics);
- manure and emissions;
- yields, the amount of production.

In beekeeping on: nectar flowering (plant flowering maps in beekeeping), bee movements, colony weight and hive temperature.

One of the challenges that is highlighting the use of precision technologies in agriculture is the European Union's ambitious targets in the Green Deal, where the EU is committed to achieving climate neutrality by 2050, with a specific role for the agricultural sector. The "Farm to Fork" strategy is part of the Green Deal and aims to transform current food systems, making them fair, healthy and environmentally friendly. This is necessary because today's food systems account for around 30% of greenhouse gas emissions, consume large amounts of natural resources, cause biodiversity loss and negative health impacts, and fail to deliver fair economic returns and livelihoods for all actors involved, in particular primary producers in food supply chains. One important element in building a food chain that benefits consumers, producers, the climate and the environment is the European Commission's commitment to take further action to reduce the overall use and risk of synthetic pesticides, including herbicides, by 50%. One of the reasons for this initiative is the widespread use of synthetic pesticides and their possible secondary adverse effects on living organisms. The need for environmentally friendly alternatives to pest control has therefore become urgent, and precision farming offers promising solutions to achieve these goals.

Weed robots are one of the solutions contributing to the problem described above, i.e. the overuse of pesticides. These robots make it possible to significantly reduce the use of chemical pesticides by identifying and pulling weeds mechanically or with a laser beam. These solutions not only improve agricultural productivity, but also protect the health of people, animals and other beneficial organisms that are negatively affected by herbicides. In addition to their positive environmental impact, robots provide automated, timely and regular on-farm weed control and reduce human labour in the field.

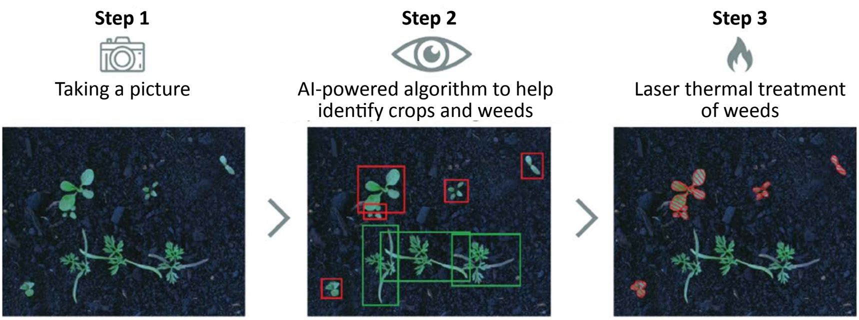
Artificial intelligence strand

A weed robot works by using computer vision and artificial intelligence technology to identify weeds, and then a laser embedded in the robot eliminates the weeds by firing a laser beam at the weed's meristem, which kills the weeds and prevents them from spreading further.

The system uses artificial intelligence, such as Microsoft Custom Vision AI, based on classification tasks. AI is trained to recognise images of weeds and crops at different stages of vegetation and from different viewpoints. This is necessary for the system to automatically distinguish between these two groups of plants. An on-board microcomputer capable of offline object detection works in conjunction with a stereo camera system that acts as the robot's eyes.

The working principle of artificial intelligence

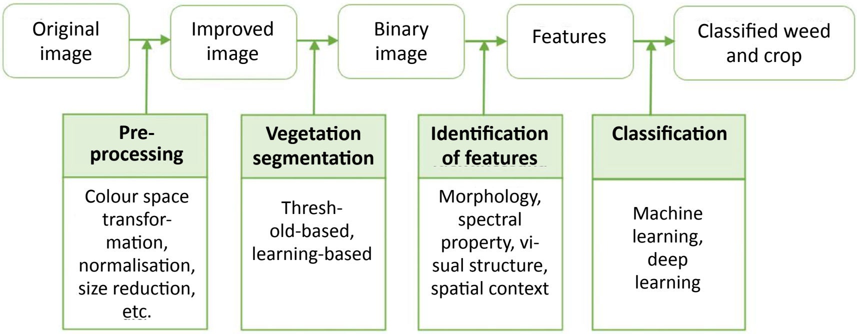
The operation of a weed robot is based on the following steps: image capture, image recognition (the computer vision can distinguish a weed from a crop using a pre-developed algorithm), heat treatment of the weed with a laser beam (see Figure 7.3).



Source: compiled by the authors, based on https://weedbot.eu/weedbot-technology/

Figure 7.3 **The main steps of operation of a weed robot**

For computer vision to recognise weeds and distinguish them from crops, digital image processing is an important step that needs to be taken so that weeds can be segmented and identified in the resulting images. Both RGB colour and infrared imaging sensors are used to capture the field images, which are then digitally processed. The resulting images are then fed as input to the processing algorithms. Basically, four image processing procedures are implemented for weed detection: 1. preprocessing, 2. segmentation, 3. feature extraction and 4. classification (Figure 7.4).



Source: compiled by the authors, based on Wang et al., 2019

Figure 7.4 **A general workflow for image-based weed detection**

Factors such as weed density, weed distribution patterns, varying light conditions in the field, overlapping crop and weed leaves, different plant growth stages, etc. can affect image processing.

Type of data	Image. Annotations.
How data were acquired	The data was acquired by capturing images with a resolution of 720 × 1280 × 3, 1000 × 750 × 3, 640 × 480 × 3, 640 × 360 × 3 and 480 × 384 × 3 pixels in a controlled and unregulated environment using the Canon EOS 800D, and Sony W800 digital cameras and the Intel RealSense D435 camera. Images were manually annotated by using software importing: python os, cv2, sys, xml.etree.ElementTree.
Data format	Raw images:.jpg format, manually annotated images: .xml files
Parameters for data collection	Data was acquired by capturing images in field conditions and in a controlled environment.
Description of data collection	Dataset consists of two directories. Directory *images*) 1118 food crops and weed images and directory *annotations*, i.e. their 1118 counterpart annotation XML files, which can be included 7853 annotations of two classes: food crops (six species), 441 annotations and weed (eight species), 7442 annotations.
Data source location	Municipalities: • Jelgava (controlled environment) • Ķekava parish (open field) • Rūjiena parish (open field) • Krimulda parish (open field) • Country: Latvia

