Czech
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Prague

Faculty of Forestry
and Wood Sciences

Forest bioeconomy

2026

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CONTENTS

INTRODUCTION

The issue of bioeconomy has a relatively short historical development. Although the management of scarce resources was already the subject of neoclassical economic theory in the 19th century, the issue of natural resources as part of natural goods was not defined and formulated into environmental policies only in the 70s of the 20th century. Government strategies focusing on the bioeconomy have been developed over the last 10 years. The present book summarizes the latest findings in the field of bioeconomy and introduces the reader to the definition of forest bioeconomy, the related issues and the potential for utilization of all natural resources derived from forests.

Forest bioeconomy is a broadly interdisciplinary subject that focuses on the use of all ecosystem services of forests, with a focus on wood and non-wood services. It deals in particular with the possibilities of using wood raw material as the most important natural resource, but also with a range of other resources and their processing in the food, chemical and pharmaceutical industries. The focus on innovation, new production processes and the use of modern technologies is important in the processing of all natural resources.

However, in addition to the use of natural renewable resources from forests, it is important to remember that, unlike other sectors, forestry also produces a number of other very important ecosystem services for recreation, water management, carbon fixation and others. The subject of forest bioeconomy is therefore not only about focusing on maximising the use of natural resources, but also about understanding the linkages with other ecosystem services and ensuring sustainable development.

The publication provides basic information on the possibilities of using natural resources from forests in the Czech Republic, including the context of global developments and strategies in this area in Europe. It can be assumed that this will be an important area of our economy in the future, as the importance of renewable resources will continue to grow with the gradual depletion of mineral resources. The publication should therefore also provide guidance on how to make more efficient use of natural resources from forests in the future and substitute some non-renewable resources.

The publication is intended primarily for students of the Faculty of Forestry and Wood Sciences of the Czech University of Life Sciences in Prague, but also for other interested parties who want to deepen their knowledge in the field of forest bioeconomy and find the broader context of the use of all ecosystem services of forestry. It is an important source of information for state administration staff as well as staff at different levels of organisations.

The structure of the publication is based on the definition of the term bioeconomy and forest bioeconomy, it focuses on the problems related to the production of natural resources, but also other ecosystem services of forestry and highlights the links with sustainable development. Most space is devoted to the use of timber and the use of other natural resources from the forest is also described. Finally, the importance of the bioeconomy for the future is mentioned, including an introduction to the strategies that are usually adopted in the timeframe up to 2030.

1 INTRODUCTION TO BIOECONOMY

The aim of the introductory chapter is to define the bioeconomy and its importance for society and to provide a closer look at the historical development and priorities of the bioeconomy.

Keywords: bioeconomy, renewable biological resources, bioproduct, bioenergy, biotechnology

1.1 DEFINITION OF BIOECONOMY

The European Commission (EC, 2012) generally describes the bioeconomy as the production of renewable biological resources (RBR) and their conversion into value-added products such as food, feed, bio-based products and bioenergy. It consists of two key components, namely:

1. sustainable production of biomass with the aim of increasing the use of its products in different sectors of society; the intention here is to reduce the impacts of climate change and the use of fossil fuels;
2. increasing the added value of biomass while reducing energy consumption and efficiently using nutrients and energy as additional products.

The importance of the bioeconomy is also demonstrated by the European Green Deal, which is fully in line with the principles of the bioeconomy and which is reflected in all its thematic areas (e.g. biodiversity, sustainable agriculture, clean energy, sustainable industry, sustainable mobility, climate change, etc.).

The understanding of the concept of the bioeconomy varies considerably between stakeholders, being more familiar among public sector entities and large industries than among smaller companies. The main tasks of the bioeconomy include:

1. sustainable management of natural resources;
2. sustainable production;
3. improving public health;
4. mitigating climate change;
5. integration and balancing social development;
6. global sustainable development.

The bioeconomy is an economic concept based on the increased use of RBR in new value chains, made possible in particular by the deployment of innovative biotechnologies. Biotechnology and the increased but sustainable use of OBZ will lead to an improvement in the state of the environment by reducing emissions to its various components, increasing biodiversity, etc. It is precisely because of its multidisciplinary nature that the bioeconomy combines the work of several ministries into one agenda - the Ministry of Agriculture (MoA), which is responsible for the sustainable production of OBZ, the Ministry of Industry and Trade (MoIT), which is responsible for the use of these resources in the Czech economy in the creation of value, the Ministry of Regional Development (MMR), which is responsible for, for example, regional cohesion and the Ministry of the Environment (MoE), which is responsible for the protection and improvement of the environment, its individual components, the improvement of biodiversity, etc.

The bioeconomy can be defined as follows: the production of renewable biological resources (RBR) and their conversion into value-added products such as food, feed, products made from biological material and bioenergy. The bioeconomy is based on agriculture, forestry, aquaculture, food, energy, chemicals and biotechnology industries. The bioeconomy currently employs 22 million people in the EU and has an annual turnover of €2 trillion. These sectors are of significant economic, environmental and social importance, both today and for future generations (EC, 2012).

Bioeconomy is an interdisciplinary field. It encompasses all industrial and economic sectors that produce, use or manage biological resources and is related to all economic activities linked to research on processes at the genetic and molecular level and their application in industry.

The bioeconomy is a social economy. It is first and foremost a service to society, to humanity and, by extension, to the planet as a whole, carried out responsibly in order to improve the quality of life. It consists primarily in the cultivation of agricultural raw materials for industrial use, and it is the development of agriculture that is key to the future of the bioeconomy. Among other things, this area includes the production of biodegradable plastics, pharmaceuticals and the cultivation of genetically modified (GM) food - one of the reasons why the bioeconomy has its critics. Yet most experts and policymakers agree that the 21st century is the age of the bioeconomy.

Biotechnology offers technological solutions in primary production, healthcare and industry. They contribute significantly to economic growth. The bioeconomy comprises three basic elements: advanced knowledge of genes and complex cellular processes, renewable biomass and the integration of biotechnology applications across sectors, see Figure 1 below.

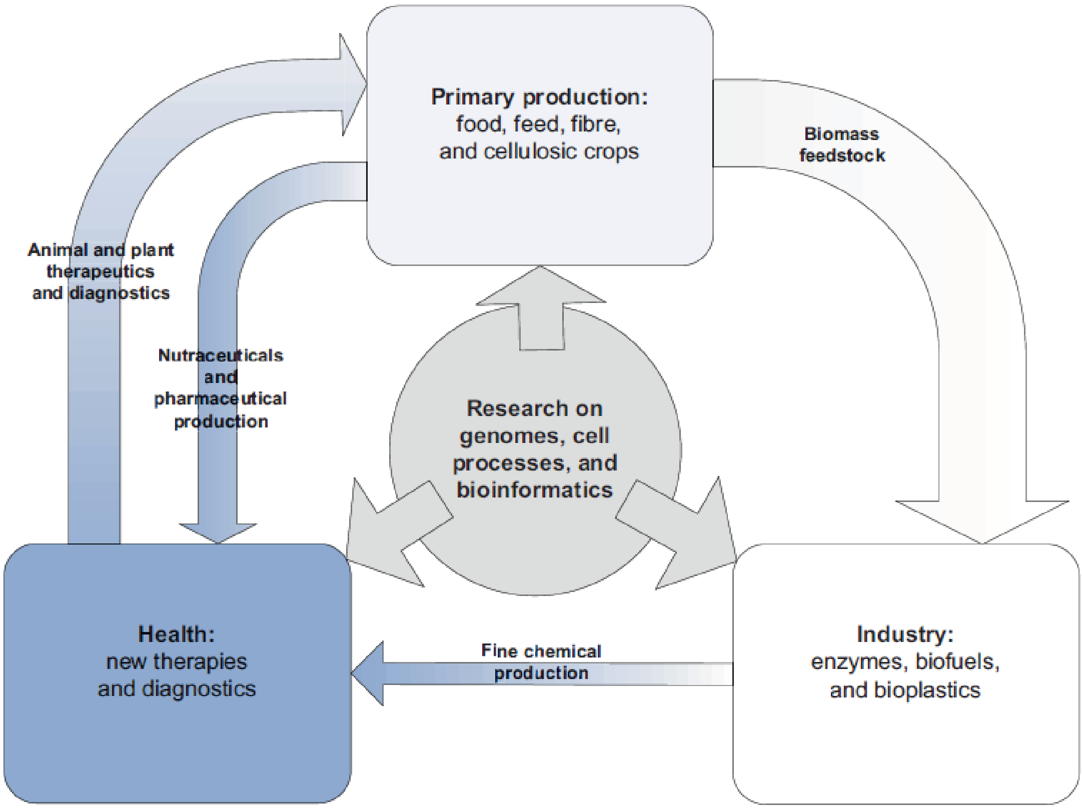

Figure 1: Integration across biotechnology applications
Source: OECD, 2009

Tackling challenges such as climate change, ecosystem degradation, poverty and public health will require innovation, international cooperation, innovation policy, economic incentives and the organisation of economic activity. A key component, as in the past, is technological innovation, which creates new resources and enables the efficient use of existing resources.

Biotechnology can provide such technological innovations. It can improve the supply and environmental sustainability of food, feed and fibre production, water quality, renewable energy, animal and human health, and help maintain biodiversity and detect invasive species. Yet biotechnology is unlikely to fulfil its target potential without appropriate regional, national and, in some cases, global policies to support its development and application.

Bioeconomy includes three parts:

- biotechnological knowledge,
- renewable biomass and
- integration in various applications.

The basic science underpinning biotechnology in primary production, health and industry is similar with all three application areas sharing the same set of platform technologies or research tools. Primary manufacturing, health, and industry have different regulations, industry structures, and cultures, while companies respond to their environments with different business models.

Bioinformatics involves the construction and analysis of databases containing information about genomes, proteins and other complex cellular processes. A number of biobanks have been established collecting genetic and other data from large numbers of individuals. The analysis of databases containing human, animal and plant genomes is likely to lead to a better understanding of gene function and to improved prevention, diagnosis and treatment of a wide range of diseases. As biotechnology evolves from gene-based to multidisciplinary sciences that take into account full cellular modules and their interaction with the external environment, bioinformatics will play an increasingly important role. This will involve modelling systems and producing three-dimensional models of a wide range of biological components.

Biotechnology is used to develop new varieties of food, feed and fibre crops that have commercially valuable genetic properties. One method is to use GM to transfer genetic material between species that cannot interbreed. Other methods use only genetic material from species that are naturally capable of interbreeding, such as gene pooling and intragenics.

1.2 BIOECONOMY AND BIOECONOMICS

The term bioeconomy is used based on the translation of the English term „Bioeconomy“ or „Biobased Economy“. Bioeconomics is not synonymous with the term bioeconomy, but is the science that deals with the bioeconomy.

Bioeconomy is not identical to the term bio-products or bio-food. The Industrial Revolution in the 20th century brought industrialisation of agriculture, chemistry in the form of fertilisers, pesticides, cattle farming etc. (including the chemicisation of other sectors). Various dyes, flavourings, enzymes, preservatives, emulsifiers, stabilisers etc. are used in the food industry. The use of the prefix bio- (BIO = the first part of compound words meaning life) expresses the desire to return to nature, to a healthier way of life and to protect the environment. However, the bioeconomy is not defined on the basis of this definition but, as already mentioned, is based on the use of renewable biological resources.

1.3 HISTORY OF BIOECONOMY

The history of the bioeconomy can to some extent be identified with the history of economics and the focus on resource scarcity, where natural resources play an important role. Adam Smith (1723-1790) is considered the founder of modern economics, see his book „The Wealth of Nations“. Thomas Malthus (1766-1834) and David Ricardo (1772-1823) discussed absolute resource scarcity. S. Jevons (1835-1882), K. Menger (1840-1921), L. Walras (1834-1910), A. Marshall (1842-1924) represent neoclassical economic theory - the concept of relative resource scarcity. H. Hotelling (1931) investigated the optimal use of exhaustible resources.

In relatively recent history, the possibilities for further economic growth and sustainability have begun to be considered. The first important works in this field are known, in particular from the early 1970s (Meadows et al., 1972). From the perspective of sustainability, the long-term assessment (more than 50 years) is particularly important, as well as, for example, the consideration of the discount rate, which is a crucial category from the point of view of time. The need for stability of the economy and the state of the environment has been pointed out by a number of authors. The origins of these considerations can be traced back to the late 1980s (Ritschelová et al., 2002).

The American physicist and economist of Romanian origin Nicholas Georgescu-Roegen introduced the concept of entropy (a measure of disorder) in economics and formulated the theory of bioeconomics (1970). He argues that in the economics of biological processes the law of entropy applies, not the laws of mechanics.

Bioeconomy evolved as a theoretical direction for the optimal use of natural renewable resources over time based on mathematical economic models (economic modelling of population dynamics of organisms). Studies have been carried out to optimise the harvesting of marine organisms (fishing in the seas and the tragedy of the commons), to model the evolution of soil fertility, and to optimise human preventive actions against the multiplication of weeds and pests. The possibilities of protecting biological organisms by private ownership and the question whether this protection is sufficient have been elaborated.

The number of scientific papers focusing on the bioeconomy has seen a sharp rise in recent years, see Figure 2 below.

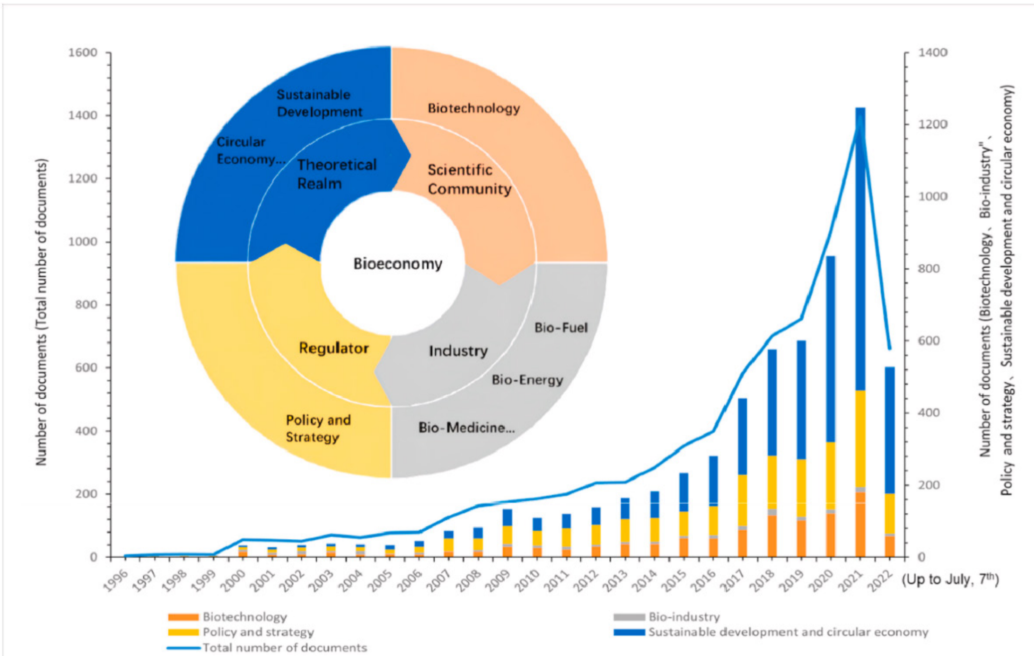

Figure 2: Number of publications related to bioeconomy in four areas
Source: Wei et al, 2022

Given the wide spread of the concept of bioeconomy in different disciplines, it is possible to distinguish between three ideal-type visions of what the bioeconomy represents. When considering the relevance of the bioeconomy in science and engineering research, it is perhaps not surprising that at least the first two visions seem to be strongly influenced by a technical perspective (Bugge et al., 2016):

1. A vision for biotechnology that emphasises the importance of biotechnology research and the application and commercialisation of biotechnology in different sectors.
2. A bioresources vision that focuses on the role of research, development and demonstration in bioresources in sectors such as agriculture, aquaculture and forestry, and bioenergy, as well as the creation of new value chains. While the biotechnology vision takes its starting point in the potential applicability of science, the bioresources vision emphasises the potential for upgrading and transforming bioresources.
3. A bio-ecological vision that emphasises the importance of ecological processes that optimise the use of energy and nutrients, promote biodiversity and avoid land degradation by monocultures. While the previous two visions are technology-centric and give a central role to research and development in globalized systems, this vision emphasizes the potential for regionally concentrated circular and integrated processes and systems.

The third wave of economic development can be seen in Figure 3.

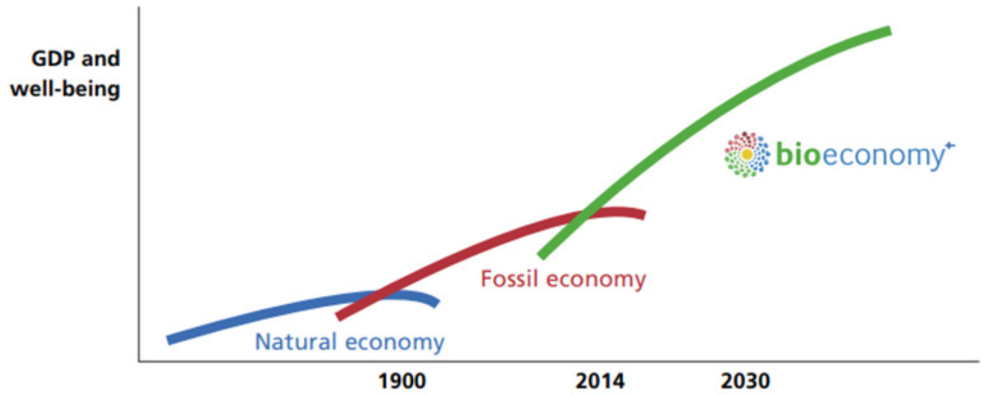

Figure 3: Bioeconomy will be the next wave of economy
Source: The Finish Bioeconomy Strategy, 2014

In the long term, a wave of bioeconomy is expected in the coming decades, similar to the use of fossil fuels and related products. However, the bioeconomy has the advantage over the fossil economy of being based on renewable (inexhaustible) resources.

1.4 BIOECONOMY PRIORITIES

Taking into account the underlying societal strategies, it is possible to establish the priorities that the bioeconomy will focus on in the coming period until 2030. These are:

1. food,
2. climate protection,
3. health,
4. biodiversity.

The bioeconomy implies a close link with sustainable development. However, sustainable development is not a priority, but a complementary aspect of all priorities.

Chapter Summary

The bioeconomy can be characterised as an economic concept based on the increased use of renewable biological resources in new value chains, enabled in particular by the deployment of innovative biotechnologies. Biotechnologies offer technological solutions in primary production, healthcare and industry. The definition of the bioeconomy implies that it deals with the production of renewable biological resources and their conversion into vital products. Bioeconomy is an interdisciplinary field. The biggest priority of the bioeconomy is food security. Bioeconomy is the science that deals with bioeconomy. Bioeconomy has evolved as a name for the theoretical direction for the optimal use of natural renewable resources.

Control questions

1) How can the bioeconomy be defined?
2) What is the difference between bioeconomy and bioeconomics?
3) What are the priorities of the bioeconomy?

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2 SUSTAINABLE DEVELOPMENT AND THE IMPORTANCE OF RENEWABLE RESOURCES IN THE BIOECONOMY

The aim of the chapter 2 is to introduce sustainable development, its goalas and importance for the bioeconomy.

Keywords: sustainability, economic, environmental and social pillar, SDGs

The main objective of the bioeconomy is to promote economic development while increasing the share of renewable natural resources. The main criterion of the bioeconomy, which is sustainable development, applies to all related activities. This is not about recklessly increasing economic performance, but while adhering to the principles of sustainable development.

A priority focus of the bioeconomy is the need to respond to the food and economic demands of a growing population. In doing so, a wide range of issues need to be addressed, including coastal-land interactions, ecosystem services, food production, rural development, agriculture, forestry and bioenergy (Nagothu, 2020). At the same time, there is a need to recall the role that the bioeconomy can play in achieving the UN Sustainable Development Goals (SDGs) without compromising environmental sustainability and equitable distribution of benefits as a result of increasing economic performance.

The experience of the deteriorating environment and the global energy crisis have provided the impetus for the debate on sustainable development. In the context of the dramatic increase in the pollution of environmental components in the 1960s, major scientific research organisations also began to address this issue in a systematic way (Rynda, 2000). Given the pressing social and environmental needs, sustainability science can be expected to play an important role in providing expertise and contributing to the realisation of a sustainable society (Vrabcova, 2021).

The bioeconomy is closely linked to sustainable development. This is because the orientation towards natural, renewable resources cannot be understood only unilaterally and it is important to consider it always comprehensively from the perspective of sustainable development. The forest bioeconomy therefore includes sustainability issues, where sustainability is sought throughout the entire production process. Forestry has an advantage in terms of sustainable development, as it is the sector with the longest experience of implementing this principle.

2.1 HISTORICAL DEVELOPMENT AND DEFINITION OF SUSTAINABLE DEVELOPMENT

The twentieth century can be characterised by strong economic growth fuelled by technological progress. On the one hand, technological progress was an important driver of economic growth, but on the other hand, environmental and social negative impacts began to emerge. Thus, the lesson from this period is to monitor the potential risks of technological change.

The associated gradual increase in international trade has raised new questions about safety for human health and the environment and impacts on ecosystems in exporting countries.

Comprehensive strategies to protect the environment were not adopted in the 1950s and 1960s. Based on the concrete practical effects of negative environmental behaviour, laws were passed to address (narrow) environmental problems, usually related to air and water cleanliness. The overall state of the environment was deteriorating significantly, and environmental experts increasingly pointed to unsustainable developments.

In 1968, the Club of Rome was founded, bringing together eminent persons from many countries to conduct research into the problems of the development of the world as a whole, so that decisive steps could be taken to set limits to growth. In 1972 the Club of Rome published a report commissioned by a team of scientists from the Massachusetts Institute of Technology, this report published the results of computer simulated human population and natural resource use up to the year 2100 (Meadows, 1972). Subsequently, environmental issues were widely discussed at the 1st United Nations Conference on the Environment in Stockholm in 1972.

In the 1980s, the OSN General Assembly focused on formulating a global agenda for change (Our Common Future, 1991). The aim was to

- propose long-term environmental strategies to ensure sustainable development up to the year 2000 and beyond;
- to recommend ways of caring for the environment that can be the subject of significant cooperation between developing countries and countries at different stages of economic and social development and that will lead to shared, multi-beneficial goals that respect the interrelationships between people, resources, the environment and development;
- to consider ways and means by which the international community can more effectively care for the environment;
- to formulate common ideas on long-term environmental issues and the appropriate steps needed for the successful implementation of programmes to protect and improve the environment, on a long-term programme of action for the next decade, and on the goals towards which the human community should work.

In 1983, the United Nations mandated a special independent commission led by Norwegian politician Gro Harlem Brundtland to find a path to sustainable human development. The Commission concluded its work in 1987 and issued the document „Report of the World Commission on Environment and Development: Our Common Future", also known as the „Tokyo Declaration" (Our Common Future, 1991). This document defined sustainable development for the first time as ‚development that will provide for the needs of present generations without compromising the needs of future generations and without doing so at the expense of other peoples'.