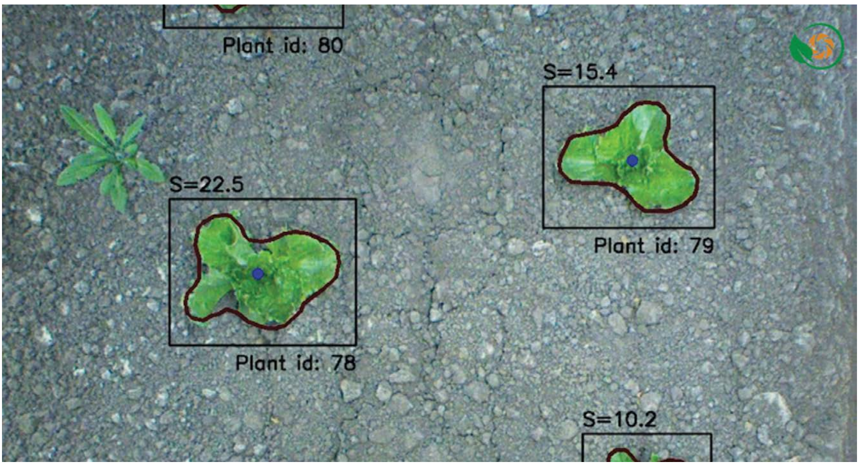
Source: Sudars et al., 2020

Figure 7.5 **Annotated food crop and weed image dataset for robotic computer vision control**

The dataset needed for further processing is based on field images. In a study carried out in Latvia, where a database of images and their annotations is being created for artificial intelligence, the dataset consists of 1 118 images identifying 6 crop species and 8 weed species, with a total of 7 853 annotations. The types of data used in this study, the way the data were collected, the data format, the data collection parameters, the description of the data collected, and the data collection locations are summarised in Figure 7.5.

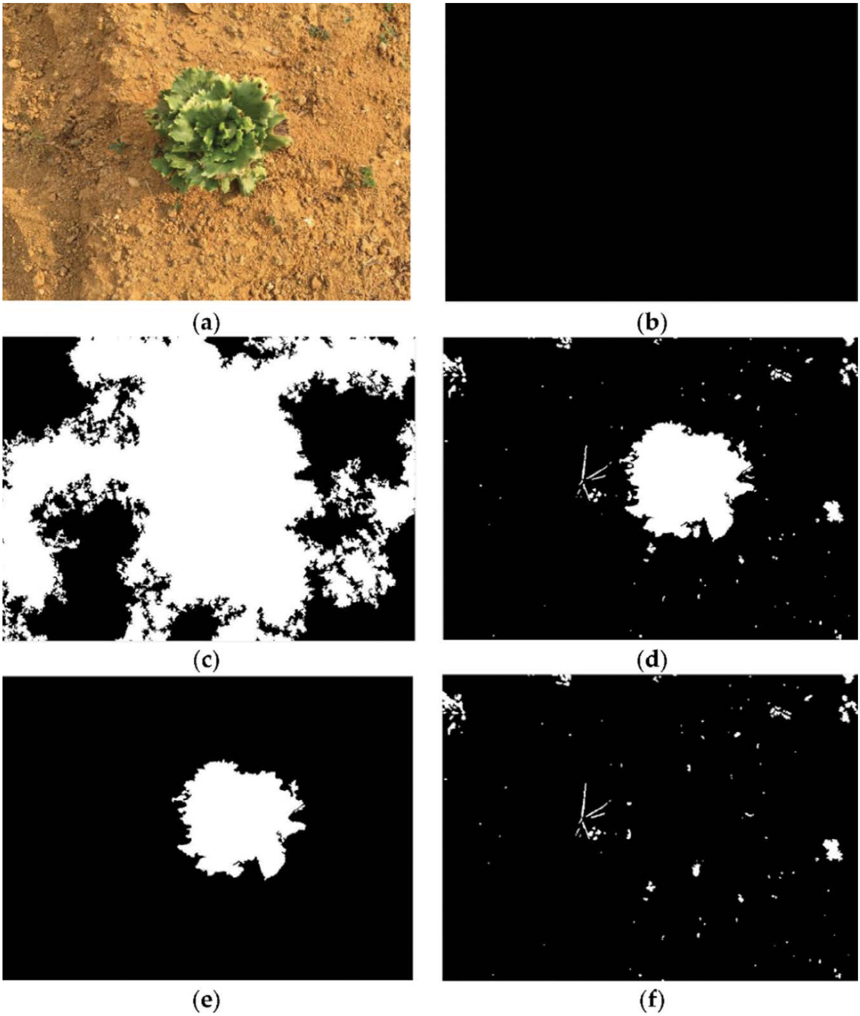
There are significant differences in the image characteristics, which are determined by the shape, colour and spatial position of different plants. These features distinguish weeds from crops (Figures 7.5–7.7). The visual features used to distinguish weeds from crops can be divided into:

- **biological morphology** – a structural feature that reflects the shape of a plant leaf or part of a leaf. Different plants have obvious differences in morphology. The feature parameters or descriptors for this feature class can be area, perimeter, length, diameter, major/minor axis length, eccentricity, HU moment, Fourier descriptor;
- **spectral features** – spectral features that reflect differences in colour between plants and soil or crops and weeds. RGB components, HIS components, ExG, NDI, colour histogram, colour moment, colour entropy can be used as feature parameters or descriptors for this feature class;
- **visual textures** – texture reflects the visual characteristics of a homogeneous phenomenon in an image and is an important feature used to identify an object or region of interest. LBP, GLCM, Gabor waves can be used as function parameters or descriptors for this feature class;
- **spatial contexts** – in modern agriculture, most crops are cultivated in rows and can be divided into inter-row weeds and intra-row weeds, depending on the weed's prominence.



Source: Francis, 2019

Figure 7.6 **Plant detection system.**



Source: Chang, Lin, 2018

Figure 7.7 **Image classification results using the proposed image processing method**

Explanation: (a) original image (10:00); (b) initial threshold; (c) threshold update (second iterations); (d) final iteration; (e) pixel attributable to the plant is highlighted in white; (f) pixel attributable to the weed is highlighted in white.

Examples of weed robots

Method for weed detection in wheat field using computer vision

In this study, a weed detection method based on position and edge feature was investigated. First, the plant pixels are separated from the soil background using the colour difference between the green plant and the soil. Second, according to the arrangement of sowing crops in rows, this paper uses the pixel histogram method to select the midline of cropping rows and set the midline as the starting point and the edge of cropping rows as the ending point, then fill the cropping area and turn off the cropping pixels. Weed detection is completed using the feature that weeds tend to grow in small associations and spread tightly. Experiments show that the algorithm provides good weed recognition rates.

Source of information used: Wu, X., Xu, W., Song, Y., Cai, M. (2011) A Det ection Method of Weed in Wheat Field on Machine Vision, Procedia Engineering, Volume 15, pp. 1998 - 2003, ISSN 1877-7058, **https://doi.org/10.1016/j.proeng.2011.08.373**.