There are many ways to graphically express sustainable development. One of the most common is through the so-called Venn diagram. This is an explanation of the membership of elements in a set, including the relationships between sets. As can be seen in Figure 4, a Venn diagram is made up of closed curves, with the points inside representing the elements of the set.

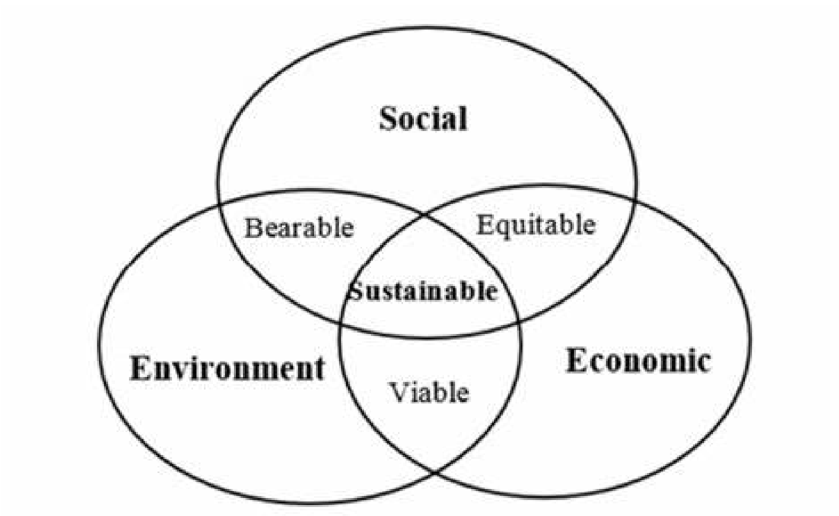

Figure 4: Sustainability represented by a Venn diagram
Source: Vrabcová, 2021

It is clear that all 3 aspects listed in the Venn diagram are absolutely necessary, as **economic sustainability** provides future income, resources and a stable environment for investors, **environmental sustainability** provides an ecosphere that supports and protects life, and social or **societal sustainability** provides functional societies and guarantees of human rights (Vrabcova, 2021).

The three pillars of sustainability are basically derived from the definition of sustainable development:

- environmental,
- social,
- economic.

The environmental pillar is based on the fact that unlimited growth is not possible in a limited system. The value of ecosystems and their services must therefore be continually recognised and properly appreciated (both spiritually and materially) and well guarded. **The social pillar** is about balancing inequalities between different social groups or individuals. Among the basic assumptions of the social pillar is the eradication of poverty, both within and between regions and in global terms between countries and geopolitical entities. It is clear that the economic side of sustainability is closely linked to the social side. **The economic pillar** consists of all economic activities, the interactions between them and the interactions between the environment and society. These three pillars often come into conflict (e.g. nature conservation versus highway construction, etc.) and therefore a consensus needs to be sought in addressing the practical problems of sustainable development.

In this context, the so-called triple bottom line concept cannot be overlooked*, which* promotes the evaluation of overall business performance based on three important areas: profit, people and planet (Elkington, 1994). The concept arose out of frustration with traditional, financially focused measures of business performance. As is evident, sustainable development is based on three pillars (Klarin, 2018):

- the concept of development (socio-economic development in accordance with environmental constraints),
- the concept of needs (allocation of resources to improve quality of life) and
- the concept of future generations (sustainable use of resources in line with the needs of future generations).

The performance of the company can also be monitored in terms of sustainability (Kocmanová and Hřebíček, 2013). The measurement of sustainable performance of enterprises is related to the introduction of financial and non-financial indicators in the management of enterprises. In recent years, companies have increasingly used ESG (Environmental Social and Governance) indicators, and investors and the banking sector are increasingly interested in the results of this reporting.

An important step in the field of sustainability was the formulation of the Sustainable Development Goals (SDGs), the result of a three-year process that began at the UN Conference on Sustainable Development in 2012 in Rio de Janeiro.

Figure 5: Sustainable Development Goals (SDGs)
Source: the UN, 2022

Figure 5 shows that a total of **17 Sustainable Development Goals (SDGs)** were formulated, representing a 15-year development agenda (2015-2030). The goals build on the agenda of the Millennium Development Goals (MDGs). The SDGs are part of the Sustainable Development Agenda, which was endorsed by the UN Summit in New York on 25 September 2015 in the document „Transforming our World: the 2030 Agenda for Sustainable Development".

More information, study materials, action manuals and many other resources can be found on the UN SDGs website (https://www.un.org/sustainabledevelopment/).

2.2 SUSTAINABLE DEVELOPMENT AND BIOECONOMY

The bioeconomy implies a close link with sustainable development (Linser and Lier, 2020). Not only the evolution of the global population, but also the continuous changes in the environment, climate and ecosystems and their negative impacts highlight the need to address the bioeconomy in a whole broad context, using a knowledge-based and innovative approach (Vrabcová et al., 2019). The concept of a knowledge-based economy reflects the vision of achieving economic growth through high-tech industries, which requires investment in innovation and a highly skilled workforce. The bioeconomy strategy includes goals aimed at addressing global challenges such as population growth, climate change, loss of soil fertility, and transforming the economy from a dependence on fossil resources to a „circular" or „recycling" approach (Vrabcova et al., 2019).

The bioeconomy can be a sustainability risk that needs to be eliminated. This risk can be described using Germany as an example (Bonger and Dahlke, 2022). Here, government strategies are not sufficiently oriented towards sustainability. This is because the German concept of the bioeconomy did not originate as a sustainability programme, but as an alternative form of achieving profits for the economy. German bioeconomy policy is effectively driven by technology and growth, but not by so-called transformative innovation policy. Furthermore, transdisciplinary research (given the transdisciplinary nature of the bioeconomy) is insufficiently conducted and involves the whole of society.

An ex-ante sustainability assessment should be carried out when planning bio-economic activities. This means that it should be carried out in time to inform the stakeholder discussion process, negotiate the best trade-offs and support decision-making in planning. This procedure can be characterized similarly to the precautionary principle in environmental policy (Ritschelová et al., 2002). Based on the results of sustainability assessments, potential trade-offs between economic, environmental and social can be identified (Lewandowski, 2018). The combination of life cycle assessment (LCA), social life cycle assessment (sLCA) and life cycle cost assessment (LCC) is considered the most advanced and comprehensive approach to sustainability assessment. All three methods incorporate the life cycle idea and together cover the three dimensions of sustainability.

Chapter Summary

The main criterion for all bioeconomy activities is sustainable development. It is not about increasing economic performance at any cost but rather ensuring that it aligns with the principles of sustainable development. Sustainable development was first defined in the document Report of the World Commission on Environment and Development: Our Common Future (1987). It is typically defined by three fundamental pillars: environmental, social, and economic. A significant step towards sustainability was the formulation of the Sustainable Development Goals (SDGs), the outcome of a three-year process that began at the UN Conference on Sustainable Development in 2012 in Rio de Janeiro. The bioeconomy is closely linked to sustainable development. However, it also presents potential risks to sustainability that must be mitigated. Therefore, an ex-ante sustainability assessment should be conducted when planning bioeconomy activities. The results of this assessment can help identify potential trade-offs between economic, environmental, and social factors.

Control questions

1. What is the definition of sustainable development?
2. When and where was sustainable development first defined?
3. What sustainable development goals have been established by the UN?
4. Why is sustainable development important for the bioeconomy?

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3 BIOECONOMY BY ORIGIN OF RENEWABLE NATURAL RESOURCES

The aim of Chapter 3 is to define the bioeconomy according to the origin of renewable natural resources, to define the agricultural bioeconomy and to list the key strategic documents that take into account the principles of the agricultural bioeconomy. A further objective is to provide an overview of the importance of forestry in the bioeconomy and to reflect on the broader context of the forest bioeconomy in the Czech Republic and the EU. A third sub-objective is to introduce the reader to aquaculture, an important sector for the production of food and technical raw materials and an important and growing bio-based industry.

Keywords: biodiversity, Farm to Fork, zero pollution hierarchy, precision agriculture, common agricultural policy, agricultural bioeconomy, agriculture, forest bioeconomy, biomass, monitoring, strategy, plants, molluscs, fish, aquatic environment, integrated aquaculture production

3.1 AGRICULTURAL BIOECONOMY

Agriculture can be considered a key sector for the development of the whole bioeconomy. The agricultural bioeconomy is a complex concept that aims at strengthening and diversifying through the transformation of agricultural production, waste and other non-productive outputs into high-value bio-based products, the development of new resistant crops and varieties to abiotic stresses and, last but not least, long-term environmental sustainability and biodiversity enhancement.

The importance of agriculture and food is reflected, among other things, in the share of employment and value added in the EU (Figure 6).

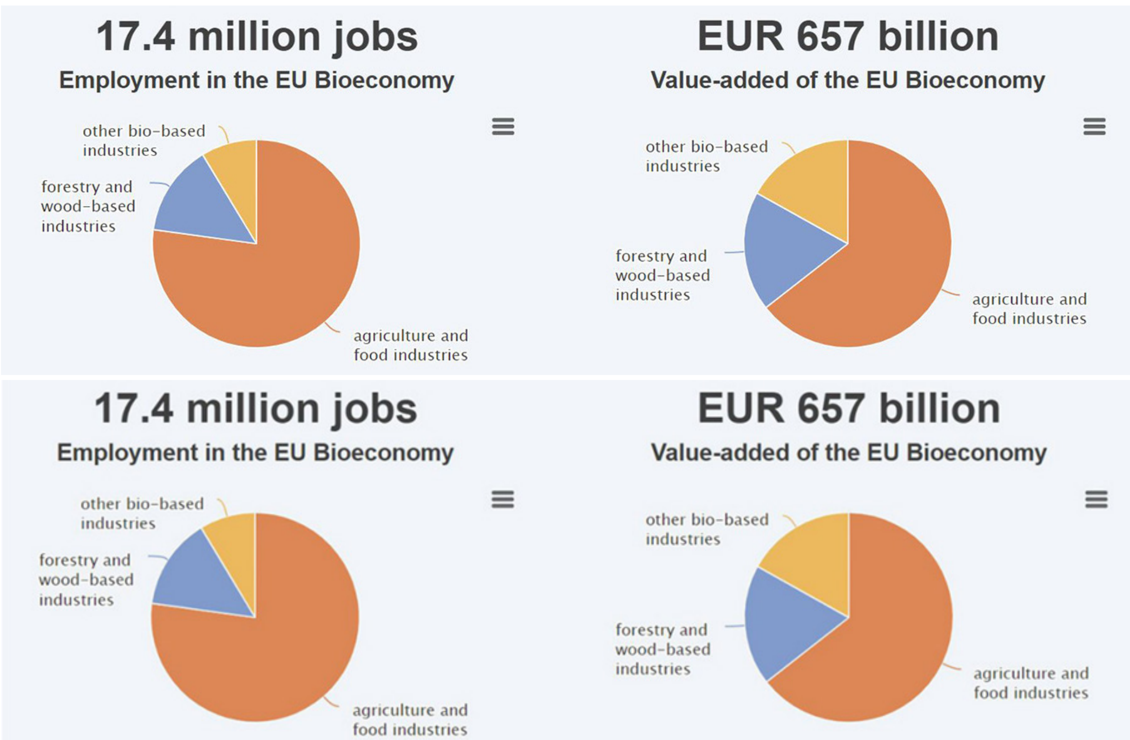

Figure 6: Economic indicators of the bioeconomy in the EU
Source: the EC, 2023

3.1.1 Main challenges of the agricultural economy

One of the main challenges of the agricultural economy is the transformation of agricultural systems to support food security in the context of global change. Reducing the agricultural carbon footprint requires the development of agroecological practices and ecological processes to convert biomass and by-products (Faucon et al., 2023). Decarbonisation policies bring new demand for bio-based products and may present an opportunity for crop diversification and by-product valorisation. These developments are leading to the study of new agricultural systems centred around the concept of bioeconomy and the development of transdisciplinary approaches combining agroecology and bioeconomy to create more resilient ecosystems.

Forms of the bioeconomy are often understood here in a technocentric approach as well, as evidenced by studies that aim to identify available biomass reserves.The benefits of moving to an agricultural bioeconomy based on biotechnology include:

- reducing greenhouse gas emissions,
- reducing dependence on fossil fuels,
- smarter management of natural resources and
- better food security.

The European Commission promotes sustainability in agriculture and rural areas across the EU through the Common Agricultural Policy (Figure 7).

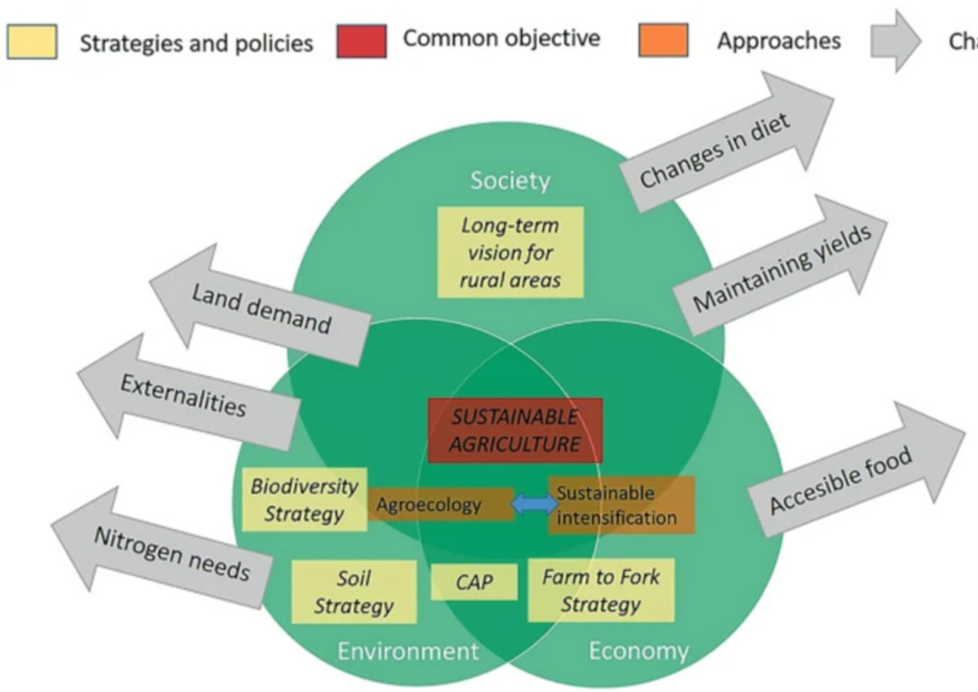

Figure 7: Combined approach to ensure sustainable agriculture
Source: Hoffmann et al., 2024

The Common Agricultural Policy combines social, economic and environmental approaches to adapt agriculture to the requirements of the Green Deal for Europe (EC, 2022a).

The agricultural bioeconomy can be seen as a ubiquitous entity whose outcomes include reducing greenhouse gas emissions, appropriate water and soil management, improving biodiversity, etc. These can be measured by technical and economic units or by social indicators in the form of well-being (health, reduced air pollution, greener cities, etc.).

The agricultural bioeconomy includes and uses (von Braun, 2018):

- sustainable management of ecological systems,
- soil protection,
- life sciences to transform established economic sectors into sustainable industries,
- social transformation and „biologisation" of the economy with new products and solutions that facilitate sustainability.

The goal of the agricultural bioeconomy is primarily to intensify land management in order to maximize biomass production (Marttila et al., 2020). At the same time, the agricultural bioeconomy aims to achieve the complex goals of sustainability in the context of food security, biodiversity care, compatibility with energy and water systems, and climate resilience. The development of biofuels, which is currently growing exponentially, derived from non-edible plant components, is a suitable alternative to fossil fuels and could play an important role in reducing dependence on non-renewable energy sources. The development of an advanced agricultural bioeconomy is an important step towards achieving sustainable development with lower fossil fuel use.

There is a strong dependence of agriculture on a number of factors such as chemical fertilisers, pesticides, subsidies and various price supports. Despite major advances in crop and livestock productivity in recent decades, driven mainly by the use of mineral fertilisers, irrigation, advanced technology and farm machinery, agrochemicals, etc., it would be overly optimistic to assume that this trend will remain linear. Agricultural production has a number of environmental impacts, including its contribution to greenhouse gas emissions, significant energy consumption, water consumption, soil conversion and associated loss of biodiversity, and the use of pesticides, herbicides and fungicides. Agriculture is currently facing a number of challenges, particularly related to:

- climate change,
- adverse weather conditions (drought, extreme temperatures…),
- the rising costs of all inputs (fertilisers, seeds, plant protection products, fuel, labour, rent…),
- an ageing workforce,
- constraints and differences in subsidies and many others.

Climate change is likely to have an impact on agricultural productivity, so policies must be put in place to enable both mitigation and adaptation. At the same time, in line with the drive for sustainability (the principles of which have been explained in Chapter 2), there is a strong will to promote and transform territories into low-carbon economies. The main priorities of the agricultural bioeconomy are:

- food security and adequate self-sufficiency,
- competitiveness of agriculture,
- sustainable management of natural resources and climate action,
- achieving balanced spatial development of rural economies and communities, including the creation and retention of jobs.

3.1.2 Non-food agricultural bioeconomy

Agricultural ecosystems are primarily managed to optimise the supply of food, fibre and fuel. In this process, they depend on a wide range of supporting and regulating services such as soil fertility and pollination. The nutrient cycle maintains soil fertility and microorganisms (bacteria, fungi, etc.) are critical mediators.

In addition to food, the agricultural bioeconomy produces a diverse biomass that responds to a variety of economic, social and environmental objectives. This biomass consists, for example, of various plants with high added value (e.g. medicinal plants) or with sought-after properties and functions, plants with high biochemical methane potential and hedgerows (Grouiez et al. 2023). A major difference from previous agricultural models is that the farmer is committed to his role and to promoting health and the environment. This production is based on an understanding of the social-ecological system that makes up the farm and the environment.

The non-food agricultural bioeconomy allows farmers to gain control over their production choices. He develops diversification strategies in his production and improves different plant functions to get maximum value addition. Non-food value chains are highly specialized, vary in length, and operate essentially on a local or regional scale.

Non-food production generally needs external sources of funding to support innovative trends. Public policies such as the Common Agricultural Policy or the Bioeconomy Strategy can help. Support can also be expected from small cooperative structures and the development of alternative distribution channels.

Agroecological agriculture is a model that incorporates and enhances ecological functions, in line with the principles of agricultural bioeconomy and sustainability. At regional level, sustainability issues can be addressed by combining food and non-food production. The agricultural bioeconomy is closely linked to ecosystem services, and takes into account the limits of the biosphere and the trade-offs between food and non-food issues. Ecosystem services are both regulatory (e.g. pollination) and cultural (e.g. agro-tourism). This approach is based on the complex interactions and coevolution between the natural environment and agriculture, which include all human activities. Measures relating to soil quality, biodiversity and the sustainability of soil fertility are central here. Crop diversity and diversity of production allow a more effective response to climate change, which makes it more difficult to predict harvests.

3.1.3 Trends in European agricultural regulation

The agricultural bioeconomy is influenced by decisions of the European Commission. In 2021, the European Commission presented an action plan for the development of organic production, the main objective of which is to promote the production and consumption of organic agricultural products. By 2030, 25% of agricultural land should be managed organically and the share of organic aquaculture should be significantly increased. The EC decided to do this for a number of reasons, including:

- ecological fields have approximately 30% more biodiversity,
- organically farmed animals have better living conditions and use less antibiotics,
- organic farmers have higher incomes,
- increased consumer preferences.

Among the EU's flagship strategies is the Green Deal for Europe (Green Deal), issued in 2019 to launch further international action to achieve ambitious climate targets. The agricultural economy plays a vital role in several key areas, namely:

- creating a sustainable food system based on a Farm to Fork strategy,
- complementing the new biodiversity strategy by protecting and diversifying the composition of plant and animal species in the rural ecosystem,
- participating in the Green Deal climate action to achieve EU carbon neutrality by 2050,
- engaging in a zero-pollution action plan by protecting natural resources such as water, air and soil.

The Farm to Fork strategy, whose core areas are listed in Figure 8, is considered a major advance in European food policy (Schebesta and Candel, 2020), as it includes targets on pesticides, fertilisers, organic farming and antimicrobial resistance to be achieved by 2030. Regulatory and non-regulatory initiatives are identified to achieve these goals, including a legislative framework for sustainable food systems, which is expected to be proposed by the end of 2023. The most important measure is the proposed legislative framework for sustainable food systems, which aims to promote policy coherence at EU and national level (Schebesta and Candel, 2020).

Figure 8: Focal areas of the Farm to Fork strategy
Source: EC, 2022b

The EU Biodiversity Strategy 2030 is also linked to the Green Deal for Europe. Key commitments by 2030 include legally protecting at least 30% of EU land and 30% of EU marine areas, integrating ecological corridors as part of a genuine trans-European nature network, and defining clear targets and measures for site protection.

The EU Action Plan: ‚Towards Zero Air, Water and Land Pollution‘ was adopted at a time when the EU has set itself the goal of achieving climate neutrality by 2050. To achieve climate neutrality, the EU needs a more effective zero pollution hierarchy that declares respect and acceptance:

- the precautionary principle,
- preventive measures,
- remediation of environmental damage at source,
- the polluter pays principle.

In terms of the anticipated evolution of the agricultural bioeconomy, Sarkar et al. (2018) identify several major challenges in the context of the agricultural bioeconomy that will require transformative and innovative processes linked to the environment, the health of individuals, sustainable production and consumer demands driven by the projected increase in world population. However, a significant challenge remains the development of national and international policies to support the wider development of more sustainable forms of agricultural production.

Precision agriculture (or digital agriculture, Agriculture 4.0) can play an important role. Enables farmers to make data-driven decisions to respond to changes in crop and soil characteristics, allowing them to minimise inputs and maximise outputs. Digitisation is moving towards automating processes that were previously handled manually. These are tasks that can be performed using computer technology without human intervention. Digitization is mainly about introducing new technologies that modernize existing processes. This includes cloud solutions, artificial intelligence and the Internet of Things, which have the potential to further grow and make employees' jobs easier. However, as the amount of digital data grows and is handled outside the enterprise, there is a relatively high security risk. Few sectors of the economy are as conservative as agriculture (untested experiments could lead to crop failure and hunger). Forms of digitisation in agriculture include modern technologies or tools (GPS, smart machines such as digital milking, satellite area measurement, monitoring, weather stations, seed records, smart sensors, self-driving tractors, drones, robots, compound feed production, grain drying and storage, remote climate control in sheds, automatic consumption control in biogas plants, etc.).

In the long term, the agricultural bioeconomy is based on investment in innovation, similar to other sectors of the bioeconomy.In supporting scientific and innovative processes, it is assumed that economic growth based on biological foundations will be strengthened in conjunction with sustainability, with agriculture itself being inherently linked to respect for nature and the protection of ecosystems (Vrabcová et al., 2024). In the longer term, the agricultural economy can be expected to be concerned with a close relationship with the environment alongside transformation and innovation processes. The impact on our health and consumer preferences will be not negligible. In parallel, there will be an emphasis on promoting more sustainable forms of all activities in the agricultural bioeconomy.

3.2 FOREST BIOECONOMY

The forest bioeconomy is one of the directions within the bioeconomy that highlights the irreplaceable role of forests and forestry in the bioeconomy. According to the widely accepted definition of the European Commission, forests are one part of the bioeconomy and renewable wood raw material is used for further processing (EC, 2012). Some authors define the bioeconomy in direct relation to the production and use of renewable biomass. Ronzon (2015) defines the bioeconomy as „the *production of biomass and its conversion into higher value-added products. It includes agriculture, forestry, fisheries, food processing, pulp and paper production, and to some extent the chemical, biotechnology and energy industries.*" The forest bioeconomy can be synonymous with the forestry sector if it includes all economic activities related to forestry and ecosystem services (Hájek, 2018). If the entire forestry sector is taken into account, the bioeconomy refers not only to forest ecosystems, biomass and raw materials, but also to the primary processing sector (cellulose, bioenergy, wood processing) and secondary processing (biorefineries, biopolymers, etc.), see the definition by Lovrić et al. (2020).

The role of forests, forestry and the whole forest-based sector depends to a large extent on national conditions - not only natural conditions but also the social, legal and cultural environment play a role, which is reflected in the bio-economic objectives of each country.

The focus is on using renewable raw materials in an innovative way. This involves not only the current use of biomass, but also the search for ways to exploit, process and better use biomass in new products. Renewable resources (including renewable wood raw material) have a crucial role to play in the drive to replace fossil resources in the context of adaptation to climate change. In the context of the European Green Deal (EGD) , the forest bioeconomy has been discussed as a central system to help meet the targets (SEI, 2022). The EGD includes a package of policies, several of which complement the bioeconomy strategy (e.g. *Circular Economy Action Plan*, Biodiversity Strategy, etc.). Achieving the different objectives can be in harmony or in conflict with each other. The same applies to forest management objectives .

3.2.1 Bioeconomy and forest bioeconomy - EU

The bioeconomy at the EU level is also linked to the new forestry strategy (*A new EU Forest Strategy: for forests and the forest-based sector*) and according to some authors, forestry is not only a key sector in the bioeconomy (Pülzl, Kleinschmit, Arts, 2014), but also plays a crucial role in the development of the European bioeconomy (Jonsson et al., 2021).

The problem of bioeconomy (specifically forest bioeconomy) is terminological and definitional inconsistency. In practice, different concepts of the bioeconomy complicate understanding by the public and experts, monitoring of the achievement of objectives and international comparisons. The adoption of the new Bioeconomy Strategy (EU) has accelerated the approach to monitoring the bioeconomy. In 2020, the EU bioeconomy monitoring system was officially launched.

However, monitoring as such is necessary to verify the objectives of the Bioeconomy Strategy,

The monitoring system allows to track indicators related to the bioeconomy also in direct relation to the Sustainable Development Goals (11 goals in total) and the EGD.

The indicators monitored include, among others: employment, value added created, GHG emissions (agriculture; land use, land use change and forestry/LULUCF), biomass use, forest harvesting, usable area for agriculture and amount of fish caught. In terms of employment and value added generated, forestry and sectors based on wood--processing account for 14.2% and 18.7% respectively (with agriculture and food processing coming first). Figure 9 shows the use of biomass.

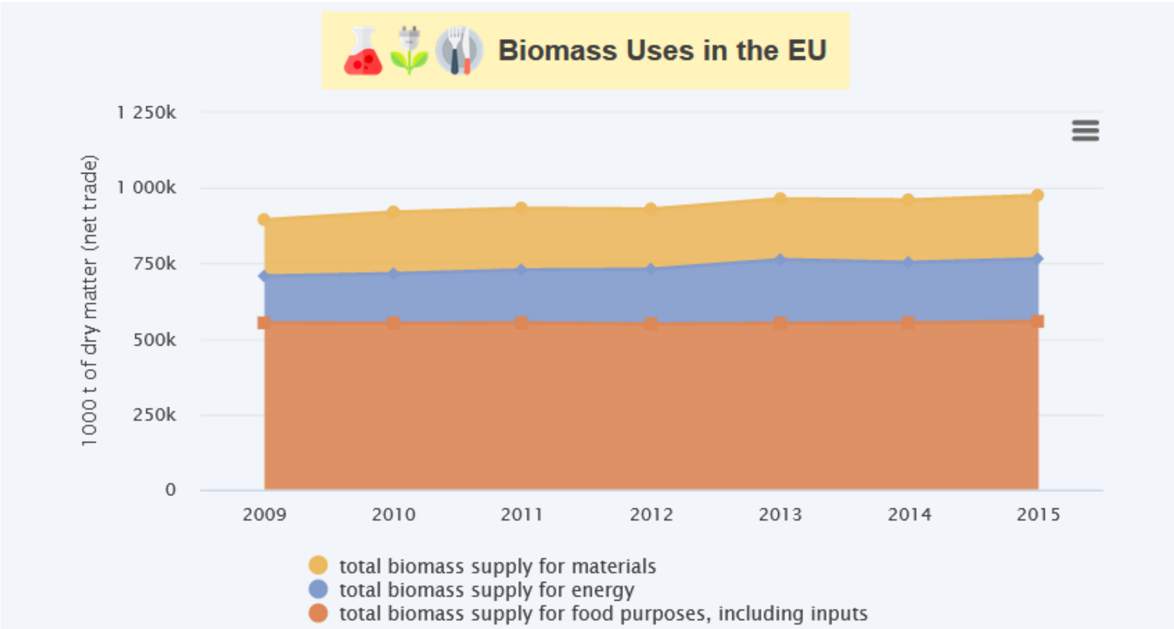

Figure 9: Biomass in the EU
Source: adapted from EU Bioeconomy Monitoring System, Knowledge Centre for Bioeconomy, 2022

**The graph shows the total biomass stock by use from 2009 to 2015 on the x-axis and the quantity on the y-axis.*

3.2.2 Forest bioeconomy - Czech Republic

The Czech Republic does not yet have a comprehensive strategy for the bioeconomy at the national level. The fundamental document is the *Concept of the Bioeconomy in the Czech Republic from the perspective of the Ministry of Agriculture for the years 2019-2024* (MoA, 2020), which should serve as the basis for the future strategy for the bioeconomy. The term „bioeconomy" is used throughout the document. „*The bioeconomy can be defined as an economy based on the sustainable use and processing of biomass, leading to increased use of biomass products in different sectors of society, based on innovation and knowledge to grow the economy and create jobs in rural areas.*" Key activities of the Concept include:

- *ensuring the management of the implementation of the Bioeconomy Concept at the national level,*
- *to support the development of the bioeconomy in the Czech Republic using international cooperation,*
- *boosting technological development and innovation.*

The concept thus refers not only to the use of renewable raw materials, but also to the essential and indispensable role of science and research, the transfer of knowledge into practice and the wider socio-economic context. The concept emphasises a number of areas closely related to forestry (sustainable forest management, biomass use, climate change, strengthening the recreational functions of forests, use of renewable energy sources, etc.).

3.2.3 Forest bioeconomy - an example of good practice and awareness from Finland

In Finland, the bioeconomy accounts for 12% of total value added. Forestry and forest-based industries play a very important role. In 2020, which was affected by the coronavirus pandemic, both value added and employment in the bioeconomy declined. However, the bioeconomy of the forestry sector plays a significant role, accounting for almost 32% of the total output of the bioeconomy in terms of value added (Luke, 2021). The forestry sector is very important in the bioeconomy, especially with respect to the export of goods, especially in the pulp and paper industry. The information is clearly presented through Figure 10 below:

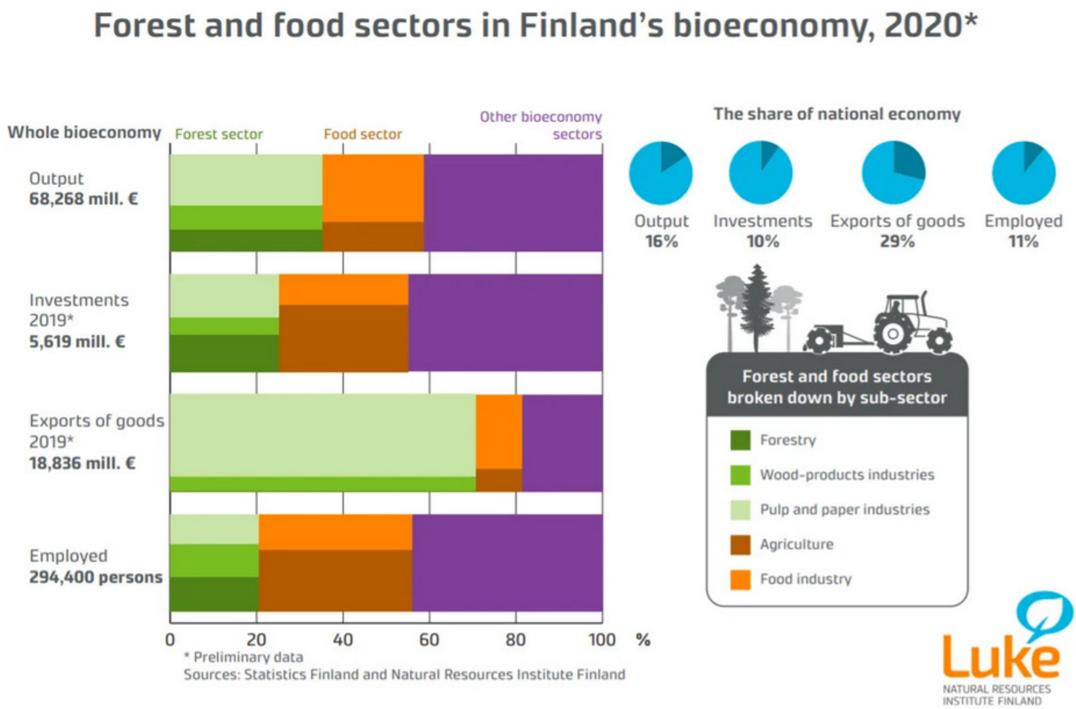

Figure 10: Bioeconomy in Finland (2020)
Source: taken from Luke, 2021

**The graph on the left shows the sectoral shares of the bioeconomy in Finland in 2020 (or 2019). Dark green shows the forestry industry, medium green the wood industry and light green the pulp and paper industry.*

The Finnish Bioeconomy Strategy was adopted in 2014 and updated in 2022 in response to a changing environment, in particular the challenges of climate change and threats to biodiversity. A certain specificity of the strategy is its multidisciplinary nature - the strategy was developed on the basis of cooperation between several actors (in this case, ministries), but it is also highly interlinked with other strategic materials, such as the National Forest Strategy 2025 (2015-2025, updated in 2019).

3.2.4 Awareness of the bioeconomy

The development of the forest bioeconomy also reflects the growing number of scientific outputs on this topic (see the Web of Science database and the information in Chapter 1). A published review (see Jankovský et al. , 2021) highlights the topic of innovation in the forest bioeconomy. Other areas are also linked to the forest bioeconomy - environment, sustainability, economics, etc.

Awareness of the bioeconomy has been the subject of both quantitative and qualitative research in recent years. The *PerForm* project (*Perceiving the Forest-based Sector in the Bioeconomy, 2018-2020*) addressed this issue in a specific setting and within the target group of forestry students at universities. A total of 1,400 respondents from 29 universities in 9 countries responded. 70% of the respondents answered that they had an awareness of the bioeconomy and perceived forestry as the most important sector in the bioeconomy. The results were presented in more detail in Masiero et al, 2020.

3.3 AQUACULTURE

3.3.1 What is aquaculture

Aquaculture encompasses human activities aimed at the production of aquatic organisms in managed aquatic environments or ecosystems subject to intentional influence. The primary output of aquaculture is biomass derived from aquatic organisms, intended for human consumption, animal feed, or various industrial and technical applications.

Aquaculture differs from capture fisheries and other forms of aquatic biomass exploitation primarily through the level of control over the aquatic environment and the cultivated organisms. Unlike capture fisheries, aquaculture involves clearly defined individual or corporate (collective) ownership of the organisms being cultivated (adapted from FAO, 2022).

Although farming of aquatic animals and cultivation of aquatic plants has been practised for thousands of years, significant growth in aquaculture occurred only after World War II. Currently, aquaculture is one of the fastest--growing sectors in global food production (FAO, 2022; Willett et al., 2019).

In 2020, total aquaculture production reached 87.3 Mt (million tonnes, animal production only), rising to 122.3 Mt when plant production is included. Individual groups of aquaculture organisms contributed to the total production by weight as follows: freshwater fish, 49.1 Mt; marine and diadromous fish (species naturally migrating between freshwater and marine environments), 8.3 Mt; molluscs, 17.7 Mt; crustaceans, 11.2 Mt; and other aquatic animals, 1.0 Mt. Aquatic plants, particularly brown and red algae, accounted for a substantial portion of aquaculture production, amounting to 35 Mt (FAO, 2022).

In contrast to aquaculture, capture fisheries production has stagnated, maintaining around 90 Mt annually since the 1990s (Troell et al., 2017). In 2020, capture fisheries production from seas and oceans was 78.8 Mt, while freshwater fisheries accounted for 11.5 Mt (FAO, 2022). A decline in capture fisheries production is anticipated due to the full exploitation or overfishing of approximately 90% of harvested marine populations (FAO, 2022).

3.3.2Production systems in aquaculture

Aquaculture production systems can be broadly classified according to their level of interaction with the surrounding environment into three main types: 1. open, 2. semi-closed, 3. closed systems (Lucas et al., 2019).

Open aquaculture systems primarily rely on ecosystem services, especially in terms of utilizing natural food resources. Aquaculture management in such systems typically includes activities such as stocking organisms, protection from predators, provision of suitable substrates for attachment, and, where feasible, maintaining appropriate hydrological and hydrobiological parameters of the environment. Examples of open aquaculture systems include most mollusc farming operations (filter feeders) and culture-based fisheries. In both cases, aquaculture provides juvenile stock (larvae or juveniles). In mollusc farming, juveniles are exposed to the aquatic environment either suspended on ropes, enclosed in mesh bags or simply placed on suitable substrates in areas with abundant plankton. After reaching marketable size, they are harvested. For fish or other mobile aquaculture organisms, artificially bred larvae or juveniles are stocked into reservoirs or other habitats, where after growing to the desired size, they are harvested using capture fisheries techniques. Open aquaculture systems are generally extensive, characterized by low input levels and typically lower productivity per unit area (FAO, 2017). Cultivation of macrophytes, particularly brown and red algae, is also carried out in open marine systems using various simple cultivation structures (Lucas et al., 2019).

Semi-closed aquaculture systems are represented by traditional setups such as pond aquaculture and cage aquaculture, which currently constitute the majority of global animal aquaculture production (FAO, 2017; FAO, 2022). These systems are partially isolated from the surrounding environment and confine the cultured organisms within a defined space. Interaction with the external environment occurs primarily through water exchange; fresh oxygenated water entering the system carries away waste products such as excrements, uneaten feed, or nutrients. Thus, the surrounding ecosystem becomes a recipient of organic and nutrient loads. Occasionally, organisms may escape into the environment due to damage in cage nets or during pond harvesting activities (Jensen et al., 2010; Kalous et al., 2010). These systems can range from intensive production, such as cage farming of salmon or shrimp pond culture where organisms receive complete formulated diets, to semi-intensive farming practices that utilize natural productivity and supplemental feeding, typically carbohydrate-based feeds like grains. Carp pond aquaculture in Czechia represents an example of semi-intensive aquaculture (Roy et al., 2020).

Closed aquaculture systems are completely isolated from natural water bodies and operate on fully or partially recirculating principles. In such systems, water is treated through mechanical and biological filtration and then recirculated back into the rearing tanks. These systems are usually highly intensive, characterized by high energy inputs related to complete formulated diets and rigorous environmental control. Aeration or oxygenation, heating, pH adjustment, and control of other water quality parameters are common practices (Ebeling & Timmons, 2012). Intensive Recirculating Aquaculture Systems (RAS), due to their high energy requirements but reduced water consumption, are particularly suitable in locations where land availability is limited, and stable electricity is available. They are also beneficial in regions facing restricted water resources (FAO, 2021). Closed aquaculture systems also include microalgae production in bioreactors under strictly controlled environmental conditions (Posten, 2009; Xu et al., 2009).

3.3.3 Circularity in aquaculture

The circular economy does not differentiate between agriculture, forestry, aquaculture, or capture fisheries; instead, it integrates these sectors within a single interconnected loop (see Fig. 11). The objective of a circular bioeconomy is to significantly enhance resource-use efficiency, minimize ecological footprints, and prevent losses through reuse, recycling, remanufacturing, and maximizing resource integration (Colombo and Turchini, 2021; de Boer and van Ittersum, 2018; Roy et al., 2021).

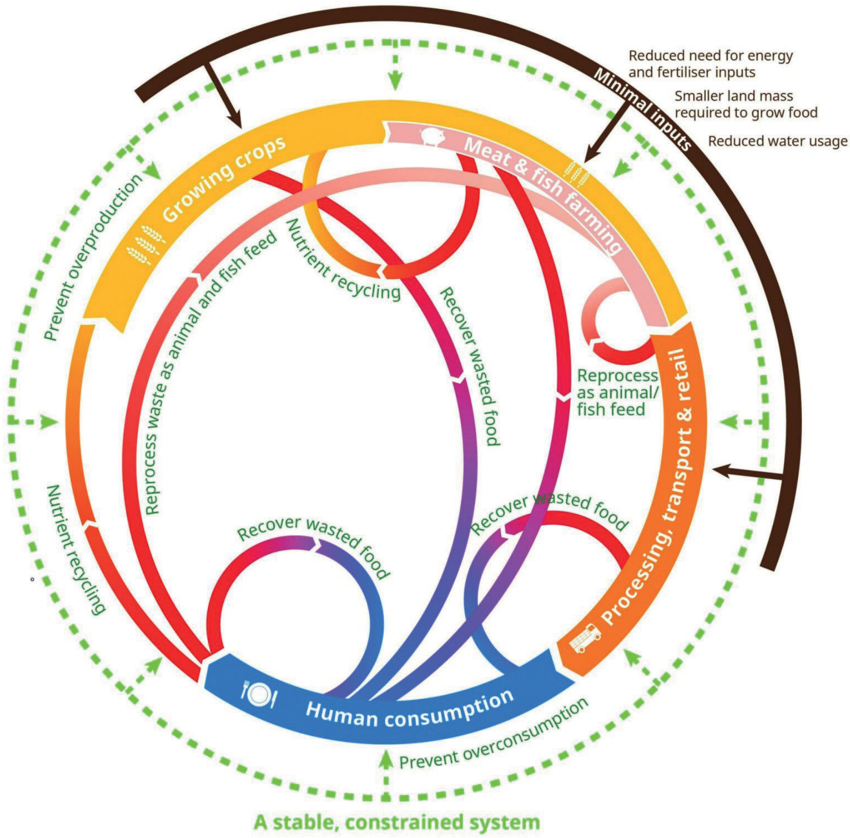

Figure 11. Schematic representation of the circular bioeconomy in local food systems
Source: Roy, 2022

Plants, which drive the carbon cycle through photosynthesis, form the basis of circularity in nature and should similarly play a central role in aquaculture (Roy et al., 2020). Aquaculture is currently undergoing a transition toward intensification and higher production efficiency in response to the growing demand for aquatic organisms as food (FAO, 2016). Nevertheless, linear practices still dominate over circularity, particularly in intensive semi-closed and closed aquaculture systems (Fraga-Corral et al., 2022).

Emerging models advocate for circular approaches by integrating resource reuse, recycling, and valorisation of by-products and residual energy and material flows. Such concepts encompass diverse technological solutions ranging from recirculating aquaculture systems (RAS), integrated multi-trophic aquaculture (IMTA), biofloc technology, and aquaponics to other innovative approaches facilitating nutrient and energy recovery, waste reduction, and sustainability improvements. These approaches have significant potential to transform aquaculture from linear towards more circular models (Fraga-Corral et al., 2022).

However, this circular concept also poses challenges, especially concerning disease transmission risks and subsequent food safety implications (Knipe et al., 2021; Melo-Bolívar et al., 2021). Integrating terrestrial and aquatic ecosystem components into a closed-loop system increases the complexity of managing disease transmission risks and ensuring food safety standards. Direct utilization of animal waste products as feed for other animals or recycling human and terrestrial livestock waste in aquaculture requires rigorous epidemiological and safety management practices (Knipe et al., 2021; Roy, 2022).

Feed as a major source of waste in aquaculture

Feed is identified as the primary source of waste in intensive and semi-intensive aquaculture systems, significantly affecting the environment (Dauda et al., 2019; Martins et al., 2010). If the aquaculture sector maintains its current structure, the demand for aquaculture feed will continue to grow rapidly. Between 2000 and 2017, global aquafeed production more than tripled, increasing from 13.8 Mt to 51.2 Mt. This represents an average annual growth rate of approximately 8.0% since 2000, with production expected to reach around 73 Mt by 2025.

Waste generated from aquaculture can be classified into dissolved wastes (e.g., mineral nutrients such as nitrogen and phosphorus ions) and solid wastes (e.g., excreta, uneaten feed) (Prabhu et al., 2019). Additionally, intensive feeding systems indirectly release nutrients into the environment, resulting in the production of greenhouse gases such as nitrous oxide and methane. These gases are many times more potent than carbon dioxide in terms of their global warming potential (Hu et al., 2012; Yuan et al., 2019).

Strategies to address these environmental impacts include improving feed efficiency, increasing digestibility, and optimizing feed composition to reduce waste outputs (Prabhu et al., 2019; Roy et al., 2020; Sugiura et al., 2000). Currently, replacing animal-based feed components with a higher proportion of plant-based ingredients is a common practice. However, this approach might negatively impact future circular bioeconomies due to the high eutrophication potential associated with lower digestibility of plant-based feed ingredients (Roy, 2022; Boissy et al., 2011).

To address resource sustainability, future solutions involve integrating alternative nutrient sources, such as biomass from recirculation processes involving IMTA (Integrated Multi-Trophic Aquaculture), biofloc technologies, aquaponics, or recycling biological wastes from terrestrial agriculture. Biomass derived from these innovative processes, integrated into agricultural waste management systems, will not compete directly with human food, thus mitigating current conflicts between food and feed production (Roy, 2022).

Integrated aquaculture

Integrated and traditional polyculture systems efficiently utilize water and nutrient inputs, producing less waste and thereby enhancing circularity at local and regional scales (Colombo & Turchini, 2021). These traditional systems contribute significantly to the efficient use of resources through effective input management and reduced environmental waste (Dauda et al., 2019; Martins et al., 2010). In traditional pond aquaculture, livestock farming—such as poultry or other terrestrial livestock—is often integrated with fish culture. Animal manure and agricultural waste products serve as primary linking components, typically after composting. This integration improves nutrient cycling and enhances natural productivity within the ponds. A notable example of such integrated systems is the traditional pond polyculture, including livestock-fish integration systems like the well-known VAC (Vuon, Ao Chuong) system illustrated in Figure 12. Originating from Southeast Asia, particularly Vietnam, the VAC system exemplifies effective local-scale circular bioeconomy practices.