Precision farming based on deep learning through weed recognition in sugar beet fields

In this study, the authors used the U-Net architecture as a deep encoder-decoder convolutional neural network (CNN) for pixel-by-pixel semantic segmentation of sugar beet, weeds and soil. The study trained the U-Net architecture with ResNet50 as the encoder block, using 1 385 RGB images collected under different conditions and at different altitudes. A combination of pitting and focus loss was used as a function of adjusted linear loss to overcome imbalanced data and small area segmentation problems. The structure of the training process dataset and the use of the adapted loss function led to a model with an precision and Intersection over Union (IoU) of 0.9606 and 0.8423, respectively. The results showed that using an image dataset with the correct distribution and a customised loss function can improve segmentation accuracy, especially in small regions. It was also concluded that CNN-based automatic weed detection in an autonomous weed control robot can be integrated into selective herbicide applications.

Source of information used: Nasiri, A., Omid, M., Taheri-Garavand, A., Jafari A. (2022). Deep learning-based precision agriculture through weed recognition in sugar beet fields. Sustainable Computing: Informatics and Systems, Volume 35, 100759, ISSN 2210-5379, **https://doi.org/10.1016/j.suscom.2022.100759**.

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8. BIOECONOMY STRATEGY IN LATVIA AND ITS IMPLEMENTATION

Authors: Irina Pilvere, Aleksejs Nipers, Ilze Upīte

8.1. Historical aspects of the preparation of bioeconomy strategies in Latvia and other countries

We live in a world of limited resources and face a number of global challenges such as climate change, pandemics, armed invasions, etc., so society will need to find new ways to produce and consume sustainably to provide for today's people and future generations. According to estimates, the world's population will reach nine billion by 2050, so the global need for new ways of food and energy production has increased dramatically as resources are running out and solutions are sought to ensure human well-being. One solution is for national governments to prepare and implement strategies to target the development of bioeconomy sectors in an environmentally and climate sustainable way, taking into account the comparative advantages of each country. Because strategy development is the way a company, government or other organisation carefully plans its actions over a period of time to improve its position and achieve what it wants. According to L Gardossi, J.Philp, et. al. (2023), the world has realised that building a sustainable bioeconomy can boost economic growth to meet environmental policy goals. This is why at least 50 countries have already put in place bioeconomy strategies or policies tailored to them to address the sustainability of bioeconomy industries. Motivations vary, based on countries' resource availability, specialisation and economic development paths. Oil-importing countries with significant biomass resources want to reduce their dependence on imports and increase the value of their biological resources. Countries with significant rural populations and high employment in primary production see the bioeconomy as an opportunity for rural development and reducing social disparities. Industrialised countries with limited biological resources and marginal primary production focus on opportunities for bio-industrialisation and value-added production through bioscience (I.Pilvere, 2022).

One of the first developed country strategies was the OECD's Bioeconomy 2030: Towards a Policy Agenda, adopted in 2009. In 2012, the US adopted the National Bioeconomy Plan (The White House, 2012). The European Commission also published a strategy and action plan on 13 February 2012: *Innovating for Sustainable Growth: a Bioeconomy for Europe.* It aims to pave the way for a more innovative, resource-efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes, while ensuring environmental protection (European Commission, 2012). In Europe, the bioeconomy is understood as the production of renewable biological resources and their transformation into food, feed, biotechnological products and bioenergy. Bioeconomy sectors include agriculture, forestry, fisheries, food and pulp and paper, chemicals, biotechnology and energy. The OECD definition of the bioeconomy refers to the set of economic activities related to the development, production and use of inventions, biological products and processes. These are the two most commonly used definitions of the bioeconomy, but each country is free to define its own definition that is more appropriate to its economic, political, environmental and social situation and historical development.

This is why several EU Member States have started to develop a bioeconomy strategy. Latvia was no exception. Kristīne Sirmā, Head of the Sustainable Agriculture Development Division of the Ministry of Agriculture, came up with the initiative that Latvia needs a bioeconomy strategy. Therefore, in 2016, the Ministry of Agriculture established an inter-ministerial working group with representatives from the Ministry of Economy, the Ministry of Regional Development, the Ministry of Education and Science, the Ministry of Welfare and the Cross-Sectoral Coordination centre, and LBTU (formerly LLU) scientists were tasked to develop the rationale for such a strategy under the project No. 190416/S7 "Development of a socio-economic basis for the Latvian Bioeconomy Strategy" (2016). Work continued in 2017 under project No. 3.2.-10/2017/LLU/24 "Socio-economic assessment of development scenarios for Latvian bioeconomy sectors" (2017). In this way, the development of bioeconomy sectors, opportunities and perspectives that should be included in the newly developed strategy were analysed in various seminars in cooperation with different ministries, scientists, sectoral organisations and entrepreneurs. LBTU scientists organised seminars and discussions with sectoral non-governmental organisations, scientific institutions and companies in cooperation with the Ministry of Agriculture and the Nordic Council of Ministers Office in Latvia, while the Ministry of Agriculture organised meetings for the established inter-ministerial group to create awareness of the bioeconomy and the importance of its sectors for the Latvian economy, to inform the public about the development of the Latvian bioeconomy strategy and to explore opportunities for expanding the use of biomass beyond the traditional bioeconomy sectors in the future. The bioeconomy strategies of other countries (Germany, Finland, Sweden, Norway, Belgium, Denmark, Austria, Ireland, the Netherlands, Portugal) at the time were analysed. The potential development of the bioeconomy was explored, as the agricultural land area per capita in Latvia is ranked 2nd in the EU, and the forest area per capita in Latvia – the 4th. The value of the produced output per unit of land is one of the lowest in the EU, fishing in the Baltic Sea and the Gulf of Riga is increasing slightly, but decreasing in the high seas, but we can develop aquaculture and fish processing; Latvia has access to fresh water, it is possible to use marine resources, there are relatively favourable climatic conditions in terms of bioresources production (I. Pilvere, 2022).

In 2017, the development of the *Latvian Bioeconomy Strategy 2030* (LIBRA) continued and on 19 December the Cabinet of Ministers approved the Information Report, which is also a strategy for the development of bioeconomy sectors by 2030, and Latvia was the first of the new EU-13 Member States to have developed a national Bioeconomy Strategy. The Ministry of Agriculture was responsible for the preparation of LIBRA, while LBTU was responsible for the technical preparation of the document.

LIBRA vision: the bioeconomy sectors of Latvia are the innovation leaders in the preservation, increase, and also the efficient and sustainable use of the natural capital value in the Baltic States. LIBRA is a long-term strategy for one of the priority directions of economic development of Latvia "Strategies for Smart Specialisation" (RIS3 direction "Knowledge-intensive bioeconomy"). This strategy outlines the development objectives, directions, and conceptual measures of the bioeconomy. The directions of the bioeconomy strategy should be taken into account in the future development of the planning documents of Latvia. The objectives of LIBRA are to be implemented by 2030 within three main fields:

1. promotion and preservation of employment in bioeconomy sectors to up to 128 thsd. employees;
2. increasing the added value of bioeconomy products to at least EUR 3.8 billion in 2030;
3. increasing the value of bioeconomy export production to at least EUR 9 billion in 2030.