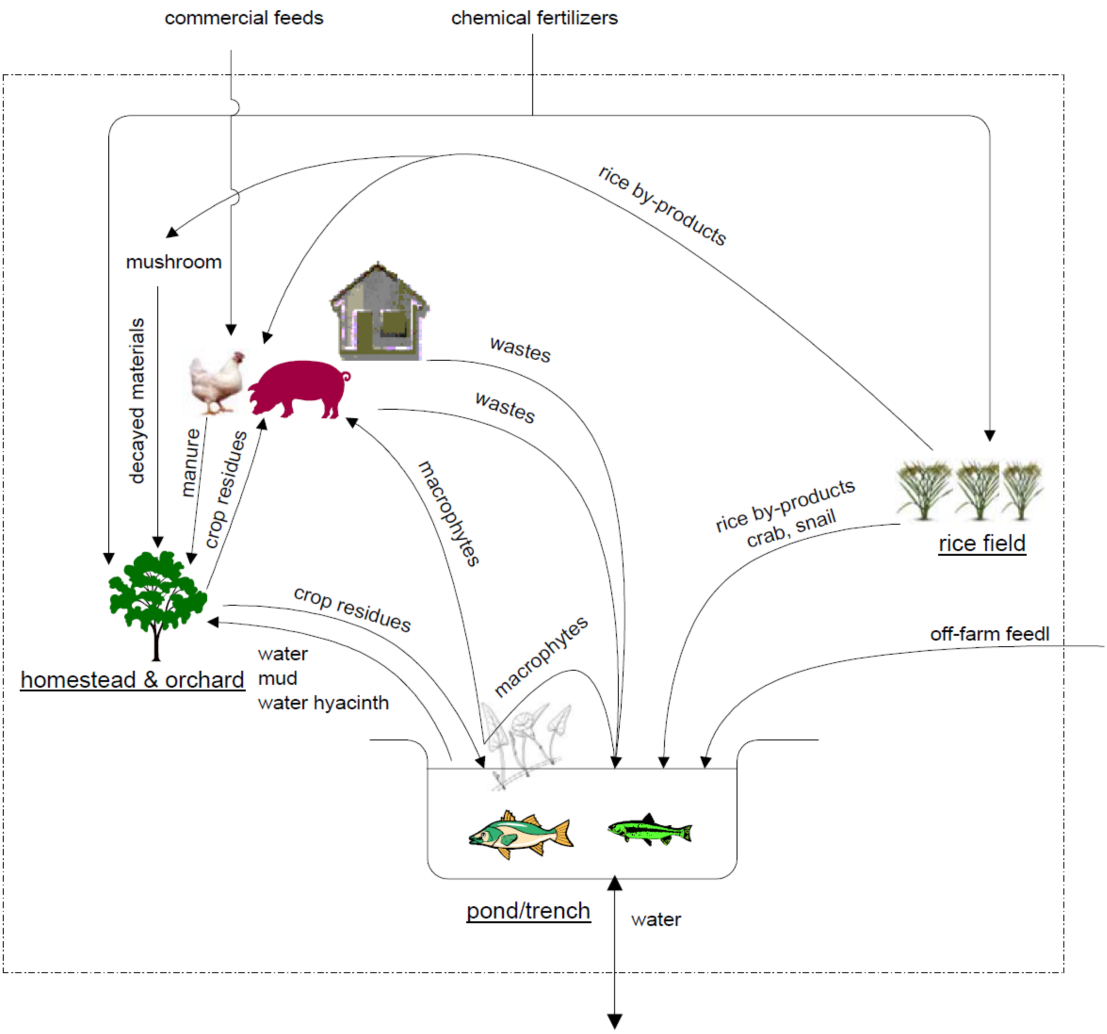

Figure 12: A diagram of biological resource flows illustrating interactions among components of a typical integrated VAC farming system in the Mekong Delta. The dashed line indicates the farm boundary. Source: Nhan et al. (2005)

Despite their environmental benefits, traditional extensive production systems cannot meet the increasing global demand for food (Troell et al., 2017). The promotion of integrated aquaculture in coastal areas has led to modern integrated approaches, primarily in temperate and subtropical marine regions. Generally, in intensive fish and shrimp farming, less than one-third of the nutrients introduced into the environment through feed are removed by harvesting (Hargrave, 2005; Islam, 2005). Integrated Multi-Trophic Aquaculture (IMTA) systems involve the integration of fish, crustaceans, molluscs, and seaweed production (Neori et al., 2004). These systems are designed so that waste materials (nutrients and organic particulates) originating from fish or crustacean farming into the environment are utilized as resources for the subsequent production of molluscs and seaweeds (see Figure 13).

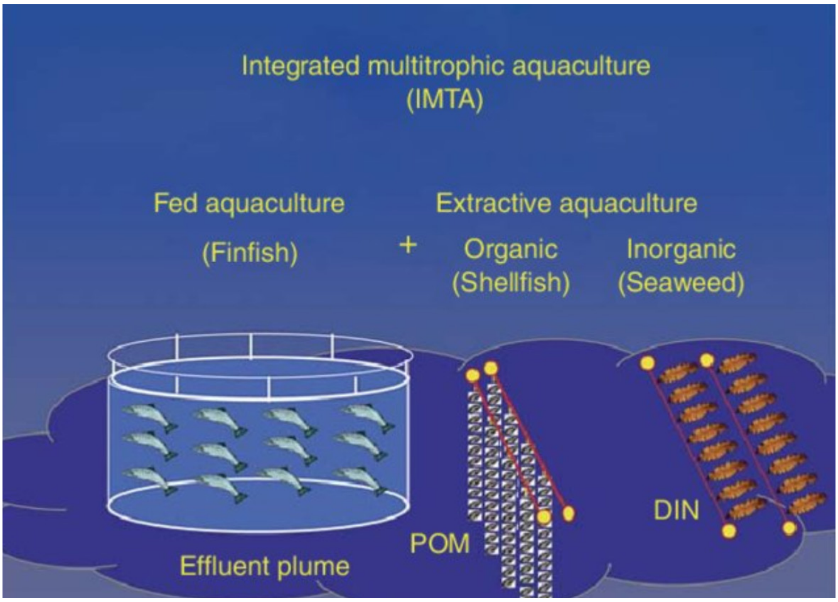

Figure 13: Conceptual diagram of Integrated Multi-Trophic Aquaculture (IMTA) illustrating a combination of fed aquaculture (e.g., fish) with organic extractive aquaculture (e.g., molluscs) utilizing enrichment by particulate organic matter (POM), and inorganic extractive aquaculture (e.g., seaweeds) utilizing enrichment by dissolved inorganic nutrients (DIN).
Source: Clements & Chopin, 2017

In the biofloc technology (BFT), see Figure 14, waste feed and excreta from fish or crustaceans are converted directly within the production tanks into feed consumable by the cultured organisms. A combination of organic matter, microorganisms, fungi and algae forms clusters(bioflocs) that absorb inorganic waste substances and improve water quality (Crab et al., 2012).

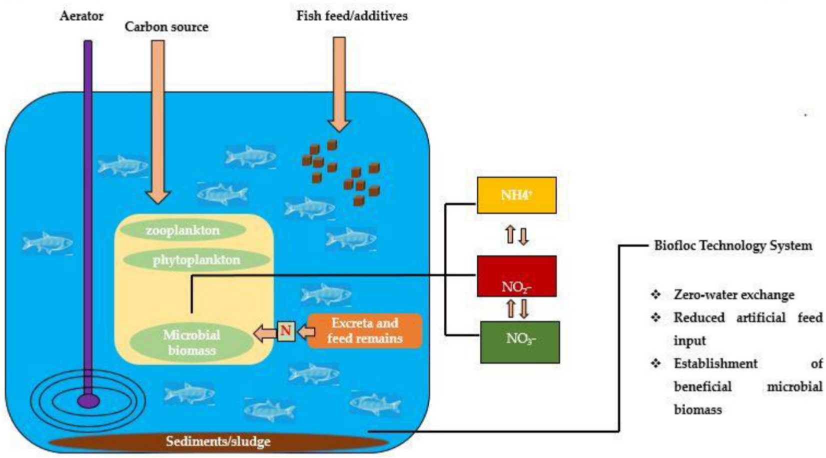

Figure 14. Schema of biofloc technology (BFT).
Source: Mugwanya et al, 2021

Chapter Summary

Aquaculture is the human-controlled production of biomass in aquatic environments. In 2020, global aquaculture production reached a record high of 87.3 million tonnes of aquatic animals and 35 million tonnes of algae. For decades, aquaculture has been among the fastest-growing biomass production sectors worldwide, and its importance in ensuring global food security is expected to continue to rise. The primary aquaculture products include fish, molluscs, crustaceans, and seaweeds. Aquaculture occurs in freshwater and marine environments (marine aquaculture is also known as mariculture). Aquaculture production systems can be classified based on connectivity with the external environment and production intensity. While extensive, open aquaculture systems primarily rely on ecosystem services, intensive, closed systems are isolated from the external environment and require a high level of management and energy input.

A significant challenge for circularity in aquaculture production is the efficient utilization of waste derived from supplied feed. Aquaculture has a long tradition of integrated multi-trophic systems that utilize waste from terrestrial agricultural production. Currently, Integrated Multi-Trophic Aquaculture (IMTA) is also implemented in marine environments. An innovative approach for waste recycling directly within production tanks is biofloc aquaculture. Aquaculture is an integral part of the bioeconomy, holding considerable potential for the circular economy.

Control questions:

How can agricultural bioeconomy be defined?

Describe the combined approach to achieving sustainable agriculture.

List the fundamental elements of precision agriculture.

What are the key areas of the Farm to Fork (F2F) strategy?

How can forest bioeconomy be defined?

Evaluate the importance of forest bioeconomy in Czechia and the EU.

What is the approximate global aquaculture production?

How is aquaculture production ensured in extensive farming systems?

How is aquaculture production ensured in intensive farming systems?

What is the main source of waste in aquaculture?

What is biofloc aquaculture system?

What is Integrated Multi-Trophic Aquaculture (IMTA)?

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4 FOREST ECOSYSTEM SERVICES

The aim of the chapter is to understand the terminology of forest ecosystem services (ES), categorize forest ecosystem services, evaluate their importance and describe the concept of payments for ecosystem services.

Keywords: forest ecosystem services; payments for ecosystem services

4.1 ECOSYSTEM SERVICES - DEFINITION AND CLASSIFICATION

Ecosystem services are the benefits that ecosystems provide to people. De Groot et al. (2002) state that ecosystem services are the capabilities of natural processes to provide goods and services that directly or indirectly satisfy human needs. The term *forest ecosystem services* refers to the benefits of forest ecosystems that are important to humans (e.g. timber production, clean air, soil erosion protection, forest crops, etc.).

The categorisation of ecosystem services is usually based on one of the following classifications: the Millennium Ecosystem Assessment (MEA), the Common International Classification of Ecosystem Services (CICES) and the Economics of Ecosystem and Biodiversity (TEEB).

MEA (2005) divides ecosystem services into:

- Production,
- Regulatory,
- Cultural,
- Supportive.

CICES (2013) classifies ecosystem services into three groups:

- Production,
- Regulatory,
- Cultural.

At this point it is worth mentioning that in the Czech environment we can encounter both the concepts of ecosystem functions and ecosystem services. Functions are determined by the very existence of ecosystems, their internal properties and processes, whereas services are defined as the benefits of the ecosystem for humanity/society. When using the term ‚ecosystem services' we assume that they are used to meet human needs. In the case of services, people directly attribute benefits or economic value.

Below is the categorization of ecosystem services according to Šišák (2010, 2017), who divides ecosystem services into market and non-market:

- Market (production)
    - » Timber
    - » Game management and hunting
- Non-market (non-productive)
    - » With a mediated impact on the market
        - Non-timber (berries)
        - Soil Conservation
        - Hydric
        - Air Protection
    - » No market impact
        - Health and hygiene (recreational, medical)
        - Cultural and educational (nature conservation, educational, scientific, institutional)

The market ones are important especially for the forest owner, or with regard to the income realized by the owner (e.g. revenues from timber sales). *Non-market* ones are a set of effects of the forest on the landscape environment or on humans and which are useful in terms of public interests and as such directly or indirectly used in social practice (Krečmer, 1993).

Ecosystem services are diverse and their importance to people/society can vary depending on who is assessing them (e.g. forest owner, tenant, forest visitor). Productive functions/services have long been at the forefront of ecoystem services - especially timber production, as this has historically been the largest source of income for the forest owner. Over time, and in relation to environmental issues, the growing importance of recreation has also increased the importance of other ecosystem services that were previously seen as more ‚complementary', such as the collection of forest fruits .

Some ecosystem services and the benefits they provide are difficult to value, or to express their benefits in an exact economic way (especially because some of them do not pass through the market - there is no standard process for setting a price based on the conflict between supply and demand). Another difficulty may be the unclearly defined demand for ecosystem services by consumers (e.g. forest visitors). Economic theory confirms that it is difficult to get consumers to clearly express preferences (needs, demand) for goods that are public goods (and in a sense ecosystem services can be understood as such), which also means that the (especially economic) importance of ecosystem services to society is unclear.

Ecosystem services are a current topic, and the assessment of ecosystem services is in line with new European strategies. However, they are significantly influenced not only by the strategies (and thus the possible prioritisation of some of them), but also by the context of socio-economic conditions, including perceptions of major stakeholders and society in general.

4.2 FOREST VISITS AND NON-TIMBER FOREST PRODUCTS (NWFP)

Czechs often visit the forest. In 2022, the average number of visits to the forest per capita was more than 36 per year, confirming the year-on-year increase that has been occurring since 2018. Almost 40% of the population are then frequent forest visitors (MoA, 2023). Gathering crops growing in the forest is also a popular activity during forest visits. FAO (1999) refers to *non-wood* (or *non-timber*) *forest products* as products of biological origin derived from forests, other wooded land and trees outside forests, excluding trees; i.e. mainly mushrooms and berries such as blueberries, cranberries, etc.

The attractiveness and possibility of collecting mushrooms and forest crops is also related to the provisions of the Forest Act, which does not directly define the limitation of the amount of crops that a visitor can collect. Section 19 of Act No. 289/1995 Coll., on forests, as amended, states: „*Everyone has the right to enter the forest at their own risk, to collect berries and dry bark lying on the ground for their own use. In doing so, he/she is obliged not to damage the forest, not to disturb the forest environment and to follow the instructions of the forest owner or lessee and his/her employees*".

Although in the Czech environment we take entry into the forest without restrictions (with specific exceptions) as a matter of course, the same approach is not applied in all European countries. The prevailing view is that forest ecosystem services are still non-tradable public goods, and therefore there are growing opinions that - also with regard to the sustainability of ecosystem services in the future - it would be appropriate to address the situation by, for example, setting fees for entering the forest, or by setting a maximum amount of production (harvested crops) that a person can take from the forest for free. Certain forms of restrictions on visitors to forests are already practically applied in some countries (e.g. France, Italy, etc.). The lack of a precise expression of the benefits of forests for individuals and society (especially economic ones), including the as yet unappreciated importance of ecosystem services from a societal perspective, complicates decision-making processes for owners and forest management itself. Changing the perception of individual ecosystem services may lead to changes in management that do not just favour timber production alone, but prioritising support for other forest services (e.g. a shift away from promoting production maximisation) may have a knock-on effect on the whole range of ecoystem services). It is certain that no ecosystem service could be provided without the existence of the forest itself, and only a healthy forest is an optimal prerequisite for the fulfilment of both production and non-production services, and thus a variety of ecosystem services.

Among the popular activities in the Czech Republic is collecting forest produce, most of them collect mushrooms and blueberries. According to the data for 2022, the estimated market value of collected forest crops was approximately CZK 2.6 billion (blueberries, cranberries, raspberries, blackberries, elderberries). Together with mushrooms, this value was almost CZK 8 billion (MoA, 2022).

In the future, increased pressure on forest ecosystem services can be expected due to the impact of new forestry legislation, but also to the expectations and demands of society, which may highlight the need for discussion on the need to change the legal regulation concerning the restriction of access to the forest and forest management in order to avoid overloading forest ecosystems and thus endangering the provision of ecosystem services. An example of this is the increased number of visitors to the forest, which can be seen as a positive development, especially if they are new visitors to the forest (whether for recreational, educational or other reasons). On the other hand, increased visitation can lead to forest congestion. In most cases, however, there is an uneven load on selected sites, with sites near large cities, natural monuments, attractive tourist destinations, etc. being particularly exposed. Significant increases in forest visitation have also been traced in the wake of the coronavirus pandemic and the change in the behaviour of the population - which to some extent also resulted from the necessary restrictions on indoor gathering - as can be seen, for example, in a case study of visitation to sites near the capital city of Prague (see Jarský et al., 2022), where in selected months visitation increased by more than half year-on-year (between 2019 and 2020). Similar results have been observed in other European countries or in relevant forests (e.g. Slovakia, Germany). In the current bioeconomy concept , increasing the stability and vitality of forest ecosystems and optimizing the ecosystem services provided by forest ecosystems are among the areas supported.

4.3 PAYMENTS FOR ECOSYSTEM SERVICES (PES)

A form of response to the potential congestion of selected sites may be the application of financial mechanisms that charge for, e.g., entry to the forest. For example, forest owners can be compensated for the damage suffered (so-called compensation payments), but incentives are the preferred mechanism. In line with European strategies aimed, inter alia, at protecting biodiversity, the concept of payments for ecosystem services is promoted, which are in principle incentive-based, motivating the forest owner or manager to go beyond the defined rules (in particular the Forest Act) to ensure that the ecosystem is of such quality that it is able to provide more benefits. Although the concept of PES has been applied for a long time, especially in the Americas, e.g. Costa Rica, it is not yet common in European conditions, although it is a market mechanism that allows the provision of ecosystem services. Ecosystem valuation and pricing is becoming part of individual forestry and environmental policies. The primary motive for introducing such payments is to restore, protect and enhance the benefits provided by ecosystems, i.e. to improve the quality of forest ecosystems and to support the provision of services.

PES involve voluntary transactions between users and service providers, which are conditioned by agreed rules of natural resource management in the creation of services (Wunder, 2015) In the Czech environment, payments will be applied under the amendment to the Forest Act.

Control questions:

1. How can forest ecosystem services be categorised?
2. Which crops are among the most important in terms of forest harvesting in the Czech Republic?
3. Explain the concept of payments for ecosystem services.

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5 FOREST BIOMASS

The aim of this chapter is to define the terminology related to forest biomass, to inform about the production capacity of European and Czech forests and to highlight the different flows of different types of forest biomass and the respective possibilities of using this renewable biological resource. In the second part, the aim is to characterise the part of forest biomass that is referred to as wood and, above all, to highlight its specificities in relation to other materials used. It looks at the advantages and disadvantages of wood, its properties and quality, and the resulting implications for its current processing and use.

Keywords: Wood, wood formation, position in society, areas of use, advantages and disadvantages of wood, basic characteristics, properties, quality.

In order to know whether European forests and forestry are ready to meet the increased demand for dendroforestry, we will first look at the state of forests in Europe and the Czech Republic in terms of the availability of this renewable biological resource and then explain why wood/dendroforestry has such a wide application and, conversely, what are its limits.

5.1 DENDROMASS

Biomass is a term used to describe any living matter. If sustainable management principles are followed, it is a virtually inexhaustible renewable biological resource. Because of the broadness of the term, the type of biomass is often specified in more detail according to its nature. In general, we divide biomass into plant biomass (phytomass) and animal biomass (zoomass). Plant biomass is then divided, for example, into agricultural or forest biomass based on the sector in which it originates, and further subdivided into forest phytomass and dendromass according to whether it is herbaceous or woody biomass. In addition to the biomass that we purposefully extract from individual ecosystems for processing in different value chains, we can also obtain biomass from so-called side streams. We refer to such biomass as waste biomass because it is generated from residues or waste at different stages of processing of this material, or by recycling or reuse after the end of the life cycle stage of biomass products. In this chapter we will look more closely at dendromass. We define dendromass as woody biomass, i.e. biomass derived from trees, shrubs and semi-shrubs. In commercial forests, it is represented almost entirely by tree biomass. It is a widely used renewable biological resource that has applications in various sectors, from pharmacology, furniture, construction, chemical industry to energy.

5.1.1 Production of dendromass in Europe and the Czech Republic

Europe‘s forests cover an area of about 227 million ha. The average forest cover in Europe is therefore 34.8%. However, a distinction must be made between managed forests, which cover an area of 170 million ha, and other forested landscapes (the remaining approximately 107 million ha). Looking at Table 1, it can also be seen that the distribution of forests in the different European regions varies, with more than 42 % of all European forests concentrated in the Northern Europe region, with an average forest cover of almost 54 %. In absolute terms, the South-Western Europe region has the lowest forested area, but it is our Central and Eastern Europe region that has the lowest forest cover - 27.3%. It is also interesting to note that the southern regions of Europe also have the highest proportion of other forest landscapes (i.e. forests that are not managed), whereas the Central European regions have less than 1% of such forests. In the Czech Republic, the total area of forests in 2020 was 2.6 million ha, of which economic forests accounted for 1.94 million ha, protective forests 52.6 thousand ha and special purpose forests 622 thousand ha. From these figures, we can see that practically three quarters of the forests in the Czech Republic are managed. Figure 1 shows the area of forests and forest cover in each EU country in 2020.

Table 1: Area of forests, managed forests and other woodlands by region in 2020

Region	Forests		Production forests		Other forested landscape	
	1000 ha	%	1000 ha	%	1000 ha	%
Northern Europe	71299	53,8	55424	77,7	5706	4,3
Central Western Europe	38966	27,9	35728	91,9	1170	0,8
Central Eastern Europe	44735	27,3	32382	72,4	973	0,6
Southwest Europe	31466	35,5	27733	88,2	12791	14,4
Southeast Europe	40887	31,5	19124	53,2	6098	4,7
EU-28	162422	38,3	137799	84,9	21052	5
Europe	227353	34,8	170390	76,6	26737	4,1

Source: Forest Europe, 2020

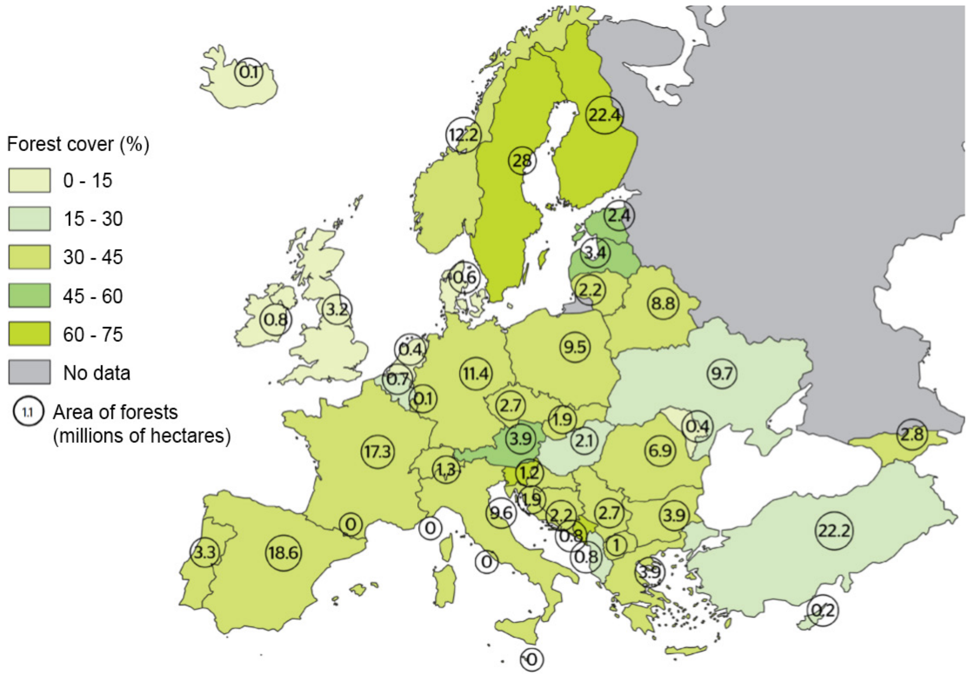

Figure 15: Forest cover and area of forests in the Eu-28 countries
Source: Forest Europe, 2020

The area of forests in Europe has been increasing for several decades (Figure 16). Over the last 30 years, forests have expanded by 193 million hain Europe, with 643 000 ha added annually from 1990 to 2020, and this trend is visible in all the regions mentioned above. Forest expansion was most noticeable in the regions of South-West Europe (0.78%), South-East Europe (0.38% per year), and Central-West Europe (0.36% per year). In terms of production forests, the trend is similar, with the exception of Northern Europe, where production forests decreased by 116 thousand ha (0.20%) between 1990 and 2020, while other regions saw an increase in the area of production forests, e.g. Central Eastern Europe by 0.15%.

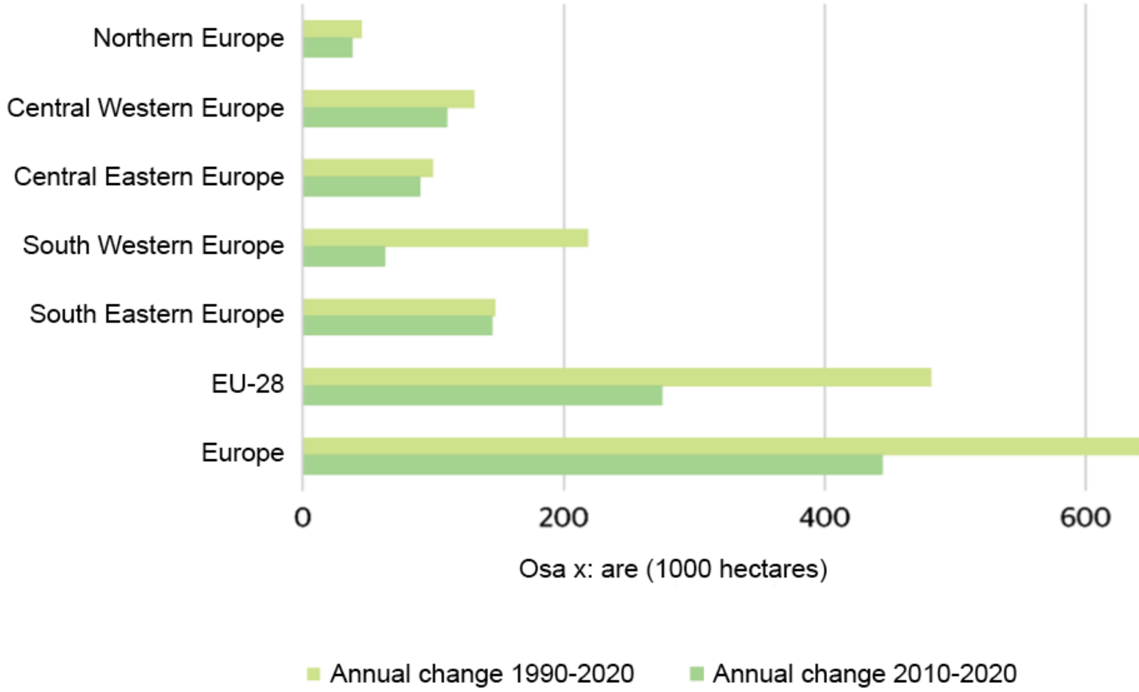

Figure 16: Trend of forest cover change in European regions since 1990
Source: Forest Europe, 2020

Timber stock in European forests reached 34.9 billion m^3 in 2020, of which about 84% was in economic forests. Figure 17 shows the spatial distribution of timber stocks in different regions of Europe. It can be seen that, even with lower forest cover, the largest stocks are found in the Central-Western Europe region, followed by Northern Europe and Central-Eastern Europe. However, it is interesting to look at the hectare stock, where the Central-Eastern Europe region has the highest stock, followed by Central-Western Europe and South-Eastern Europe. In terms of the Czech Republic, total timber stock has been increasing over the long term (Fig. 18). In 2020, total timber stocks in the Czech Republic reached 701 million m^3 average stock per 1 ha of forest land reached 269 m^3 . However, as a result of the extensive bark beetle disturbance, there has been a year-on-year decline in total timber stock in recent years (in 2019, total stock was at 704.9 million m^3 and in 2018 at 702.9 million m^3). Even so, hectares timber stock in the Czech Republic is higher than the average for the CEE region or all European regions (Fig. 18).

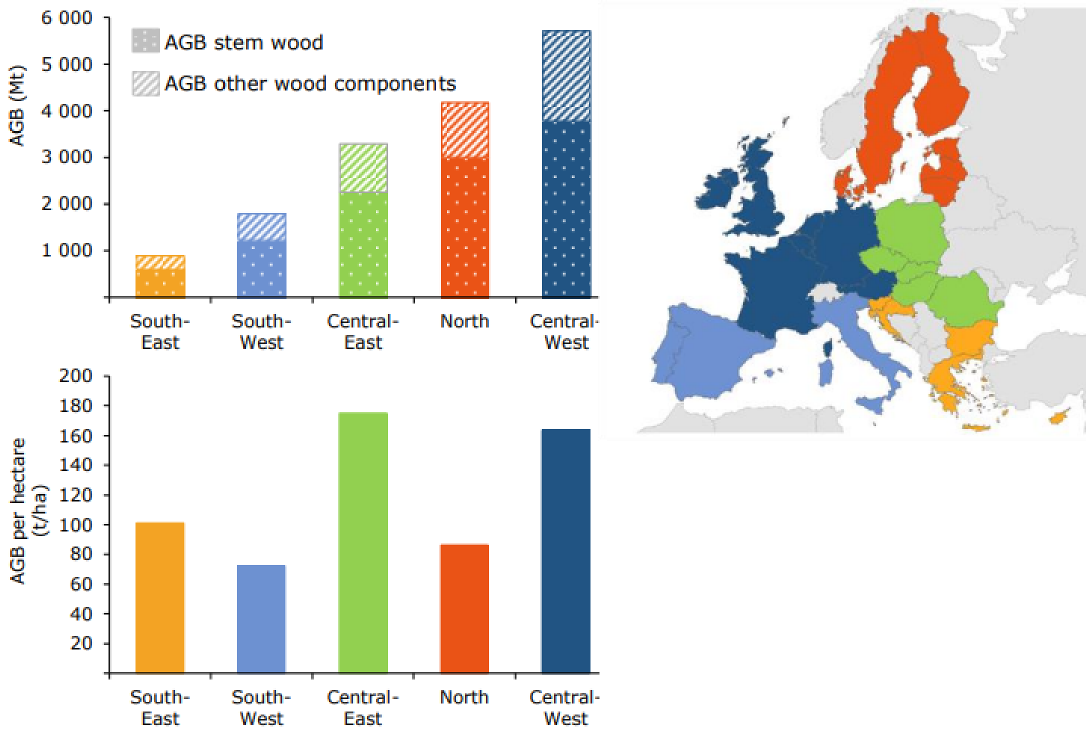

Figure 17: Total and per hectare above-ground biomass in EU forests by regions
Source: Brief on forestry biomass production, 2017

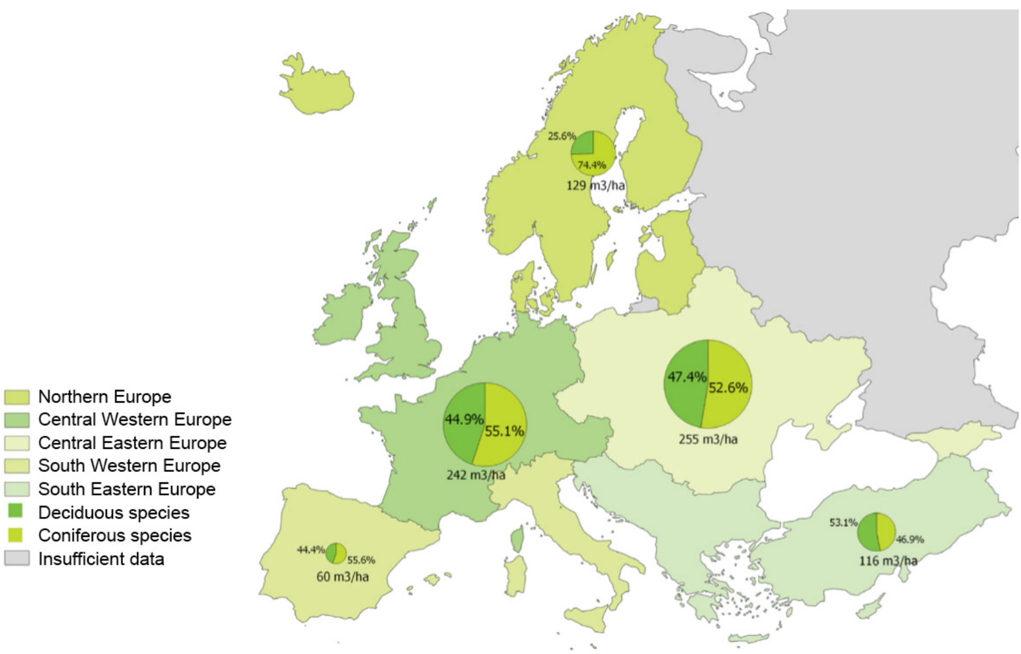

Figure 18: Hectares of timber in European forests by region
Source: Forest Europe, 2020

To ensure the vitality of the forest bioeconomy, however, it is not only important that dendro-mass, as the main renewable biological resource (input for value chains), is abundant in the country or macro region. It is also important whether we can harvest the dendromass and get it to the right place in the supply chains while respecting the principles of sustainable forest management. The fact that less timber is being harvested from European forests than is the increment is evident from the figures on growing stocks. A closer look at the structure of harvesting is provided in Figure 19, which is constructed from average values between 2004 and 2013. Of the total annual increment of 505 million tonnes of timber, the net annual increment over the period was 444 million tonnes (61 million tonnes were attributable to natural mortality of trees). Within the net annual increment, only about 63% was harvested annually on average, i.e. 281 million t of timber, of which 224 million t was standing timber that was extracted from the forest for further processing and 57 million t were logging residues (non-standing timber - e.g. branches and tree tops) left in the forest stands. This shows that Europe's forests are capable of fulfilling their production function and that the forest bioeconomy is not fully exploiting their growth potential. Even with a significant increase in the use of dendromass as a renewable biological resource, it can be assumed that European forests will be able to absorb the increase.

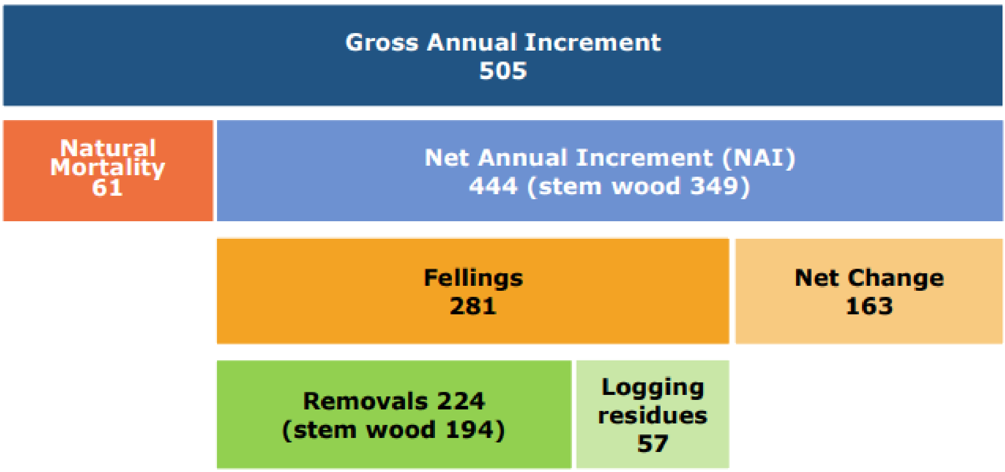

Figure 19: EU growth, harvesting and removal of timber from managed forests; average values 2004-2013
Source: Brief on forestry biomass production, 2017

5.2 WOOD PROPERTIES

5.2.1 Wood formation

Wood, in this context, is a result of the growth activity of living trees. Namely the cambium, which is located between the wood zone and the bark zone (Fig. 20). It is a meristem (kind of tissue) that creates new wood cells throughout the life of a tree. Thus, thanks to the activity of the cambium, tree trunks increase in size and volume. In the temperate climate zone, growth is intermittent, in the form of annual rings. In tropical regions, however, wood formation is continuous. Photosynthesis is the source of substances for the formation of new wood cells. In the process photosynthesis, carbon dioxide is incorporated into the simple organic substance (glucose), which is then used for wood formation. Wood is subsequently made up of complex organic compounds. Wood thus clearly fulfils definition of the renewable raw material with a net zero emissions (Kozlowski 1997).

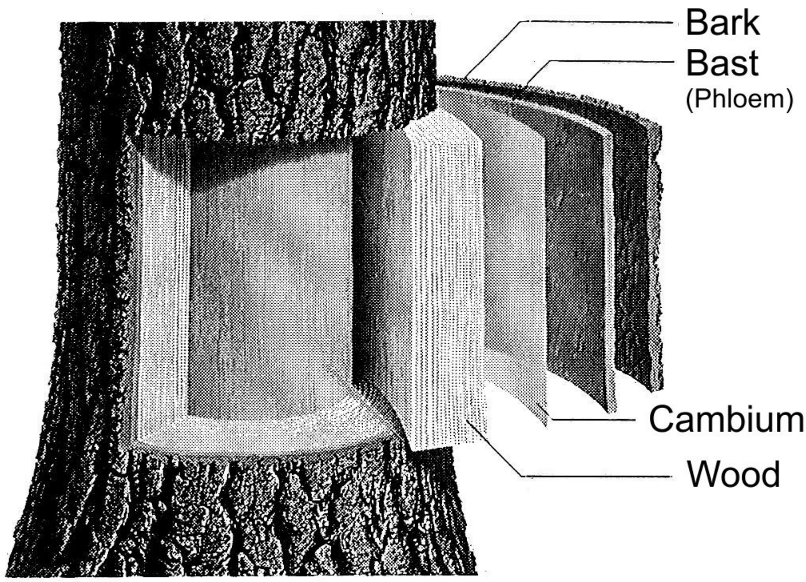

Figure 20: Stem structure – position of the individual tissues.
Source: modified according to Kozlowski and Pallardy, 1997

5.2.2 Position of wood in society

Before the discovery of metal processing technologies, wood was one of the most widely used materials. Wood was almost the only source of energy in history. With the development of new materials and the introduction of fossil fuels, the importance of wood declined. However, there are still areas of human activities where wood still has an important position. We can even find areas where wood is still irreplaceable. With the gradual depletion of non-renewable raw materials, we can again expect growing position of wood in society.

Today, wood is used for various applications, particularly in the building industry, in the production of furniture, paper and pulp, special musical instruments, household goods, toys, packaging materials and other products. Wood plays an important role as a source of energy worldwide, especially in developing countries where other energy resources are not available. With declining coal, oil and gas supplies, the importance of wood in this area will increase. Its position in furniture production is unique and irreplaceable, because no other alternative material is available for such production. The situation is similar for stringed musical instruments (e.g. violins), where we take advantage of the unique acoustic properties of wood. Finally, wood is almost exclusively used as a raw material for paper (pulp) production.

5.2.3 Advantages and disadvantages of wood

Each material could be characterized by its advantages and disadvantages, which predetermine or exclude it for usage in the relevant field of human activity. The main advantages of wood that have contributed to its widespread utilisation and considerable popularity in society are the following:

- Accessibility and almost omnipresence
- Good machinability with common tools
- Nature of the renewable raw material
- Good thermal insulation properties
- Excellent acoustic properties
- Waste-free processing technology
- Good strength properties at relatively low weight
- Low energy input for production
- Natural origin and aesthetic appearance

Of course, it is also necessary to know the disadvantages of wood as a material, which limit, make difficult or even exclude the use of wood in some areas. In particular:

- Occurrence of defects
- Low resistance to biotic agents (wood-destroying fungi and insect pests - Fig. 21)
- Flammability
- Considerable variability in appearance and properties
- Different properties depending on direction
- Hygroscopicity

Figure 21: Decay. Easy degradation by wood-destroying fungi is one of the main disadvantages of wood.

The disadvantages of wood should always be considered in relation to intended wood usage. An example can be the flammability, which is in the building industry considered to be one of the main limiting factors for wood utilisation in this area. Conversely, the ability of wood to burn and release heat makes it an important resource for energy purposes. The widespread use of wood in different areas confirms that we can cope with these disadvantages and current technologies can eliminate to great extent some of them.

5.2.4 General characteristics

Each material has its own characteristics that inform us about the possibilities of its use for certain purposes, especially in terms of specifics and limitations. If we are dealing with wood, as a material, then its basic features, which we must take into account when using it, include anisotropic behaviour, heterogeneity, hygroscopicity and porosity.

Anisotropic nature of wood (more precisely, orthotropic character) means, that wood has different properties in different directions. Properties, in this case, mean primarily strength (e.g. in compression, tension or bending), but we can reveal anisotropic behaviour during wood shrinking or swelling. Anisotropy is a consequence of the growth of a tree, the way the wood fibres (cells) are arranged in a trunk and the way the chemical compounds are arranged in the cell walls. The two basic directions that we can distinguish in wood are the direction along the fibres and the direction perpendicular to the fibres. In these two directions, wood exhibits a significant difference especially in strength. In the case of some properties, wood shows a significant differences in the direction perpendicular to the fibres in the radial and in the tangential directions (Fig. 22). Anisotropy thus has the striking impact on utilisation of wood, especially in constructions, where wood is exposed to mechanical stresses and where it is necessary to load the timber in the direction with the highest strength.

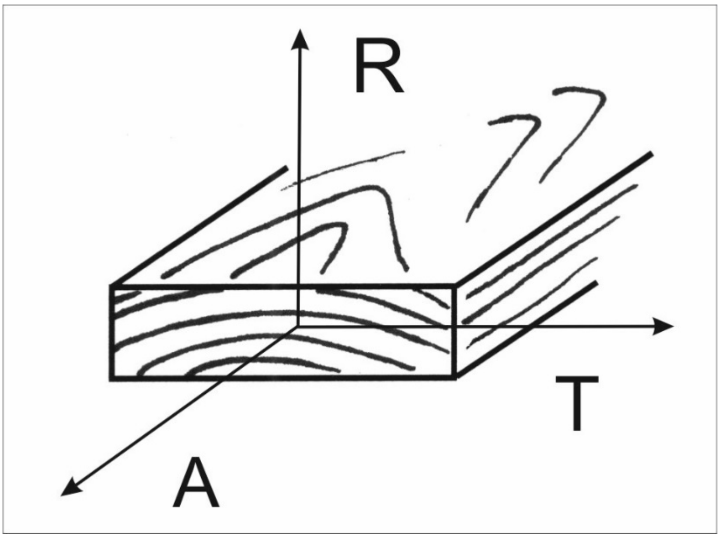

Figure 22: Basic directions in wood. A – axial (longitudinal, along the fibres), T – perpendicular to the fibres tangential, R – perpendicular to the fibres radial.

Heterogeneity (variability in structure) means that wood differs in its structure depending on the kind of tree species, site, age, altitude, position in the trunk and many other factors (Fig. 23). Heterogeneity is subsequently reflected in the related variability of properties. This feature makes production difficult, especially where, for example, a uniform appearance or the same properties of the material are required. The heterogeneity in wood structure makes it difficult to exactly express wood properties with a fixed value, in contrast to other materials.

Figure 23: The varying annual rings width, the different proportion of the latewood in the rings, or the differently coloured zones occurrence in the trunk are examples of the heterogeneity in wood structure.

The water content in wood has an impact on most processing activities, including utilisation for energetic purposes. Fresh wood (tree after felling) contains a high amount of water. For most applications, it is necessary to lower the water content, either naturally or artificially (in kilns). **Hygroscopicity** of wood is a characteristic that reflects the relationship between air humidity and wood. Due to its chemical composition, wood can bind water vapours from its surroundings depending on their concentration. Depending on the conditions of the surrounding environment (air temperature and relative air humidity), wood increases or decreases its moisture content (amount of water in wood) in order to reach a state of equilibrium with the surrounding environment (Fig. 24). This means that the moisture content of wood is permanently changing. This feature has significant impact on the processing and usage of wood, as these changes in moisture content are associated with changes in weight, dimensions and even properties (including strength). When using wood as a source of energy, it is important to realize that wood will always contain a certain amount of water due to hygroscopicity (see the nomogram in Fig. 24). It is so evident that the stated theoretical figure for the calorific value of wood can be hardly achieved in real conditions.

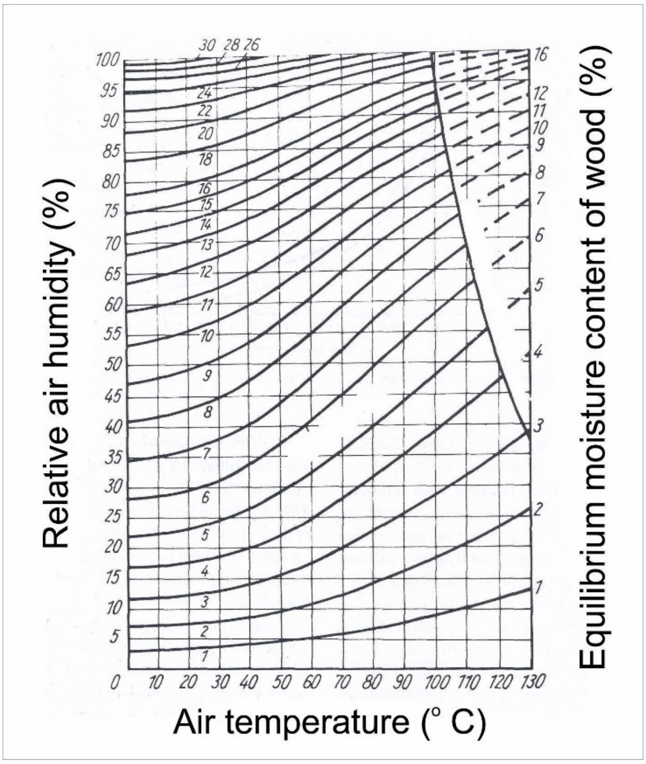

Figure 24: Nomogram of equilibrium wood moisture content as a function of relative humidity and ambient air temperature.
Source: modified according to Tsoumis, 1991

Porosity of wood (Fig. 25) is given by the type of cells involved in its structure. It is not only the inner cell space, but also the intercellular spaces and places in the cell walls. Porosity mainly affects the amount of liquid water in wood, which needs to be removed for most purposes (e.g. drying). Conversely, it can also affect the amount of substance used to saturate the wood mass (impregnation). The number of pores (empty spaces) also influences density (weight) of wood, its thermal insulation properties or sound insulation properties (Shmulsky and Jones 2011).