Importantly, LIBRA also had a fourth (cross-cutting) objective – research excellence of the traditional bioeconomy sectors and efficient transfer of knowledge to ensure the achievement of the strategic objectives for the development of bioeconomy (Ministry of Agriculture, 2017).

Why was the period until 2030 chosen for the implementation of LIBRA? This is because the external policy context had changed and was set to move towards a low-carbon economy by 2050. LIBRA was designed to achieve the objectives set out in the Europe 2020 flagship initiatives "Innovation Union" and "Resource Efficient Europe" (Europe 2020), as well as the priorities set out in the European Bioeconomy Strategy (2012) and its Action Plan:

- investment in research, innovation and skills;
- closer links between different policies and stakeholder involvement;

- improving markets and competitiveness in the bioeconomy;
- stimulating a sustainable, efficient and green economy.

Five main interlinked and complementary action lines were identified to achieve the Bioeconomy Strategy's objective:

1. attractive entrepreneurial environment for the bioeconomy (6 sub-measures);
2. result-oriented efficient and sustainable resource management (5 sub-measures);
3. knowledge and innovation (3 sub-measures);
4. promotion of manufacturing the produce in bioeconomy (10 sub-measures);
5. socially responsible and sustainable development (4 sub-measures) (Ministry of Agriculture, 2017).

Until 2022, Latvia was the only one of the 13 new EU Member States that joined the EU after 2004 to have a bioeconomy strategy. In 2017, scientists from the Aleksandras Stulginskis University (now the Vytautas Magnus University) in Lithuania also tried to develop such a strategy, preparing a very good study of the situation and inviting LBTU scientists as advisors in the development of the bioeconomy, but no further work on the strategy was carried out (Vl.Vitunskienė, V.Aleknevičienė et al., 2017). Estonian ministries, on the other hand, repeatedly asked about Latvia's experience in preparing a bioeconomy strategy and this process was successful in 2023, when the Ministry of Regional Affairs and Agriculture together with the Ministry of Climate prepared and published the "Roadmap to the Circular Bioeconomy in Estonia", which sets out broad areas for the development of the circular bioeconomy in Estonia and the activities needed to develop it in the short (2023–2027) and long term (until 2035) (Ministry of Regional..., 2023).

The EU Bioeconomy Strategy was evaluated in 2018, finding that the EU Bioeconomy Strategy and Action Plan 2012 has been implemented in all key actions. The EU has successfully mobilised funding for research and innovation, in particular by doubling EU funding for the bioeconomy under Horizon 2020 compared to FP7 and funding from the European Fund for Strategic Investments. The importance of the Bioeconomy Strategy for society and the need for further investment and a stable regulatory environment were recognised by finding that the new policy context underlines the need for a sustainable circular bioeconomy (European Commission, 2018a).

At the end of 2018, the new EU strategy “A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment” was endorsed. It highlights the importance of developing a sustainable and circular bioeconomy that aims to maximise its contribution to the 2030 Agenda and its Sustainable Development Goals, as well as to the requirements of the Paris Agreement. The Action Plan, which is part of the updated Bioeconomy Strategy 2018, sets out three key actions to achieve its objective, including 14 sub-actions: (1) strengthen and scale up the bio-based sectors, unlocking investment and markets; (2) rapidly deploy local bioeconomies across the whole of Europe; (3) understand the ecological boundaries of the bioeconomy (European Commission, 2018b).

LBTU scientists actively participate in international projects to strengthen bioeconomy research and develop innovations for the implementation of various bioeconomy strategies in EU Member States. Key projects include:

1. Horizon 2020 project “Bio-based innovation for sustainable goods and services – Supporting the development of a European Bioeconomy” (BioMonitor) (2018–2022) to address the information gap in bioeconomy research by restructuring existing data and modelling frameworks (*https://biomonitor.eu/project/*);
2. Interreg Baltic Sea Region project “Unlocking the potential of bio-based value chains in the Baltic Sea Region (BalticBiomass4Value)” (2019–2021) aims to increase the capacity of public and private actors in the Baltic Sea States to produce bioenergy in a more environmentally sustainable and economically viable way by using new biomass sources (mainly bio-waste)

for energy production as well as opportunities to use bioenergy side streams to extract and produce higher value bio-products (*https://balticbiomass4value.eu/*);

3. Horizon 2020, BIOEAST project “Central-Eastern European initiative for knowledge-based agriculture, aquaculture and forestry in the bioeconomy (2019–2023) (https://bioeast.eu /), where our scientists Dr.oec. Aleksejs Nipers and Dr.oec. Aina Muška prepared the “Strategic Research and Innovation Agenda” for Central and Eastern European countries (*https://bioeast.eu/download/bioeast-summary-a4bl3mm-par/*);

4. LIFE Programme project “Demonstrating the climate change mitigation potential of nutrient-rich organic soils in the Baltic States and Finland” (LIFE OrgBalt, LIFE18 CCM/LV/001158) (2019–2024), which aims to: (1) improve the GHG accounting methods and activity data for nutrient-rich organic soils under conventional management conditions; (2) identify and demonstrate sustainable, resilient and cost-effective climate change mitigation measures suitable for nutrient-rich organic soils; and (3) provide tools and guidance for elaborating, implementing and verifying the impact of the climate change mitigation measures(*www.orgbalt.eu*);

5. Horizon Europe project “Accelerating circular bio-based solutions in European rural areas (BioRural)” (2022–2024), which aims to create a pan-European rural bioeconomy network where stakeholders will work together to promote small-scale bio-based solutions currently available in rural areas to increase the share of the bioeconomy in the economy, thereby increasing the value of remote rural areas. To this end, BioRural has identified success stories covering bioeconomy sector themes in the four geographical groups of countries in Europe where the BioRural consortium operates (*https://biorural.eu/about-biorural/*);

6. Horizon Europe project “BOOST4BIOEAST: Boosting the bioeconomy transformation for the BIOEAST region” (2024–2026),

which aims to empower national stakeholders in Central and Eastern European and the Baltic countries to develop national bioeconomy action plans and build long-term structures and dialogue spaces and networks for national and macro-regional cooperation (*https://bioeast.eu/contacts-2/*).

Such international activities, in synergy with research and activities of national interest, strengthen the bioeconomy, generate new knowledge and experience, and provide innovation for relevant strategies.