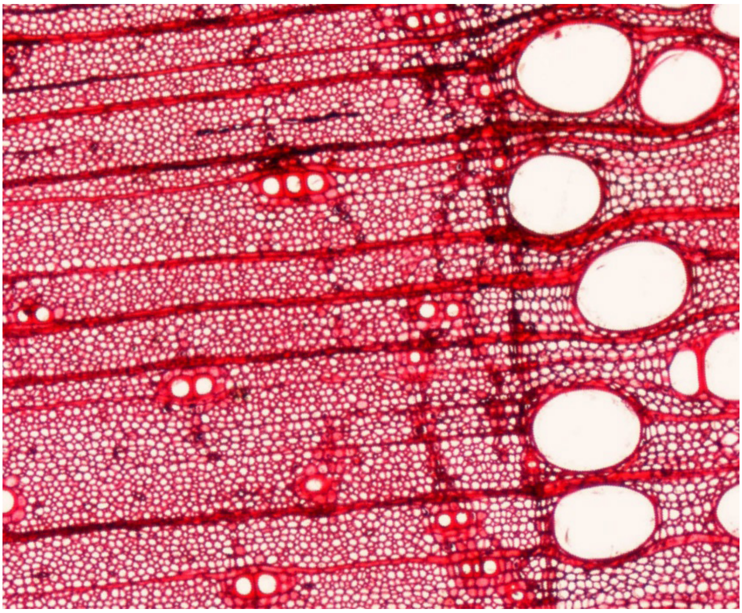

Figure 25: Porous nature of wood structure (microscopic photograph of ash tree cross section)

5.2.5 Wood properties

A property is a general term that refers to a feature or characteristic that in this case belongs to material. Wood properties are the result of the unique chemical composition, the way the chemical compounds are arranged in the cell walls, the shape of the cells and the way they are oriented in a trunk. Wood consists of cellulose, hemicelluloses, lignin and extractives. The most abundant is cellulose (about 50 %), which is the subject of chemical processing of wood. Most of the cells that form wood are fibrous and these fibres are arranged in a longitudinal direction (parallel to the vertical axis of the trunk).

Wood properties can be divided into physical and mechanical ones. Physical properties are those that can be investigated without breaking the integrity of wood. Physical properties include mainly wood-water relationship, density, surface and optical properties (colour, gloss), thermal properties, acoustic properties and electrical properties.

Wood-water relationship describe an effect of moisture content. Due to hygroscopicity, water is always present in wood. Moisture content represents an amount of water in wood (in %). There are two ways of expressing moisture content, namely absolute moisture content and relative moisture content. In the case of absolute moisture content, the weight of water in the wood is related to the weight of the dried sample; in the case of relative moisture content, the weight of water is related to the weight of the wet sample. It is necessary to always distinguish between these ways of moisture content expressing. The amount of water bound in the cell walls affects the dimensions of wood. As the amount of water increases, wood is swelling until the cell walls are fully saturated. Conversely, as the water content in the cell walls decreases, wood is shrinking (decreasing its size). Swelling and shrinkage have anisotropic nature (different extent depending on the direction) and significantly affects the usage of wood.

Density is generally defined as the amount of mass concentrated in a unit volume (expressed in $kg.m^{-3}$ or $g.cm^{-3}$). Density is one of the main wood quality indicators. The reason for this is that correlates very closely with other wood properties, especially mechanical properties. Wood with high density has high strength and vice versa. By knowing the density value, it is possible to assess the suitability of certain wood for a given purpose. It is also important in buying, selling and processing, where the density value informs us of the amount of wood mass contained in the volume unit. Wood is the hygroscopic material that constantly changes its weight and dimensions. These changes have also the effect on the density value. When expressing density, it is necessary to specify the moisture content for which it has been determined. The most common way is to specify the density for 0% or 12% moisture content. Another way of density expressing is so-called basic wood density, which is defined as the ratio of the dry weight of wood to the volume of fresh wood (cell walls fully saturated with water). Due to heterogeneity in wood structure, density is subject to variation, mainly depending on tree species. Wood density of our native tree species ranges approximately between 400 and 800 kg.m^{-3} (for 12% moisture content). Due to the chemical composition, wood density cannot exceed value of approximately 1,500 kg.m^{-3}.

Mechanical properties describe how some material resists external forces. In the case of wood, mechanical properties have distinct anisotropic behaviour. Mechanical properties include strength (e.g. in bending, compression, shear or tension), elasticity, toughness, hardness, or technological properties (cleavability, abrasiveness, etc.). The favourable relationship between wood strength and its weight makes it suitable for structural purposes. Some of physical and mechanical properties of important native commercial tree species are given in Table 2.

Tab. 2: Wood properties of native tree species representatives (Wagenführ 2007)

	Norway spruce	**Scots pine**	**English oak**	**European beech**
Density* (kg.m^{-3})	470	510	690	720
Shrinkage volumetric (%)	11.6-12,0	11.2-12.4	12.6-15.6	17.9
Bending strength perpendicular to fibres* (MPa)	78	80	88	123
Compression strength along fibres* (MPa)	50	55	61	62
Impact bending* (J.cm^{-2})	4.6	4.0	6.0	10.0

*… for 12% moisture content

As mentioned above, the biological nature and way of wood formation causes that wood properties are highly variable. This is valid not only for individual tree species but can be revealed within one species. Factors influencing wood properties include especially tree species, moisture content, chemical composition, age of a tree, position in a trunk, annual rings width, proportion of late wood, site, altitude or silvicultural measures. In the case of mechanical properties, density plays an important role. When using wood for different purposes, the variability must be taken into account and, for the same reason, the values given in the literature, in contrast to e.g. metals, should be regarded as indicative. (Shmulsky and Jones 2011, Walker 2006, Tsoumis 1991).

5.2.6 Wood quality

Wood quality is a purpose-oriented expression that should be understood in relation to a specific product or utilisation of wood. Different requirements are placed on wood for energy or paper production, and different requirements are placed on wood for furniture or building constructions exposed to mechanical stresses.

In addition to dimensions (diameter, length, volume of a trunk) or tree species (e.g. softwoods or hardwoods), we often encounter in the processing industry the expression of quality as a set of desired wood properties. This may be high density, sufficient strength and hardness, or durability, which will predispose some timber to a particular application.

The occurrence of defects is another parameter used to assess the quality of wood. In contrast to properties, they limit utilisation of wood, reduce yield, make processing difficult or affect appearance. The defect is defined as a change in the external appearance of wood, a disturbance in its structure regularity, deviations from the ordinary structure of wood which can adversely affect its intended usage. Like the term “quality”, the term defect is purpose-oriented, related to a specific processing and use (Figure 26). The type of defects and their frequency are used to divide raw timber into quality classes, which are defined in the relevant rules (standards, regulations, etc.). Richter (2014).

For some applications of wood, for products with higher added value (veneers, furniture, etc.) an appearance of wood (aesthetic criteria) is the important parameter.

Figure 26: Burls is one of the defects affecting a shape of a trunk that limits the possibilities of sawmilling and utilisation of lumber in constructions (left). Thanks to their unique texture, bulges are popular for veneer production (right).

Summary

In the second part of this chapter, we focused on wood properties. Wood, as the main component of dendromass, represents a natural renewable material with carbon neutrality. Despite the discovery of new materials, there are areas of application where wood is irreplaceable. Its importance and use in society will grow in the future as the availability of non-renewable raw materials decreases. Its favourable properties are the main reason for its widespread utilisation. However, in order to process and use it appropriately, its specific characteristics must be taken into account, compared to other materials. These include its high variability in structure and properties, low resistance to weather and wood-destroying pests, hygroscopicity, its different properties depending on direction and, for some purposes, its flammability.

Control questions

1. Estimate the area covered by commercial forests in individual regions of Europe. What is the average forest cover in Europe?
2. Rank individual European regions according to their hectare stock.
3. What proportion of the aggregate growth in European forests is harvested by European foresters and what proportion is removed from the forest?
4. Specify at least 4 advantages of wood compared to other commonly used materials.
5. Explain the term „hygroscopicity of wood“. How does it affect the utilisation of wood?
6. What is the range of wood density for our native tree species?

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6 WOOD PROCESSING INDUSTRIES

The chapter deals with mechanical technologies of wood, primary and secondary wood production, sawmill production, breakdown and characteristics of sawn timber. Another subchapter deals with the chemical composition of wood and perspectives on chemical processing of wood with emphasis on papermaking, bioethanol production and chemical modification. The third subchapter focuses on innovative technologies and the last chapter focuses on the energy recovery of disintegrated wood.

Keywords: wood primary and secondary production, sawmill production, lumber, lignin, briquetting, pelletizing, biomass, composite materials

6.1 MECHANICAL WOOD PROCESSING

Wood has been associated with human civilization since ancient times. The primitive method of woodworking was mastered by our ancestors with the help of fist wedges. It is regarded as one of the most promising raw materials and as the load-bearing material of the future. Wood is a material that, thanks to its unique properties, is still a very popular and essential raw material for the functioning of our society. However, transforming wood from a natural product (tree) into a technically usable material is far from easy. The process of processing wood begins with its harvesting. Once the selected trees have reached the required maturity (coniferous 80-100 years, deciduous 100-150 years), it is time to harvest them. Long-term impacts on our forests (reckless logging, air pollution, acid rain, landfills, tourism, etc.) are the cause of their ‚unhealthy' state. Therefore, forests must be protected and used to ensure their ecological value and the necessary regeneration. It is essential to think about this from the growing process to the processing of the wood into products. When trees are harvested, after the branches or roots have been removed, they are approached by slides, cable cars or tractors. From there, the timber is transported to the forestry company's warehouses or, more often, directly to the sawmill, where it is then processed using various technologies into a semi-finished or finished product. The wood processing technology is very extensive. Technology is defined as the study of the methods of processing raw materials, materials and semi-finished products and the procedures for manufacturing a product. With the very dynamic development of science and technology, technology is evolving to increase labour productivity. In designing a technological process, other factors such as laboriousness of production, complexity and availability of means of production, amount of waste, energy consumption, quantity of products, manpower requirements and production time are taken into account. These factors are used to assess the efficiency of the technological process.

We distinguish the following basic areas:

1) **Mechanical technology**, which defines the procedures for processing wood mechanically, i.e., by cutting, sanding, milling. Mechanical processing changes the shape and dimensions, but does not change the substance and composition of the wood. If mechanical and physical processes predominate in the technological process, it is a mechanical technology.
2) **chemical technology,** which deals with the chemical processing of wood - its chemical decomposition. This produces a product of completely different composition and properties (e.g. paper). *See Chapter 6.2 for more details.*
3) **special technologies** deal with the processing of other materials used in the woodworking industry (e.g.: upholstery, furniture and windows made of plastic).

To begin with, we will approach processing with the help of mechanical technology. Wood is processed in two stages. Primarily, the division of wood processing into primary production and secondary production is important. Primary production comprises the processing of wood at the initial stage, i.e. where raw wood or wood waste is processed. Since it is primary production, the raw material is the trunks of coniferous and deciduous trees. Primary wood production can also be understood as the processing of wood raw material into materials and semi-finished products for further production. This segment of production includes sawmilling, plywood, veneer and particleboard and fibreboard production. Secondary production includes the secondary processing of wood, such as the production of furniture, toys and small objects, art objects made of wood, construction and joinery production such as windows, doors, built-in wardrobes, wall and ceiling cladding, wood and wood-based flooring, staircases. Carpentry production includes the manufacture of wooden buildings and other wooden structures, whether rafters, roofs, pergolas, sheds. Mechanical technology is used to change the shape and volume of the wood into a product by using tools through various work processes. Several types of machines and equipment are used for wood processing. Experts divide them into several groups according to their functions. If we take the path of wood from the tree to the creation of, for example, furniture or other products, we need several machines, tools and equipment. Probably the first machine used in woodworking is the chainsaw. A chainsaw is used to cut down a tree. The felled tree is then pruned and stripped of the top part. Depending on the quality, the individual pieces of logs are classified into species and quality ranges.

Considering the overall proportion of processed wood, it is good to first of all introduce the sawmill production and its products. The raw material for sawmilling is the parts of the trunks of deciduous and coniferous trees (raw timber). Raw timber is characterised as felled, branched and possibly debarked trees intended for mechanical, chemical and other processing. Timber may be understood as a technical, generic or collective name for a range of products from the primary or further processing of felled trees. On the other hand, the term timber also includes the material between wood and cambium. Raw material enters sawmills in the form of sawlogs, which are graded according to the applicable standards into the relevant quality classes. The higher the quality of the raw material, the less defective it is and the less by-product (waste) is produced. Quality determines the way the timber is used and, above all, its financial value. The basic indicator of timber quality is the number of defects and their extent. Knowing how to recognise defects and assess their potential impact on timber processing is essential for any timber work. Sound timber is considered to be healthy, straight, undamaged, free of knots, cracks, splinters, twigs and natural colour and smell. Defects are defined as variations in growth, structure, texture and colour, as well as damage and blemishes, which adversely affect the wood‘s usability, use and functional characteristics. The relationship between the functional characteristics and defects of timber is used to classify timber according to defects. Defects are assessed according to size, shape, condition, frequency, location and combinations of these parameters.

Wood defects can be divided into:

I. irregularities in growth and trunk shape,
II. defects in the anatomical structure of wood,
III. defects caused by weathering, living organisms and chemical influences,
IV. defects in the production and processing of wood.

Group I and II defects are already present in the timber at the time of harvesting, are mostly due to objective natural causes and can be called primary defects. Group III defects may be both primary and secondary. Group IV defects are always caused by human action during or after harvesting and may be called secondary defects.

Also as input raw material can be the so-called saw cuttings, which meet the requirements for their size and quality. About one third of the raw timber is consumed in the country in its unprocessed state - in mining, construction, agriculture and as fuel. The pulp and timber industry processes two-thirds of raw wood - sawmills, veneer mills, plywood, structural panel production, pulp production, pulp production, wood flour.

Sawmill raw material is cut using sawmills.. The basic method of cutting wood in manual and machine machining is **sawing**. It is the separation of a section of wood by the action of a cutting tool. The tool cuts the material with a cutting edge, which is called the cutting edge.

According to the number of cutting edges we distinguish tools.

- single-edged, i.e. elementary (knife, planer, chisel, etc.),
- with multiple blades (e.g. saw tools, cutters).

The most common way of cutting wood is with a sawing tool. The actual functional part of sawing tools is the gearing. Its shape depends on the type of material to be cut and the way it is cut in relation to the direction of the grain of the wood. Each tool is characterised by certain cutting angles, the size of which determines the geometry of the tool. Already in the first part of the sawmill operation (raw material store), we use stands and tools for processing. In this warehouse, the timber is subjected to basic but very important operations that are necessary for further processing in the sawmill. The future of each log is already decided in the raw material store and, after good record keeping, it is possible to follow the fate of each element in the store during the processing process. The last operation in the raw material warehouse is the feed to the sawmill, where the raw material is cut.

During the processing of wood mass in the sawmill itself (the second part of the sawmill operation), both main (frame, circular, band saws or sawmill aggregates) and secondary machines (shortening, plastering, by-product processing machines) are used.

The main product range of the sawmill is **sawn timber** (Fig. 27) produced by longitudinal sawing of sawlogs or even cutouts. Sawn timber is a technically defined material obtained by sawing longitudinally suitable raw timber assortments, in particular so-called sawmill cuttings (sawmill logs). As a rule, it has at least two opposite faces parallel to each other and is at least 10 mm thick. The second main product is sawdust - wood chips. These are chopped pieces of wood intended for the production of large-scale materials and for chemical processing. Additional assortments of sawmills are for example cross-sections (friezes), parquet friezes, etc. (Kvietková and Bomba, 2013).

The lumber is obtained by cutting. It is a complex of technological operations by which specific sawmill cuttings are processed by longitudinal cutting into sawn timber. When processing wood, we choose different cutting methods in order to take advantage of some of the properties of the wood and then to obtain suitable material for further processing and use.

Over time, the following main types of cuts have evolved:

- a sharp cut,
- prism cutting,
- segmented cutting.

The cuttings are used to obtain sawn timber that can be further processed. In the case of sawn timber, we also encounter the term ‚sawn timber‘, which is defined as sawn timber or semi-finished timber with dimensions corresponding to the end use, supplied at a certain moisture content and with a certain degree of surface finish. Depending on the degree of machining, sawn timber is divided into unmachined and machined.

Lumber is divided according to the shape and size of the cross-section into:

- board lumber - has a rectangular cross-section with a width greater than twice the thickness and is subdivided into planks (thickness from 15 to 38 mm) according to the thickness , landscape planks (maximum thickness 25 mm and must have the left side at least touched by the saw along its entire length), planks (thickness from 40 to 100 mm), landscape planks (thickness from 18 to 24 mm, only occasionally touched by the saw on the left side, the side is rounded), cratina - cut landscape planks.

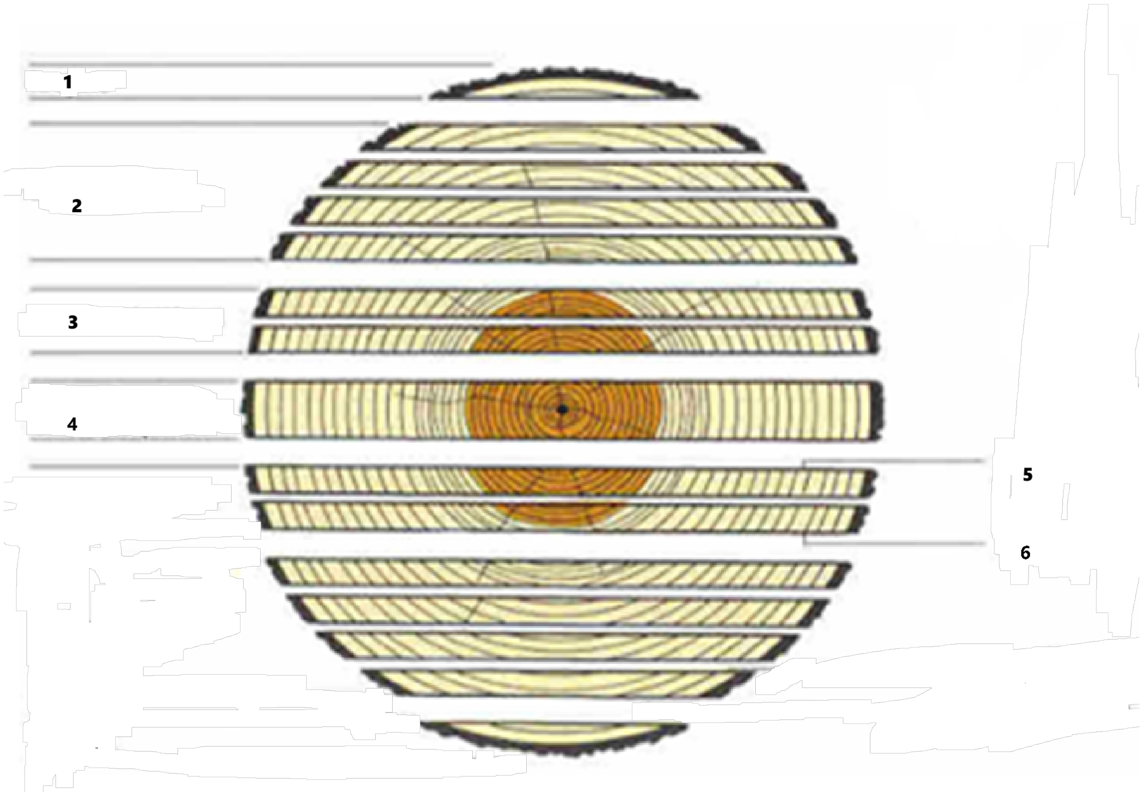


Figure 27: Assortment of lumber

1 - cratina - cut landscape planks, 2 - side boards, 3 - center boards, 4 - core or pith boards, 5 - right side, 6 - left side

- **edge sawn timber** - it is usually right-angled in cross-section and the width is less than twice the thickness. It is subdivided into prisms (with a cross-section greater than 100 cm^2), squares (with a cross-section of 25 - 100 cm^2), battens (with a cross-section of 10 - 25 cm^2), strips (with a cross-section of less than 10 cm^2).
- **Half-edged lumber** (Fig. 28) - has two parallel faces and rounded sides. This includes joists (greater than 100 mm thick and greater than or equal to 2/3 of the thickness), cushions (no more than 100 mm thick) and sleepers.

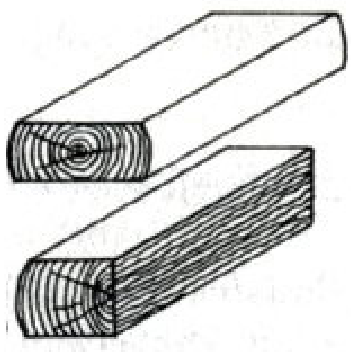


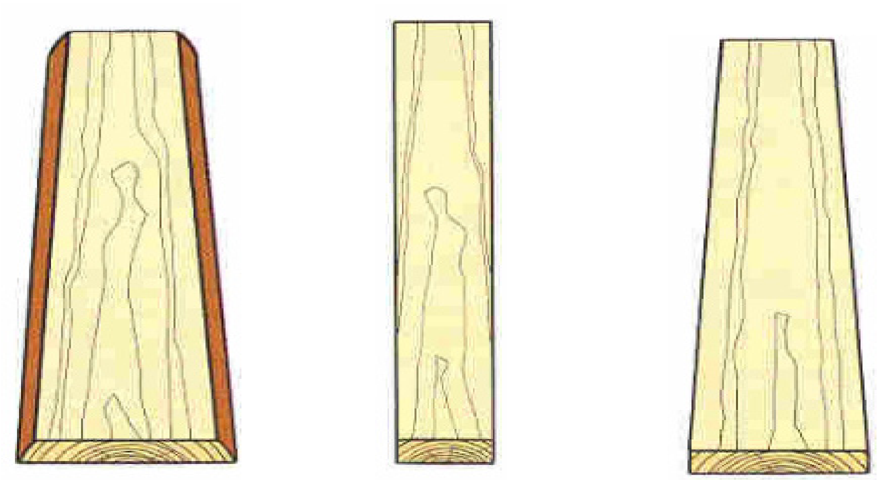
Figure 28: Half-edged lumber

Lumber by type of wood:

- **coniferous** timber,
- **broadleaf** lumber:
  - » hard (DB, BK, JS, JV, BV, OŘ, TŘ),
  - » soft (LP, OL, TP, OS, VR).

Classification of sawn timber by production method (Fig. 29):

- **Plastered lumber** (sides form a 90° angle with the surface),
- **unplastered lumber**,
- **Drip-sawn timber** (face to face angle 90°),
- unsealed lumber.



a) unfiled b) parallel plastered c) converging plastered

Figure 29: Sawn timber production methods

In practice, we also use other subdivisions depending on supply and demand, e.g. the purpose for which the lumber is used - for the manufacture of ships, for aviation purposes, for the manufacture of toys, for the manufacture of railway sleepers... All subdivisions are based on the quality classes defined by the standard. The technological quality of the timber remains the decisive criterion, as does the irreplaceable responsibility of the worker carrying out the grading, with sensitive and professional judgement, or even the terms of the commercial contracts concluded.

The lumber then goes to the lumber yard, which is the third part of the sawmill operation. Several operations also take place here. From sorting, stacking, drying, packing and export.

Wood is a widely usable material ranging from the production of unique musical instruments to energy use, with the type of wood species having a decisive influence on the possibility of use. To give you an idea, the following subsection will give an overview of the uses of different tree species.

6.1.1 Use of wood from different tree species

Economic tree species - tree species commonly used industrially (SM, JD, BO, BK, DB, respectively other deciduous trees than industrial timber) (Sarvašová Kvietková, 2019) . In this subchapter I will present the most exploited woody species in our territory.

Norway spruce - *Picea abies*

In our forests, the Norway spruce has the largest surface area. It is planted in parks and gardens as an ornamental tree and in economic forests as a source of timber. The wood of the spruce is yellowish-white, brownish, shiny, the rings are clearly visible with a gradual transition between spring and summer wood. Spruce wood is a soft and light wood. It is less durable and resistant to insects and fungi. The use of spruce wood is multifaceted. It is used as a building and construction material, in the furniture industry and for chemical and semi-chemical processing. Spruce is also used to make some musical instruments, especially violins (the so-called resonance spruce, which is usually over 120 years old, grows in mountain and foothill areas in the centre of the forest, ideally on the northern slope, is free of knots and has regular and dense rings).

Scots pine - *Pinus sylvestris*

This tree is our most important coniferous tree after the Norway spruce. It has an orange-brown heartwood and a broader yellow sapwood. It has distinctive rings and therefore a considerable difference in the density and hardness of the spring and summer rings. The natural lustre is due to the high resin content. Scots pine provides a very good resinous, soft and durable resinous wood with a distinctive pattern of rings. It has the largest knots of all the conifers, but is used extensively for machining. The wood is easy to split and the high resin content makes it durable in water. The uses of pine wood are very diverse. It is used in the construction industry, furniture and joinery, as well as in the manufacture of columns, plywood and particleboard. Pine is commonly used in the manufacture of windows, doors, beams, sleepers, etc.

White fir - *Abies alba*

The white fir resembles spruce in its anatomical structure and most of its properties. However, fir wood does not reach the quality of spruce wood, has no resin and is less durable. The colour of the wood is greyish-white to brownish-grey, the summer rings are clearly visible with a gradual transition between spring and summer wood. The wood is soft and light, easy to work and dry, easy to split and moderately resistant to insects and fungi. The use of fir wood is similar to that of spruce. In the past, the wood was also used for waterworks, as construction timber, in the manufacture of shingles, barrels and in cooperage.

Larch - *Larix decidua*

Larch wood is very valuable for its hardness, flexibility and durability. The wood has a yellowish, narrow sapwood with a dark red to purple, slightly glossy heartwood and is classified as a medium-hard wood. The leaf rings are clearly defined and there is a sharp transition between spring and summer wood. Larch is considered the most valuable domestic coniferous timber of all uses. It is used in furniture making, wall panelling, for water construction, in joinery, wheelwrighting, in the chemical industry and as construction timber. Larch resin, called Venetian turpentine, is also highly valued.

Summer oak, winter oak - *Quercus robur, Quercus petrea*

Oaks are long-lived, slow-growing trees with hard, heavy and strong wood. The wood splits well in the raw state and is highly durable. Winter oak usually has narrower rings, the wood is more porous, softer and easier to work. Summer oak, on the other hand, has wider rings, is harder, heavier and less workable. Oak wood has a distinction between heartwood and sapwood, sapwood being narrow yellowish to light brown, heartwood light to dark brown. Winter and summer oak wood is widely used. It is used extensively in sawmilling, construction, joinery, furniture making, e.g. railway sleepers, barrels, veneers and is also popular as fuel.

Beech - *Fagus sylvatica*

Its wood is hard, heavy, uniformly dense and easy to split. It is strong but not very flexible. The workability is very good, in particular it is well impregnated, stained and polished. The mature wood and sapwood are light pink. The heartwood of beech is very often false, coloured brownish-red. It is easy to distinguish a false heartwood from a steamed beech, especially in cross-section, because it does not follow the shape of the rings closely and its outlines are more distinctive in colour. Beech has the widest range of uses of all deciduous trees. In sawmilling, it is the most important species within the deciduous trees. It is used in the furniture industry for plywood, veneers and bentwood furniture, in construction, joinery, in the manufacture of popsicle sticks, chopping boards, cooking pots and is an important fuel because of its high calorific value.

Ash - *Fraxinus excelsior*

Ash wood is hard, heavy, very flexible and flexible, strong and durable. It has a broad light yellow sapwood and a grey-brown heartwood. The blood vessels of the ash wood are distinctive and form clearly visible grooves in the longitudinal sections, similar to those of oak. The workability is good, especially when polished. It is popular in the furniture industry for veneers and paneling, but it is also used for handles, tops, handrails, gym equipment, hockey sticks, baseball bats and musical instruments. Skis and sledges used to be made mainly of ash.

Sycamore, Norway maple - *Acer pseudoplatanus, platanoides*

Maple is a hard, flexible, resilient, less splittable and not very durable wood outside. Its anatomical structure is similar to beech, but it is much lighter. It does not have a distinct colour in the heartwood, but sometimes in older trunks there is a dark brown to black coloured cylinder near the pith, the so-called expanded pith. The wood is well worked, especially stained and polished. It has a hard, creamy-white, dense wood that is used for musical instruments, furniture, joinery, wooden flooring and kitchen tools. It is also good as firewood. There are also uses for maple wood in sawmilling for lumber, furniture making, carving and woodturning. Spring sap is used for sugar production and for making alcoholic and non-alcoholic beverages.

White birch - *Betula pendula*

Birch has wood without a colour-coded heartwood. Mature wood is greyish yellow to pinkish and dull glossy. It greatly surpasses oak and ash in toughness, bending strength and flexibility. However, it is not very durable in outdoor use. Therefore, if the good properties of birch wood are to be exploited, its use in damp and outdoors must be restricted as much as possible. This wood is of considerable importance in the wheelwright's trade, as it replaces almost all hardwoods because of its flexibility and toughness. It is also a sought-after raw material for the production of ornamental veneers and plywood, is easy to machine by carving and turning and is also a good fuel. Birch even burns well raw and its bark is an ideal substitute for paper and dry kindling.

Heart lime, large-leaved lime - *Tilia cordata, Tilia platifila*

This tree is without a distinct colour core, yellow-white, without spots and colour flashes. The leaflets, pith rays and pores are indistinct. The wood is light, soft, easy to split, easy to work and not very durable outside - often attacked by wormwood. It is the most important wood in woodcarving and artistic joinery, and is also used in furniture making for plywood, model making, trusses, pencils, plugs, stationery and other products.

Poplar - *Populus*

Poplars are fast-growing woody plants with alternate and long-stemmed leaves. Among the several species of this genus, black poplar, white poplar and aspen are important. They are similar in appearance and mechanical properties to lime wood. The wood of the poplar is very soft, light, with little strength, less shrinkage and little durability outside. They are one of the fastest growing timber species in the Czech Republic, and in a short time achieve considerable growth in height and volume. This species is mainly used in the furniture industry because it takes glue well and does little work. It is also very suitable for plywood, paneling, wooden crates and matchboxes. It is purposefully cultivated for biomass production.

We also process other tree species that occur in small quantities and their economic use is underestimated. For example, douglas fir, oak, black walnut, alder, willow, fruit trees and deciduous shrubs.

In addition to the primary product, we also produce a by-product, known as wood waste or wood waste. Several types of waste are generated during the cutting of logs in sawmills, despite efforts to maximise yield. The type of waste depends on the machinery of the sawmill, the processing method and the quality of the raw material. Waste from sawmills can be classified as biomass suitable for energy production. Biomass is a suitable source of fuel, because, in general, the carbon dioxide (CO_2) released when biomass is burned is absorbed by plants as they grow. Biomass has become a focus of interest as an energy feedstock in recent years. It is defined as all matter of organic origin produced through photosynthesis.

6.1.2 By-product of wood production - wood waste

The view of waste treatment in sawmills and the wood industry in general has changed significantly over the last fifty years. The waste generated in wood processing plants is not always suitable for direct energy recovery and several methods of treating this waste have been developed. Some treatments improve the properties of the waste (calorific value, lifetime of the machinery). Furthermore, consideration must be given to the facility in which the specific waste material will be disposed of. Using the right form and type of fuel in the right plant will maximise energy efficiency.

Compared to waste from large wood-based materials, which contain various chemicals, wood-based wood waste is virtually free of „environmental contaminants". And it is encountered, for example, in forests in the form of branches and log residues, or in the wood processing industry in the form of various sawdust, chips, bark (Fig. 30).

Figure 30: By-product forms - wood chips, fuel cuttings, sawdust

We also encounter the term woody biomass, where it is understood as wood in pieces, wood waste such as bark, chips, sawdust, or even dry parts of plants grown for the purpose of combustion (poplar, aspen, willow, sorrel, Jerusalem artichoke, hemp, elephant grass, etc.).

As such, wood is one of the most important fuel sources for humans. Dry wood with a moisture content of up to about 25 % is suitable for combustion.

Wood as fuel can take many forms - it can be in lumps or as wood waste (in the form of chips or pellets). In addition to energy, environmental and economic criteria, fuel in the 21st century must also meet the criteria of high comfort and safety when burning it. The oldest and still probably the most popular type of biomass used for domestic heating is wood in chunks. Its biggest advantage is its price and local availability. However, the high storage space requirements and, last but not least, the impossibility of automating these boilers to any great extent are major drawbacks. The required moisture content for combustion is around 20-25 % and it only reaches this moisture content after about a year of storage (when felled, it has a fresh moisture content of 50 % or more). Moisture affects not only the combustion efficiency but also the lifetime of the boiler. The calorific value of wood at 25 % moisture content ranges from 8,8 MJ/kg to 11,3 MJ/kg (beech). The greatest efficiency is achieved when burning lump wood in gasifier boilers. This is why it is necessary to look for alternatives to lump wood, which can be a mechanical by-product treatment. Mechanical treatment of biomass is done by reducing the size for handling and better burnability. The treatment can be carried out using shearing equipment, mowers, shredders, pressing, briquetting, pelleting, etc. The biomass is first dried to reduce moisture and then processed. The output product is solid biofuels, which are further used in combustion plants.

A modern energy carrier must have a uniform fraction size, density, moisture content and suitable shape. The technologies that transform biomass into biofuels with the desired properties are compaction technologies. Compaction technologies have been known for more than 130 years. The common feature of all compaction technologies - pelletizing, compacting and briquetting - is that it involves pressing the material at high pressure. The necessary conditions for the compacted material to be compact after compaction, even without binder, are a suitable choice of pressure and temperature. Another condition is the maximum fraction size as well as the permissible moisture content of the compacted waste and if these values are exceeded, the waste must be crushed and dried. The briquetting, compacting and pelletizing processes result in mouldings of various shapes and sizes.

The technologies used in the waste treatment process can be divided into three basic phases:

- preparation phase (transport, handling, storage, cleaning, drying, sorting, crushing),
- transformation phase (briquetting, pelleting, compacting).
- waste recovery phase (handling, transport).

However, the gradual development of waste processing technologies, and especially the production of board materials, has meant a shift away from the use of wood waste, and nowadays these materials are mainly made from quality logs. An exception is particleboard, which is still made from all types of waste, such as sawdust, brown chips (production also allows the use of bark, especially in the middle layers), sawmill trimmings, etc.

There are several types of waste material, which are mainly divided according to fraction and shape. The least suitable waste is the wood dust produced when sanding the wood surface with sandpaper. Not only is this dust harmful to health, but it is also technologically more difficult to collect (extract), store and process within the machinery. It is used in the chemical industry or added to adhesives as a filler, just like technical flour. We also encounter lump waste. This is a massive lump waste that cannot be further used in production. This waste includes so-called sawmill landscapes, cuttings after trimming and manipulated defects. These scraps are characterised by widely varying dimensions and must therefore be disintegrated, and the resulting chips are most often processed in the production of agglomerated materials or sold to paper mills or even power stations. Another type of waste is the wood chips produced by waste wood chipping machines or as a by-product of the cutting of timber on aggregates using cone chopping heads for single or compound cross-sections of sawn timber. Bark is also encountered during processing. Bark is of limited use for energy purposes because of its high moisture content. It is therefore more often used for the production of bark peat substrates or processed by hydrolysis processes. When bark is processed by hydrolysis, the bark is first homogenised. Hammer crushing mills are used to homogenise the bark. These machines do not require the presence of foreign objects, particularly mineral and metallic impurities. Then the shavings or sawdust produced by machining the wood with milling or sawing machines, whether circular, band or frame saws. The amount of waste produced in the timber industry is used, for example, for energy purposes, either in the form of pellets, briquettes, which we will zoom in on.

The starting material for the production of eco-friendly wood fuels is pure wood sawdust. The sawdust has small dimensions without large differences. The dimensions are given in coarseness from 1,5 to 5 mm. It is a loose material containing fine particles of wood of varying moisture content, and is produced as a by-product of the mechanical cutting of wood by sawing tools. It is in sawdust that the shift from simple combustion to industrial use is most marked. In the past, they were regarded as useless waste, whereas today they are becoming a scarce commodity. The current use can be divided into three options - briquetting/pelletizing, particleboard production and addition in the production of ceramic bricks (Zhou et al., 2013).

Briquettes and pellets can be considered as ecologically very clean fuel with high calorific value. In addition, their production contributes to reducing the volume of waste from wood production. It is an easily transportable and storable fuel. In addition, briquettes can be used in conventional solid fuel combustion plants.

6.1.3 Processing of loose wood waste by mechanical methods

Briquetting is the most well-known and widespread compaction technology. **Briquettes** are made from wood waste (e.g. sawdust, shavings, exceptionally bark) by high-pressure pressing without added chemical binders and it is important that they do not crumble. Shavings and chips from machining (milling, drilling…) and wood dust are also added to briquettes. The maximum bark content should not exceed 8 % and the dust content 20 %. Briquettes are made from wood or plant residues by strong compression, which is known as briquetting. The main principle of wood briquette production is the transformation of large volumes of waste wood into a new, noble form of fuel that is cheap, environmentally clean, takes up minimal storage space and has a high calorific value. Briquetting produces a new type of solid biofuel with a calorific value between brown and black coal, with excellent transport and handling characteristics that allow economical storage and high heating comfort in solid fuel boilers. Most manufacturers of wood briquettes have a press for their production connected directly to a joinery or sawmill. The moisture content of the wood residue and thus the calorific value is determined by the moisture content of the input material, i.e. sawdust and sawmill shavings. The moisture content of the wood residue for successful briquetting should be between 6 and 15 %, the optimum being 11 %. Higher moisture contents of the feedstock would cause the briquettes to burst due to excessive water vapour formation. The dried wood residues are then compressed. A powerful hydraulic press with a pressure of up to 250 bar is most often used to produce quality wood briquettes. After pressing, a smooth, pore-free briquette surface is achieved. Shapes and dimensions vary. The briquettes are usually in the shape of a block or a cylinder. The briquettes are 70 to 300 mm long and 50 to 60 mm in diameter (Fig. 31). Briquettes with a hole in the middle are also produced. This hole inside the briquette increases its surface area, allowing a better oxygen supply and thus a more perfect combustion. Standards must be observed when producing briquettes. The cleanliness of the briquetted waste must also be ensured. It is not advisable to sweep the waste on the workshop floor and throw it into the hopper. Waste contaminated with sand, soil and pebbles destroys the pressing tools, which then have a shortened service life. Waste with contaminated crushed tree bark, tree roots, plant bottoms are unsuitable for pressing.

Briquettes can be of different colours depending on the type of biomass used, the quality of the raw material affected by moisture or bark admixture and the technological process used.

There are 3 basic principles for briquette production:

a) Mechanical crank principle - presses work on the principle of crank mechanism with powerful flywheels. They are characterized by the highest pressures in the press chamber, which is left by an infinitely long briquette, precisely cut behind the outlet by a cutting saw. The output of the press is usually around 1 t/h, the briquettes are usually cylindrical, but they are also produced in prismatic shape. The most popular briquettes are cylindrical briquettes with an internal bore. They burn better because there is more surface area for heating and oxygenation.
b) Hydraulic principle - this principle works with lower pressures than the mechanical crank principle, the presses have lower performance - from 0.05 to 0.5 t/h, but they are cheaper. The basis of this principle is a hydraulic piston which presses the material into the mould. The raw material to be pressed must have low moisture content, so a drying device is often added before the press piston. The presses are suitable for briquetting straw and sawdust. Briquettes produced by hydraulic pressing have a lower cohesiveness than mechanical crank pressing and are intended for use close to production without frequent handling.
c) Screw principle - the necessary pressing pressure is created by rotating the pressing screw in the conical chamber. The cohesiveness of the briquettes is very good, as the high pressures and friction of the material on the screw heat the wood and partially plasticize the lignin, which acts as a binder. The surface of these briquettes is coated with hardened lignin, similar to wax, after cooling and is thus protected against moisture. The disadvantage of these presses is the considerable wear and tear on the screws and chambers.

Figure 31: Briquettes
Source:Scobis, 2022

Of course, as with all these fuels, they are produced from renewable raw materials (wood). The material for their production is constantly growing, and this material is also produced as a by-product of other activities. The ash from burning briquettes is not dangerous and can be used as an excellent compost material. Depending on the wood species, the calorific value is around 17 to 20 MJ/kg, the ash content less than 1 % and the water content less than 10 %.

However, heating with wood briquettes is not only environmentally friendly, but also very easy and comfortable. They are easy to handle, as they are usually packed in bags of 5 and store well. The final packaging of the product is done in recycled PE packaging. This both prevents atmospheric moisture from reaching the product and makes this practical packaging easy and dust-free to handle. Absolutely clean heating operation is achieved.

Nowadays, we are encountering fully automated briquette production lines.

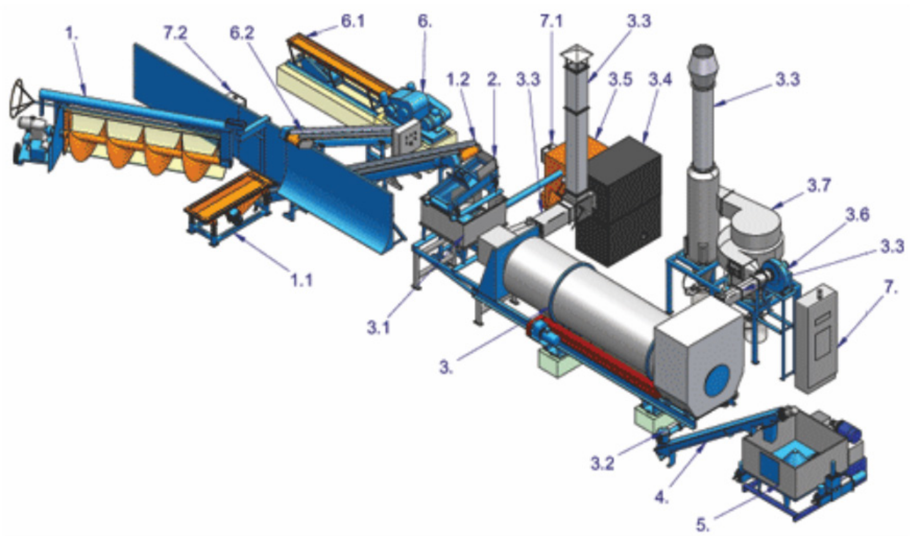


Figure 32: Illustration of the briquetting line
Source:Briklis, 2022

1. feeding auger, 1.1. vibrating conveyor, 1.2. belt conveyor,2. vibrating classifier, 3. dryer, 3.1. dryer hopper, 3.2. discharge auger, 3.3. pipeline, 3.4. boiler, 3.5. fuel tank, 3.6. fan, 3.7. cyclone, 3.8. fuel conveyor, 4. screw conveyor,5. briquetting press, 6. knife mower, 6.1. vibrating conveyor, 6.2. belt conveyor, 7. electrical main switchboard, 7.1. electrical boiler switchboard, 7.2. electrical material switchboard

Automated lines have fraction sorters and can be equipped with a dryer for drying the input raw material. They are also suitable for briquetting raw material containing high moisture content. In the Czech Republic, one of the best known manufacturers of these lines is BRIKLIS spol. s r.o. (Fig. 32).

Pellets are made from the same material and in a similar way as wood briquettes, they differ only in size. Pellets are made from wood or agricultural residues by strong compression, which is called **pelletizing.** Pelletizing produces a completely new type of wood fuel with high energy density, good fuel properties and excellent transport and handling characteristics. Wood pellets are produced by pressing on extrusion presses. In addition to pressure, the lignin and resin content of the wood is important for the cohesiveness of the pellets. Pellet production consists of drying, crushing - grinding, steaming, pelleting, cooling and storage.

The raw material is dried to a moisture content of 10 to 15 % before pressing. Pellets are usually made from the residues of processed raw wood, which has a water content of 40 to 60 %. It is therefore necessary to dry them well. This is followed by crushing, because pellets are made from wood residues of different sizes (sawdust, shavings, small chips) and therefore the raw material must be adjusted to a certain grain size before pressing. When producing pellets with a standardised diameter of 6 or 8 mm, a maximum size of 3 to 3,5 mm of the processed wood particle is required. This is followed by softening. The addition of water in the form of steam at a rate of around 2 % by weight of the raw material is evaporated during pressing and subsequent cooling of the pellets and the moisture content is adjusted to between 11 % and 14 %. The quality, appearance and strength of pellets made from steamed raw material are much better than those made from raw material not treated in this way. The input material is forced under high pressure through small circular holes in a steel matrix and heated to a temperature of around 100 °C.

Pelletizing presses differ from briquetting presses in that they use a different pressing method, namely the principle of pushing the raw material through the matrix by means of pressure rollers rotating in close proximity above the matrix openings.

These presses are of two types - according to the type of die:

a) With a horizontal, disc-shaped rotary die and a system of rotating rollers that roll down the circular, disc-shaped die and push the raw material down through the holes in the die. The output of this system is 0.5 to 1.5 t/h.
b) With a ring die rotating on a horizontal axis and press rolls rotating freely on fixed pins, CPM system (USA). Output up to 5 t/h. Power input of pelleting, granulation presses ranges from 40 to 100 kW. Energy consumption is about 3 to 5 % of the energy content of pellets about 20 % of the pelleting costs.

Pellets are highly compressed cylindrical mouldings, most commonly produced in 6 - 8 mm and varying lengths of 5 - 40 mm (Fig. 33).

Figure 33: Pellets
Source:Scobis, 2022

Alternative pellets, called agropellets, are also produced. They are made from agricultural surpluses such as straw, hay, waste from cleaning grain, oilseeds and legumes. Compared to wood pellets, they have a higher ash content (5 %). Agropellets are an important source of renewable energy and represent a significant potential for rural economic development. Emissions from the combustion of agropellets are below the permitted standards for the combustion of solid fuels. An important aspect is that they cannot give off more nitrogen than the plants use to grow. The use of agropellets for heating and energy production is an important contribution to environmental protection and has an economic justification. Pellets, especially agropellets, are a rapidly renewable source of energy. Depending on the wood species, the calorific value is around 15 to 21 MJ/kg, the ash content less than 1 % (agropellets 5 %) and the water content less than 10 %.