8.2. Implementation of the Bioeconomy Strategy in Latvia

Overall, the implementation of the measures set out in LIBRA has involved a significant investment of resources (public funding (grants), relevant EU funds – European Agricultural Guarantee Fund, European Agricultural Fund for Rural Development, research funding, etc.), targeted policy planning and the development of a number of necessary regulatory documents. However, periodic evaluation and follow-up are necessary to understand how the strategy is being implemented. For the first time such LIBRA assessment took place in the LZP approved and implemented tenure project No. 0413 "Assessment of the implementation of the Latvian Bioeconomy Strategy 2030 and possible solutions for achieving the set goals (LIBRA-LV)" in 2020/2021, which was implemented by LBTU scientists.

Overall, it was concluded that the implementation of all actions necessary for LIBRA implementation has started and is ongoing. Therefore, the implementation of the measures of the Latvian Bioeconomy Strategy 2030 shown in Table 1 was evaluated by indicating in green the significant investments and the achieved progress, in yellow – the medium investments and the achieved progress, but in red – the insufficient investments and the progress in the implementation of the measures.

Table 8.1

Summary of the evaluation of the measures of the Latvian Bioeconomy Strategy 2030 in 2021

	Measure	Investments made	Progress achieved
	1. Attractive business environment		
1.1.	Predictable and stable tax policy in the bioeconomy sector		
1.2.	Creating an investment-friendly environment		
1.3.	Ensuring the reduction of administratively regulated prices		
1.4.	Expansion of sales opportunities for small producers in the agri-food sector		
1.5.	Addressing unfair competition in the bioeconomy sector		
1.6.	Replacing non-renewable resources with sustainable bioresources in public procurement		
2. Result-oriented, efficient and sustainable resource management			
2.1.	Orientation of agricultural and rural development support towards higher added value and employment per 1 ha		
2.2.	Forestry		
2.3.	Result-oriented motivation system for local governments		
2.4.	Spatial development planning, including economically viable use of land and natural resources		
2.5.	Assessment of impact on the bioeconomy in all Country Strategy Papers		
3. Knowledge and innovation			
3.1.	Promote research excellence and effective knowledge transfer in traditional bioeconomy sectors		
3.2.	Providing excellent educational services for the bioeconomy sectors		
3.3.	Take advantage of new research opportunities to address social, environmental, climate change and economic challenges		
4. Promotion of manufacturing the produce in bioeconomy			
4.1.	Investment promotion and attraction		
4.2.	Increasing efficiency and productivity in all sectors of the bioeconomy		
4.3.	Development of a long-term land use policy		
4.4.	Inclusion of bioeconomy in the Latvian brand		

	Pasākums	Veiktie ieguldījumi	Sasniegtais progress
4.5.	Export promotion measures		
4.6.	Development of a risk management system		
4.7.	Promoting cooperation between small producers		
4.8.	Use of biomass for energy, using cascading principles where possible		
4.9.	Increased use of bioresources in construction and other non-traditional bioeconomy sectors		
4.10.	Promotion of certification of forest owners		
5. Socially responsible and sustainable development			
5.1.	Reducing GHG emissions in the bioeconomy sectors		
5.2.	Ecosystem culture or intangible services as development of public goods		
5.3.	Promoting the bioeconomy and involving the public		
5.4.	Introduction of the principles of rational use of bioresources in the habits of the population		

Source: LZP Tenure Project, 2020/2021

In 2024, when this monograph was prepared, it can be noted that there is still no long-term land use policy in Latvia and land use issues are still regulated only by the Land Management Law (2014). The situation is slightly improved by the fact that in 2020 the MoEPRD approved the national research programme "Sustainable territorial development and rational use of land resources (LandLat4Pol)" and the results of this research are available in 2024 (MoEPRD, 2024). It should be noted that LBTU scientists also participated in this research, so information about the results of this project is publicly available to all interested parties: https://bioekonomika.lbtu.lv/ll4p/.

Information on the main directions of LIBRA implementation activities and the individual implemented measures has been collected in several scientific publications by LBTU researchers, therefore a brief summary of the most important results will be presented here.

In Latvia, traditional bioeconomy industries play an important role in the national economy. Traditional bioeconomy industries account for a significant share of value added in the commodity sector, and total exports and play an important role in rural employment. The 2015 survey showed that 86% of respondents welcomed the role of the bioeconomy and recognised its impact on the wellbeing of the country's citizens. Further growth in the bioeconomy sector is not possible without research and innovation. Research development, innovation and technology transfer are therefore key to achieving LIBRA's objectives, where the ability of research institutions to solve problems that matter to business is crucial. In 2014, the Bioeconomy Research Strategic Alliance was established in Latvia, whose member research institutions are the main actors in dealing with the bioeconomy's traditional business sector orders. They have accumulated experience and achieved considerable capacity, their scientific activity is characterised by a growing number of publications and patents, including a significant proportion of scientific articles in *Web of Science and Scopus* databases (B. Rivža, I. Pilvere et al., 2018; I. Pilvere, A. Nipers et al., 2017; I. Pilvere, A. Muska et al., 2021).

The strengths of the bioeconomy in Latvia are the research infrastructure and modern technical equipment to develop the bioeconomy knowledge base and the broad regional coverage, as well as the extensive initial activities and knowledge base for bioeconomy research. Weaknesses – insufficient and unpredictable public and private sector funding for R&D, its dependence on the availability of foreign (mainly EU) funding, and weak cooperation with researchers in other fields in interdisciplinary research. Therefore, there is a need to support independent innovation projects by large companies and innovation in the SME sector in active synergy with national research priorities and available funding, and to increase public and private sector funding for research and development to foster the development of Latvia's bioeconomy. The availability of funding should be balanced and predictable in the long term to reduce the impact of risks. Public policies and insufficient and unpredictable research funding hinder the development of bioeconomy industries and sustainable growth opportunities. Public support and various incentives for entrepreneurs are needed to encourage the business sector to invest in research and development, including in the bioeconomy (A. Muška, A. Zvirbule et al., 2021).

Analysis of the available data on the progress of LIBRA implementation in 2022 shows that the most significant progress has been made on the strategic objective of promoting the manufacture of the produce in bioeconomy, which could be achieved as early as 2027, while the objective of increasing the added value of bioeconomy products could be achieved in the final year of the strategy, 2030. It can be concluded that the objective of promoting and maintaining employment in the bioeconomy sectors up to 128 000 people will not be achieved, as the number of employees in the bioeconomy can be expected to decrease by 27 000 as compared to 2015, which, in turn, allows for a 27% increase in labour productivity in 2030 compared to the target set in the Strategy. In-depth interviews with business leaders and scientists revealed that bioeconomy sectors were predicted to have growth potential, as Latvia can produce biomass in larger volumes and use it to produce products and services needed for human consumption. However, bioeconomy industries need to make substantial financial investments to bring new technologies, products and processes and innovations to their enterprises (I. Pilvere, A. Muska et al., 2021).

There are differences in the level of fulfilment of the LIBRA's strategic objective of "Result-orientated, efficient and sustainable resource management" under the implementation section "Forestry". The goal of changing regulations to define the minimum number of trees necessary for forest regeneration and afforestation depending on the dominant species of trees, and to define the main felling diameter of trees based on the numerical value of the dominant species of trees, was not achieved. There were good results in forest regeneration and afforestation with the use of correct planting materials, maintenance of young growths, reconstruction and development of forest amelioration systems, as well as preservation and renewal of the range and intensity of the ecosystem services provided by managed forests. Funding from the Latvian Rural Development Programme 2014–2022 has been successfully used for several tasks (I. Upite, A. Pilvere et al., 2022).

The implementation of the LIBRA's strategic objective "Attractive entrepreneurial environment" under the heading "Predictable and stable tax policy in the bioeconomy sector" for the period 2017–2020 is positive, as: (1) According to the State Revenue Service data, taxes paid by companies in various sectors of the bioeconomy accounted for an average of

20% of total tax revenues, which indicates the importance of the bioeconomy sectors in the Latvian economy and making the national budget; (2) VAT accounts for the smallest share (5%) of tax revenues in the bioeconomy sectors, because the primary production of bioresources and the use of bioresources for the provision of services, due to the reduced VAT rate in the fruit and vegetable sector, as well as the reverse application of VAT taxes on crop production and timber supplies, result in overpayment of VAT; (3) as a result of the tax reform implemented in 2018, various CIT reliefs were abolished, including in the primary production of bioresources; however, CIT paid by companies in various sectors of the bioeconomy accounted for 24% of the total revenue of this tax in Latvia in 2017–2020; (4) the mandatory state social insurance contributions paid by companies in various sectors of the bioeconomy in Latvia in 2017–2020 were 20% of the total amount, which indicates a stable level of employment and wages in these sectors; however, it raises the issue of reducing the overall burden of labour taxes to ensure the successful operations of companies; (5) there is a need to further evaluate and improve the tax system, in particular with regards to the ability of companies to adapt to the new EU *Green Deal* policy (I. Upite, I. Pilvere et al., 2022a).

The EU Member States and also Latvia spend significant state budget resources on public procurement – 19% and 17% of GDP, respectively. It is therefore important to include environmental requirements in public procurement in order to achieve the goals of sustainable development. Countries are doing this by developing and defining a regulatory framework for green public procurement (GPP), which is one of the priority instruments of the EU's environment, climate and energy policy, and the inclusion of environmental conditions in procurement specifications is becoming a priority in Latvia as well. In Latvia, a system of regulatory enactments has been established since 2017, which provides for certain groups of goods and services to which green procurement is mandatory in public procurement and groups of goods and services to which GPP is applicable on a voluntary basis. LIBRA includes a section on "Replacement of non-renewable resources with sustainable bioresources in public procurements" under the strategic objective "Attractive entrepreneurial environment". The implementation of this section in 2017–2020 is to be assessed as positive, as: (1) GPP is mandatory for food delivery and catering services, the purchase of office paper and cleaning products, and on a voluntary basis for horticultural products and services, electricity, furniture, wall panels, textiles and construction works; (2) over the analysed period, the GPP in both mandatory and voluntary procurement has increased from EUR 244 million in 2017 to EUR 671 million in 2020 and its share in the total value of the respective goods and services increased from 21% to 46%; (3) it should be noted that the volume of GPP procurement in 2020 made up 27% of the total volume of public procurement and was 3 percentage points below the target set in the Green Procurement Promotion Plan 2015–2017 (30%) (I. Upite, I. Pilvere et al., 2022b).

According to the Local Government Law of the Republic of Latvia, local governments have various functions, but the promotion of business development can be regarded as important, as it ensures employment and the well-being of the population in the territory. The analysis of the implementation section "Result-oriented motivation system for local governments" of the LIBRA strategic objective "Result-oriented efficient and sustainable resource management" showed that there were no positive changes in 2020 compared to 2016, as: (1) the number of enterprises in the bioeconomy sectors has decreased by 5% over the same period, although their net turnover in 2020 was 30% and their profits were 50% of the corresponding Latvian total; (2) Riga and Pierīga regions in 2020 hosted half of the total number of companies in bioeconomy sectors, which indicates an uneven development of the national territory, (3) the number of start-ups decreased by 30%, although it was less than in Latvia as a whole (-32%); (4) although municipalities in Latvia had a wide range of business support instruments in four main categories – administration, infrastructure, marketing activities and start-up support – there was no monitoring system in place and therefore no publicly available information on municipal activities to stimulate entrepreneurship in the regions (I. Pilvere, I. Upite et al, 2023a).

In Latvia, total funding for scientific research increased 2.1-fold between 2016 and 2021, reaching EUR 232 million in 2021, but it is the third lowest in the EU, accounting for only 0.71% of GDP. In addition, public funding in 2021 was only 36% of the total, the country employed 4 526 researchers and only 16% of them worked in the public sector. Latvia has five Strategic Areas of Smart Specialisation (RIS3), one of which is the Knowledge-intensive Bioeconomy, which in 2018 accounted for 62% of the total number of enterprises in the RIS3 areas, employed 45% of the workforce in the RIS3 areas and generated 35% of the total value added in all RIS3 areas. In 2018, 1 600 scientists were employed in bioeconomy fields in Latvia, or 23% of the total number of scientists in RIS3 sectors. The amount of R&D funding attracted in the bioeconomy in 2014–2018 was only EUR 27 million, or 14% of the total RIS3 funding, reflecting the insufficient capacity of bioeconomy scientists to attract funding and lower productivity. Bioeconomy is characterised by diverse research directions; the main scientific institutions in this field are the University of Latvia, Riga Technical University, LBTU, LBTU scientific institutes – Institute of Agricultural Resources and Economics and Institute of Horticulture, Latvian State Forest Research Institute "Silava", Institute of Food Safety, Animal Health and Environment "BIOR", Latvian State Institute of Wood Chemistry and Daugavpils University, which employed 89% of the total number of scientific staff in the field of bioeconomy. Scientists from these institutes were the authors of 98% of Web of Science indexed scientific publications in 2014–2018. The average number of publications per employee in the bioeconomy field in the 9 analysed institutions was 0.27, but in 3 scientific institutions it exceeded the average level, namely, LBTU – 2.4 times, Institute of Horticulture – by 22%, BIOR – by 15%. In Latvia, the future demand for research and innovation in the bioeconomy will be driven by global challenges such as climate change, food and energy security (I. Pilvere, I. Upite et al., 2023b).

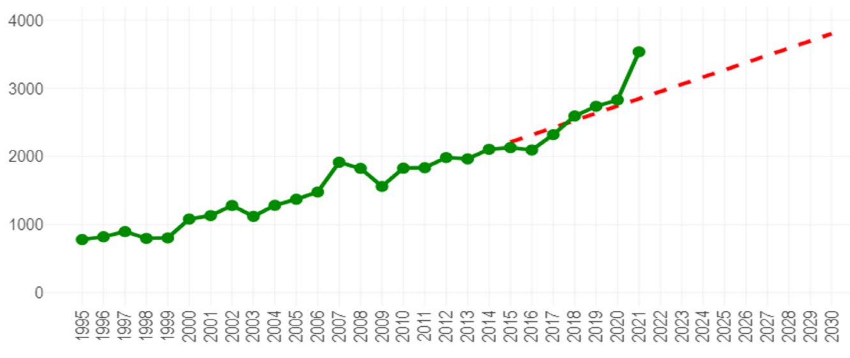
Investment is an important driver for the development of companies, sectors and the overall national economy. And the bio-based industries are seen as crucial for the global transformation towards a more sustainable economic system and climate neutral Europe in 2050. Therefore, an analysis of the implementation of LIBRA in the investment area shows that: (1) gross capital investment in bioeconomy companies in 2022 was EUR 1,673.4 million, 48.6% more than capital investments in 2015; (2) the amount of gross investment and the rate of growth have been insufficient to reach the target set in the Strategy, which is to ensure the total investment amount of EUR 20 billion in the bioeconomy sectors by 2030, as the expected performance could be around 93%; (3) foreign direct investment is essential for the development of the bioeconomy, and has increased significantly in the bioeconomy in 2015–2022 from EUR 3.3 billion to EUR 5 billion at the end of the respective year; (4) the largest increase in FDI in the period 2015–2020 was in the processing industry – by 78%, and agriculture, forestry and fishery – by 53%, while investments have decreased in the construction sector – by 14%; (5) it can be noted that compared to the other Baltic countries, Latvia has the lowest foreign direct investment as a share of total gross domestic product, therefore it is important to continue activating the activities of Latvian public administration institutions in improving the investment environment, attracting state and foreign investments (I. Pilvere, I. Upite et al., 2024a).

Latvia needs to pay more attention to boosting productivity, because productivity is crucial for economic growth and prosperity. By taking appropriate measures and promoting effective regulation, Latvia could close the productivity gap with the EU average. Productivity levels and productivity growth are also important in the bioeconomy. In Latvia in 2022, the lowest productivity, irrespective of prices (actual or reference) or per employee or per hour worked, was in accommodation and food services, construction and agriculture, forestry and fishing. The highest productivity levels in 2022 were in the electricity, gas, steam and air conditioning supply and certain manufacturing sectors.

In Latvia, productivity growth in real prices was the highest in the electricity, gas, steam and air conditioning supply and agriculture, forestry and fishing sectors in 2015–2022, and in the agriculture, forestry and fishing sectors in constant prices. In the processing sectors, productivity in 2022 was significantly higher in basic pharmaceuticals and pharmaceutical preparations, while in the primary sectors, productivity was the highest in fisheries and aquaculture, which had the sharpest growth rates between 2015 and 2022. This means that the bioeconomy sectors have different levels of productivity and further work is needed to increase productivity in sectors where it is lagging significantly behind the national average (I. Pilvere, I. Upite et al., 2024b).

In the framework of the LZP-approved tenure project No. 0413 "Assessment of the implementation of the Latvian Bioeconomy Strategy 2030 and possible solutions for achieving the goals set (LIBRA-LV)", a publicly accessible website https://bioekonomika.lbtu.lv/LIBRA2030merki/ (Latvian Bioeconomy Strategy Objectives and their Implementation) was also developed, where the most up-to-date information on the implementation of the main objectives of LIBRA is available to any interested party, as the latest statistical indicators are displayed on the website as soon as they become available. The achievement of LIBRA targets in 2024 is shown in Figures 1–3.

In 2015, the value added of the bioeconomy industries was EUR 2 129 million, which was used as the baseline for LIBRA, and then increased to EUR 3 535 million in 2021 (an increase of 66%) and accounted for 93% of the 2030 target. While in the first years after LIBRA was developed, value added increased close to the projected trajectory, it increased by 25% in 2021 compared to 2020, driven by high inflation after the Covid-19 pandemic. It can be projected that the value added target set by LIBRA could be exceeded in 2030 (Figure 1).

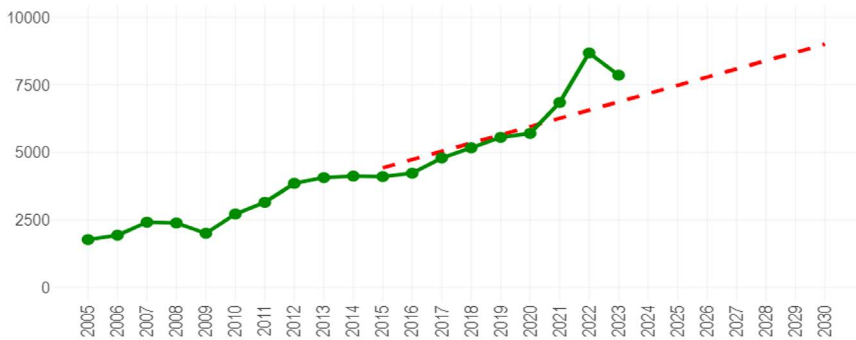


Source: https://bioekonomika.lbtu.lv/LIBRA2030merki/

Figure 1 **Value added in the bioeconomy 1995–2021: actual (green line), 2015–2030 forecast (red line) in Latvia, billion.**

In 2015, the value of export production of bioeconomy industries was

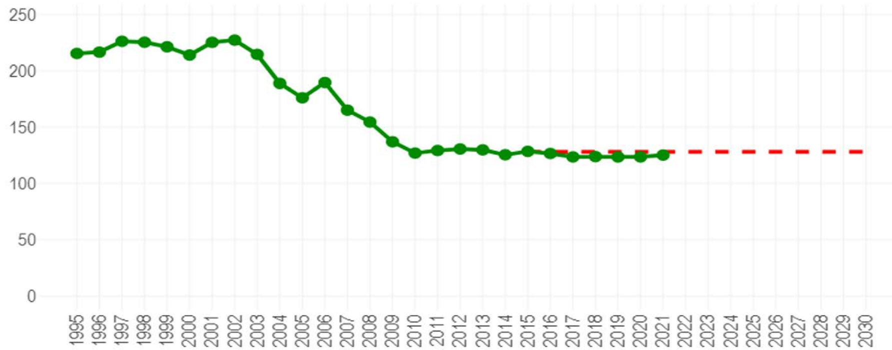
EUR 4 104 million, which was taken as the baseline for LIBRA, then increased to EUR 7 855 million in 2023 (an increase of 66%) and accounted for 87% of the 2030 target. The value of export production also increased close to the projected trajectory in the first years after LIBRA, but increased by 20% in 2021 compared to 2020, and by a further 27% in 2022 compared to 2021 due to high inflation after the Covid-19 pandemic, and by 9% in 2023 compared to 2022. The value of bioeconomy export production can also be projected to exceed the 2030 LIBRA target (Figure 2).



Source: https://bioekonomika.lbtu.lv/LIBRA2030merki/

Figure 2 **Value of export production in the bioeconomy 1995–2023: actual (green line), 2015–2030 forecast (red line) in Latvia, billion.**

In 2015, 128 000 people were employed in the bioeconomy. This is also the LIBRA target for 2030. Unfortunately, the retention target will not be met as the number of employees has decreased since 2016, which is understandable as the introduction of new technologies in key primary sectors has increased productivity and not as many workers are needed (Figure 3).



Source: https://bioekonomika.lbtu.lv/LIBRA2030merki/

Figure 3 **Employment in the bioeconomy sectors 1995–2021: actual (green line), 2015–2030 forecast (red line) in Latvia, thsd.**

In order to ensure that LIBRA is implemented responsibly in the future, LBTU scientists actively participate in working groups and activities at various levels, as they have accumulated experience and knowledge since the Strategy was established in Latvia. For example, Dr oec. Irina Pilvere is a representative of Latvian scientific institutions in the EU Rural Network Assembly and a member of the EU Standing Committee on Agricultural Research (SCAR), has participated in the establishment of the Latvian Bioeconomy Research Strategic Alliance in 2014 and chaired it, is the Chair of the Steering Group “”Knowledge Intensive Bioeconomy” of the Innovation and Research Management Council of Latvia (from 2023), a member of the Climate, Environment and Energy Advisory Board of the Ministry of Climate and Energy (from 22.02.2024), while Dr oec. Aleksejs Nipers is the LBTU representative on the National Energy and Climate Council Working Group on the Land Sector (including Forestry) and Agriculture.

Therefore, the Sustainable Bioeconomy Research Group (*http://socialsciences.lbtu.lv/en/about-us/research-groups*), established by LBTU ESAF and headed by Dr oec. Aleksejs Nipers, is becoming stronger every year. The group’s research focuses on the sustainable development of the bioresource industries, especially agriculture. The aim of this group is to identify opportunities, barriers and solutions for the sustainable development of the country's bioresources industries. This research group provides: (1) international cooperation with leading European scientific institutions and their scientists; (2) interdisciplinary research (agriculture-food, forestry-wood, climate-smart agriculture and forestry); (3) innovative solutions for assessing the impact of the bioeconomy; (4) impact assessment of different areas of the bioeconomy using modelling tools; (5) synthesis of research results in high-level publications and publicly accessible websites.

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AFTERWORD

The origins of the bioeconomy at LBTU

In the 30 years following Latvia's independence, scientists at the Latvia University of Agriculture have been intensively involved in research and studies in the life sciences and technologies. The university has thus become one of the world's leading universities. In 2022, it was decided that the new name, Latvia University of Life Sciences and Technologies (LBTU), would more accurately reflect the scope of its activities.

The lecturers of LBTU economics have also shifted from the traditional research of agriculture, forestry, food, wood and related biology, economics, technology and other problems to interdisciplinary issues. They explored the possibility of developing interlinkages between these sectors, identifying ways to use bio-resources more rationally and efficiently, creating renewable products to replace fossil resources, while identifying opportunities for sustainability and respect for the environment. Scientists joined international projects. The European Union institutions have also been keen to look at ways to develop the bioeconomy. In 2013, the Rectorate encouraged the Faculty of Economics to add the Faculty of Social Sciences, where the number of students had declined. A new name for the faculty had to be found. The faculty suggested the name Bioeconomics. The Senate did not approve, arguing that the whole university should work on bioeconomy research. The leaders were lecturers from the Faculty of Economics and Social Development (ESAF). ESAF Vice Dean, Professor Aina Dobele, invited me as a researcher and professor in the field of agrarian economics to take over the development of the bioeconomics study programme and to start teaching the new course. I saw the new shift in interdisciplinary research in the bioeconomy and recommended entrusting it to them.

As a result, after 10 years of work, ESAF lecturers are now presenting the scientific monograph "Bioeconomy: Development Roadmap" to the public, especially to students. The authors have spent a long time preparing this edition. During their studies, they studied economics in agriculture, forestry, fisheries, food production and other fields. They have carried out comprehensive macro and micro-economic research in the fields of economic and natural resource use – land, plants, animals, timber and others. They have developed and defended doctoral theses, for which they have been awarded doctorates in economics.

The monograph is the result of an analytical review of many literature sources, as well as the personal scientific research of the faculty lecturers. The findings presented in the monograph have been verified in the preparation of several study courses and programmes, where the knowledge provided has been evaluated in students' bachelor's, master's and doctoral theses, in conference audiences in Latvia, as well as abroad.

The transition from agrarian economics to bioeconomics was initiated at the university by the authors of this book – Associate Professor Kaspars Naglis-Liepa and Assistant professor Arnis Lēnerts in 2014. They were gradually joined by the other authors of the monograph, who included a broader interpretation in the contents of bioeconomics (Professor Dina Popluga). Assistant professor Līga Feldmane has linked the content of the bioeconomy to ecosystem services. Insight into the use of digitalisation in the bioeconomy was provided by Associate Professor Sandija Zēverte-Rivža. The complex issues of the bioeconomy as a combined form of bioscience in the European Union and Latvian economies and their enterprises have been studied and some of the research has been presented in the book by Associate Professor Aina Muška and Lecturer Vineta Tetere. The authors of the monograph can be grateful that the book has also benefited from the research of many other university lecturers, both inside and outside the university, in recent years. This has been carried out under the guidance of Professors Pēteris Rivža and Irina Pilvere and Lead Researcher Aleksejs Nipers

The authors of this scientific monograph have walked a creative and thorny path of growth. As a result, they have been able to produce this bioeconomy roadmap, bringing together in this creative process scientific knowledge from the fields of agriculture, forestry, fisheries, food production economics, linking it to discoveries in biology, biotechnology and the manifestations of economic processes. This has created a single bioeconomy space and environment, where the processes described above create products with added value. It has been achieved by linking scientific research with practical developments – in agriculture, forestry, food, wood processing and many related industries (energy, paper, perfume, pharmaceuticals, etc.).

Professor Emeritus Voldemārs Strīķis