Due to their smaller size, they are suitable for boilers with automatic feed, which provides similar comfort to gas heating and you don‘t have to worry about anything. In doing so, the pellets have all the advantages of wood heating, but with even better energy properties thanks to the pressing process.

Wood briquettes and pellets have gained in popularity due to the annual increase in the price of fuel oil and natural gas. They are used to replace fossil fuels in boilers and domestic stoves. From an ecological point of view, the burning of fossil fuels produces a huge amount of harmful substances. Nowadays, more and more emphasis is being placed on ecology and alternative sources are much more environmentally friendly. Wood processing plants consume large amounts of energy, which is very valuable nowadays. This is linked to high energy costs. These costs can be minimised by the energy recovery of waste. It is essential to address the issue of the versatile use of biomass and to follow new trends in this sector.

Compacting is a waste compaction technology in which material of the desired fraction and moisture content is compacted between two counter-rotating smooth or profiled rollers. These rollers are pressed together as required. The compaction process results in granules or plate-shaped agglomerate which, after being chopped into granules, is suitable for further processing, especially in the chemical and metallurgical industries. It is the least used technology for biomass compaction. As already mentioned, in addition to the high pressure, the high compaction temperature is also a feature of briquetting and pelletizing. It is the high temperature, followed by a ‚settling‘ and slow cooling phase, that is absent in compaction. A binder is therefore often used to improve the strength of the resulting agglomerate.

6.2 CHEMICAL PROCESSING OF WOOD

6.2.1 Wood chemistry and analysis

Chemically, wood can be characterised as a three-dimensional composite composed of interconnected networks of cellulose, hemicelluloses and lignin with minor extractives and minerals, see Figure 34.

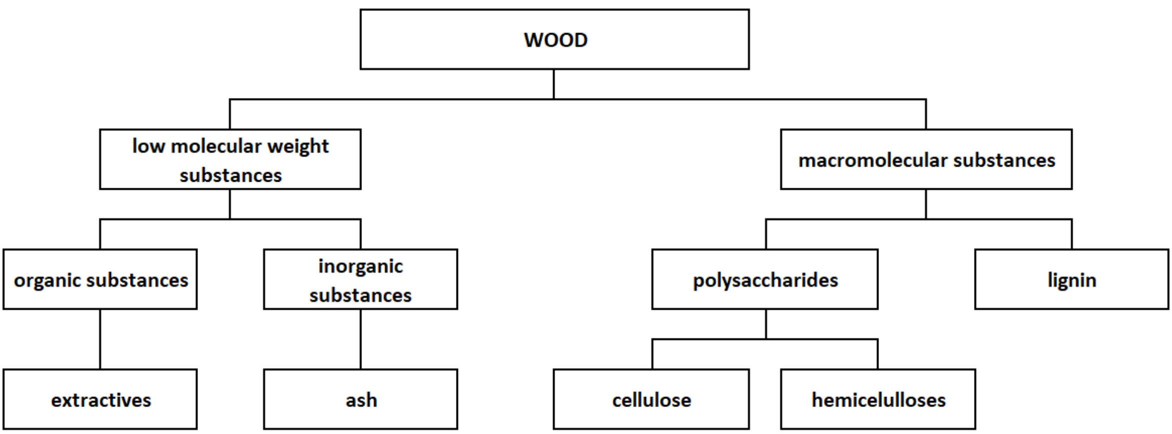


Figure 34: Chemical composition of wood

The representation of the individual components varies according to the species of tree, age, season, climatic conditions, health status and the sampling location (heartwood, sapwood, summer or springwood, plant parts; branches, bark, etc.).

Although the primary chemical compound in a living tree is water, in dry wood, all cell walls are mainly composed of macromolecular substances. The elemental constituents of wood are mostly carbon, oxygen, and hydrogen, while bark and leaves have different compositions and may contain trace amounts of nitrogen. In addition to these elements, other substances are also found in wood.

The ranges of the main components are variable, but in simplified terms it can be said that wood contains approximately 35-50% cellulose, 20-35% hemicelluloses and 15-35% lignin (Čunderlík, 2009).

6.2.1.1 Mineral substances

Inorganic substances are necessary for plant growth. In wood, inorganic (mineral) substances are dissolved in plant juices and bound to fatty, uronic or resinous acids, especially metallic ones.

The amount of minerals varies according to the wood species, but it also depends on the part of the plant, the climatic conditions of growth, the season or the soil conditions. Mineral content is rarely reduced by water extraction. After burning the organic part, the minerals remain as ash.

Unfortunately, the composition of the ash is not identical to that of the original minerals, as the organic acid salts are converted into carbonates when burnt. Thus, wood ash is primarily composed of carbonates but also, to a lesser extent, of sulphates, silicates, phosphates or chlorides (Červenka et al., 1980).

6.2.1.2 Extractives

Extractive substances have a specific function in wood: terpenes, tannins, stilbenes, some glycosides, fats, waxes, etc. increase the resistance of wood to biotic damage, either by hydrophobicity or potential toxicity. Other sugar alcohols, soluble low molecular weight fractions of polysaccharides, vitamins, proteins, etc. are storage substances or metabolites and, on the contrary, may reduce stability against biotic influences, as they usually have substrate properties. Furthermore, extractive substances can affect properties of wood such as its calorific value, color and other (Blažej, 1975).

This amount of substances can be extracted from wood by specific solvents of organic substances or water. The substances obtained are called extractives and are mainly of organic origin. The content and composition of the extractives are variable according to the wood species, varying with the type of cells predominating. Parenchymatous cells contain fats and some glucans, while epithelial cells contain higher amounts of resin acids.

Extractives are determined by extraction. Extractives are grouped according to chemical nature and structure or according to polarity and, thus, dominant solubility in solvents. Extractives can be determined using non-polar solvents such as petro-ether, ether, benzene, or toluene. These solvents are mainly used to remove fats, fatty acids, esters, resins, resin acids or waxes, and sterols. In addition to non-polar solvents, water (polar solvent) is used, either hot or cold, and salts and carbohydrates are transferred mainly. Other polar solvents include, for example, ethanol, which removes tannins, glucosides, or dyes from the sample. Polar solvents penetrate well into cellular spaces, causing partial cell wall swelling. They dissolve fatty and resinous acids, waxes, and resins and, to a lesser extent, dissolve fats, some carbohydrates, tannins, and lignin of low polymerization (Kačík & Solár, 1999).

6.2.1.3 Hemicelluloses

Hemicelluloses are a group of substances of polysaccharide character, soluble in dilute alkalis and easily hydrolyzed by dilute acids. Hemicelluloses can be divided into native hemicelluloses, found directly in plant materials, and hemicelluloses in fibers, isolated from plant sources by chemical means. Because native hemicelluloses are mainly bound in wood as a lignin-saccharide complex, they have entirely different properties than hemicelluloses in isolated fibers (Kačík & Solár, 1999).Chemically, the hemicelluloses are pentoses and hexoses (L-rhamnose, L-fucose, L-arabinose, D-xylose, D-mannose, D-glucose and D-galactose), and some are also composed of polyuronic acids

(4-O-methyl-α-D-glucuronic and α-D-glucuronic). Hemicelluloses affect the physical and chemical properties of wood and wood processing.

The composition and abundance of hemicelluloses in the wood of coniferous and deciduous plants differ. The most abundant group of hemicelluloses in broadleaved wood is xylan, which differs from conifer xylan in having bound acetyl groups. Xylan chains in conifers are shorter and less branched. In conifer hemicelluloses, the most abundant group is the glucomannans, which differ from the mannans of deciduous trees in that the main chain of the molecule is made up of one type of monosaccharide. The basic building units of hemicelluloses are shown in Figure 35 (Požgaj, 1997).

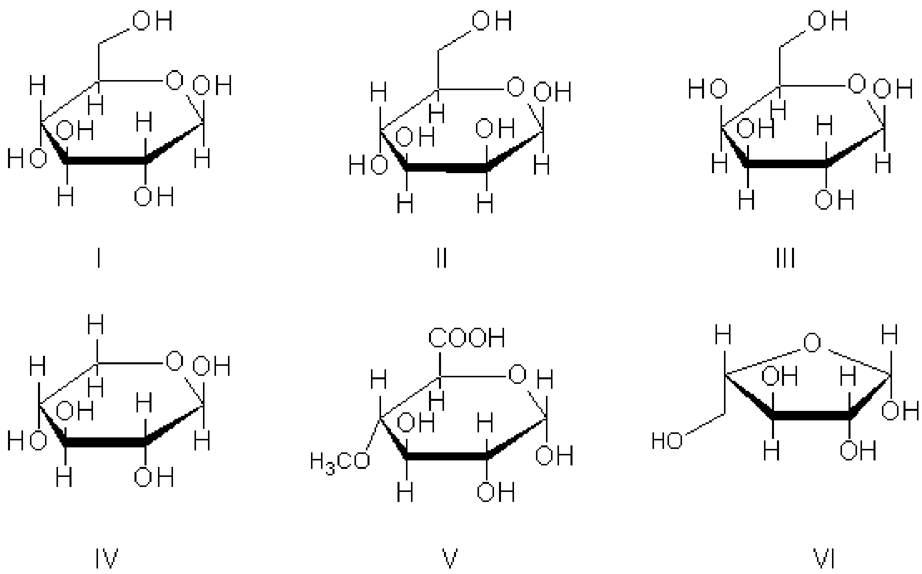


Figure 35: Basic building units of hemicelluloses
I - β-D-glucopyranose, II - β-D-mannopyranose, III - β-D-galactopyranose, IV - β-D-xylopyranose, V - 4-O-methyl-α-D-glucuronic acid, VI - α-L-arabinofuranose

With the current trend towards a more complex and efficient use of biomass, attention has been paid in recent years to using hemicelluloses as a source of biopolymers applicable in the following areas: packaging, food, biomedicine, pharmaceuticals, and paper production. Various chemical modifications of hemicelluloses are also being investigated to improve the properties of the original hemicelluloses, such as thermoplastic properties, reduction of crystallinity, etc.

6.2.1.4 Cellulose

Wood is composed of main components and after components. The importance of cellulose lies mainly in its being the most abundant, renewable, and biodegradable polymer. Cellulose is one of the main constituents of wood and is present in almost half of the wood, 35-50 %. Of course, it depends on the type of wood (conifers generally contain more cellulose than deciduous trees), age, location, etc.

The basic bonding unit is cellobiose (Figure 36), which consists of two β-D-glucopyranose units bound by a 1,4-β-D-glycosidic bond, which are rotated 180° to each other. This linkage allows linear chain elongation. The cellulose chain runs through crystalline and amorphous sites. Cellulose contains up to about 70 % crystalline parts. The greater the length of the cellulose polymer chain, the higher the strength of the wood. Cellulose chains are longer in conifers and may contain 5 000 to 12 000 units. Cellulose macromolecule chains hold secondary hydrogen bonds to each other laterally. These secondary bonds cause anisotropy in the elastic and strength properties of cellulose and affect the anisotropy of the mechanical properties of the wood (Červenka et al., 1980).

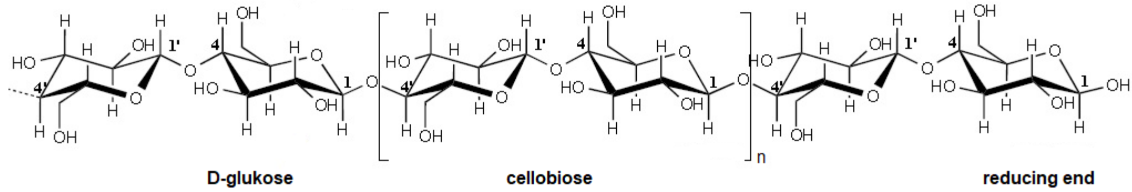


Figure 36: Schematic representation of the cellulose chain

Although cellulose is a chemically stable compound, it is subject to various types of degradation, such as effect to acids or alkalis, elevated temperature, mechanical action, or radiation.

Cellulose isolation highly depends on the association of substances in the cell wall. Chemical compounds such as fats, waxes, proteins, and pectins can be easily removed by extraction with organic solvents and diluting alkalis. Cellulose is bound to hemicelluloses through various polysaccharide linkages and lignin through hemicelluloses. Their separation requires intensive chemical action (Kačík & Solár, 1999).

The primary industrial importance of cellulose is that it is a source for pulp preparation; it is a process in which delignification takes place. Thus, lignin is primarily removed, as are hemicelluloses and extractives. Lignocellulosic materials have applications in the production of 2nd generation bioethanol.

6.2.1.5 Lignin

Lignin is one of the main components of wood, 15-35%, and is, therefore, the most abundant aromatic polymer on earth and the second most abundant polymer after cellulose. Its distribution in the cell wall or the different parts of the tree is not uniform. Lignin is a characteristic chemical and morphological component of higher plant tissues, predominantly found in the conducting laminae, which provide both fluid transport and strength properties. In addition to its mechanical function, it also has a protective function, mechanically preventing the penetration of microorganisms into wood (Fengel & Wegener, 2003).

In terms of chemical composition and structure, it is a highly irregular, randomly cross-linked three-dimensional polymer, which is composed of phenylpropane units linked by two types of bonds, i.e. carbon-carbon (C-C) and ether-type (C-O-C), and containing two basic types of functional groups, i.e. hydroxyl (-OH) and methoxyl ($-OCH_3$). The different structures of lignin are shown in Figure 37.

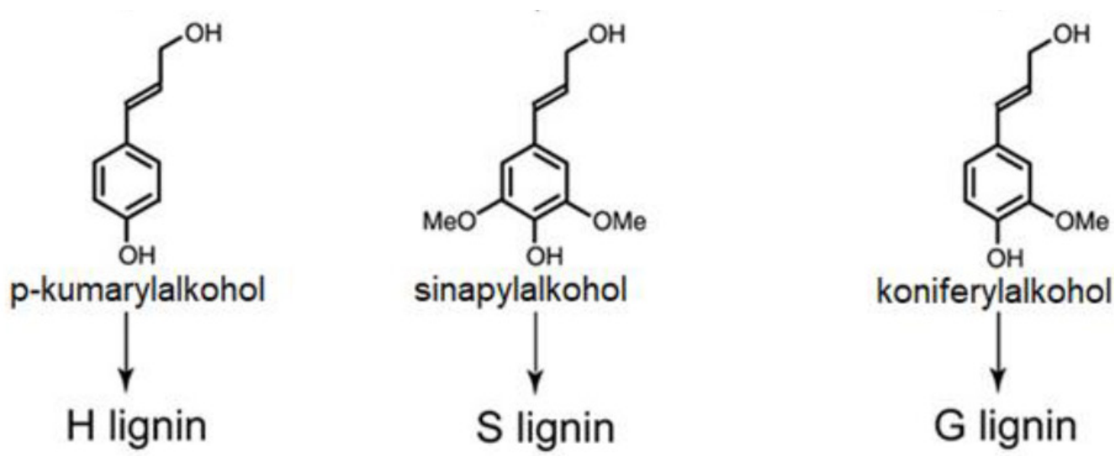


Figure 37: Schematic representation of lignin structure

Lignin in plant materials, in its native state, can form chemical bonds with polysaccharides. These bonds affect the properties of wood in its native state and during its processing by various methods (Kačík & Solár, 1999).

Lignin has a high energy content, which makes it an excellent fuel. Lignin's energy potential is exploited, especially in the pulp and paper industry. Theoretically, the energy required to isolate lignin from wood corresponds to the purity level of the cellulose-rich pulp that is the pulping feedstock in the pulp and paper industry. However, the energy recovery of lignin is not the only optimal use of this macromolecular substance. The potential uses of differently reactive lignin can be assigned to the following areas: energy combustion, paper, and wood industries, fragmentation into chemical feedstocks, production of binders and adhesives, use of lignin derivatives, additive in polymers, carbonization, agriculture, biochemical processing and production of copolymers or polymers with new properties (Laurichesse, 2014).

6.2.2 Chemical processing of wood

Today, there is an increasing emphasis on the use of plant biomass for the production of value-added products. The most important areas of chemical wood processing today include:

- **The pulp and paper industry** – the chemical processing of woody matter produces pulp, which is the starting material for paper production or is used to produce or prepare other products (nanocellulose, oxycellulose, etc.);
- **Thermal decomposition** – the thermal processing of wood to produce other industrial products such as charcoal, gas, tar, acetic acid, methanol, acetone, various oils, disinfectants, etc;
- **Hydrolysis of wood** – a process that produces carbohydrates such as crystalline glucose, xylose, etc., bioethanol and other alcohols and other valuable substances;
- **Wood extraction** – allows the obtaining of various volatile organic compounds, turpentine, resins, and others.

In addition to these examples, there are many other possibilities for the chemical processing of plant materials and wood (Chartier et al., 1995).

6.2.2.1 Pulp and paper production

The pulp and paper industry has always been considered a major consumer of wood and has also solved the use of small-scale forest and industrial wood assortments, such as sawmill trimmings, which were used only as fuel in the past.

The paper industry includes both the processing of wood pulp and the production of pulp, or the recycling of fibers from secondary paper, and above all, the production of paper, cardboard, and paperboard and their subsequent processing, mainly for packaging. The final paper products are used in all other industries, not only in manufacturing but also in the printing industry. World statistics indicate that the paper industry is the second largest, using renewable resources after the food industry (Bajpai, 2012).

Pulp is the technical term for the raw material (semi-solid) of fibrous matter produced by chemical processing of wood pulp. It is mainly used for producing paper but also applies to producing artificial fibers, plastics, and others.

There are many raw materials in nature from which even high-quality paper can be made, but few that meet the technical and economic requirements. In particular, the fiber materials for papermaking must meet the following conditions: they must be available in large quantities, they must be cheap and yield a high percentage of cellulose, they must be easy to pulp, easy to bleach, easily applicable to the screen of a paper machine, their fiber must be long enough to make strong paper and, last but not least, their processing costs must be low. Fibrous raw materials of vegetable origin meet these conditions, the first of which is wood. The second fiber material, in terms of volume processed, is recovered (secondary) paper.

Fibrous materials are semi-solids made from fibrous materials mechanically, thermomechanically, semi-chemically, or chemically. They are processed by pulping or milling. They may be dyed, filled, glued, bleached, and have auxiliary chemicals added. These processes are used to prepare pulp, the raw material for papermaking, according to the type of paper produced and the requirements. Figure 38 shows how the pulp is made into pulp, fibers, and paper.

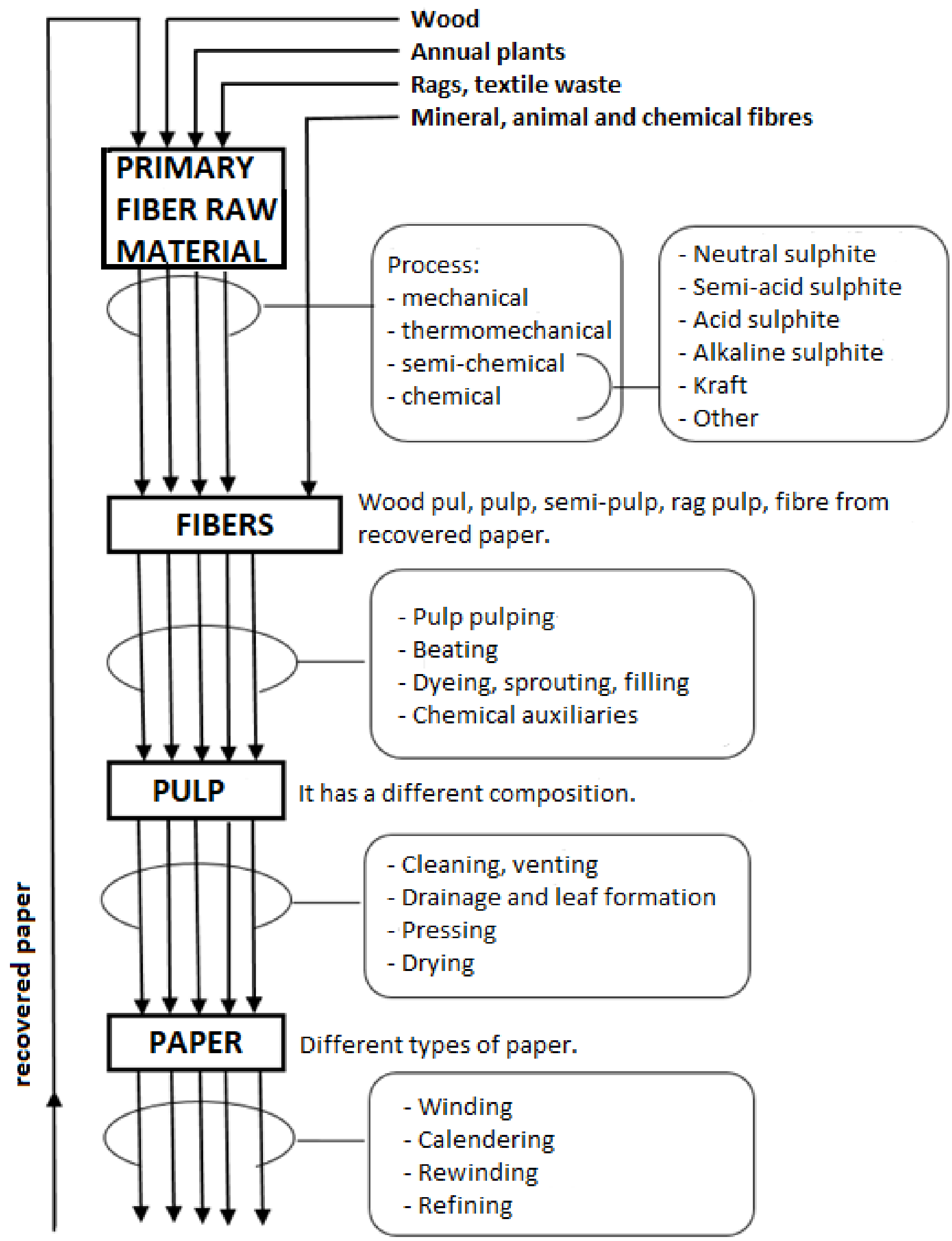


Figure 38: Primary fibre raw materials for paper productions
Source: Buk, 2013

The three main ways of obtaining fibre from wood are:

- **The mechanical method** is where the fiber is extracted mechanically by sanding. The fibers are only mechanically broken down, so the resulting pulp contains all the components of wood: cellulose, hemicellulose, lignin, and others. This fiber is called the wood pulp. The lignin content of wood pulp causes the paper produced to turn yellow. The paper is of lower quality but very strong. Wood pulp is used to make cardboard, cartons, and wrapping paper.
- **Combined (chemical-mechanical) method**, the pulp is obtained by exposing the so-called chips to chemical action (water vapour-heat/chemicals) and then further processing them mechanically. The pulp thus obtained is referred to as semi-pulp. Wood from deciduous trees is used to produce this pulp.

- **The chemical method** is the chemical processing of wood, which is based on cooking the chips in a solution of chemicals. The resulting product is pulp, an almost pure cellulose fiber; the other components are chemically removed. Pulp can be produced in two ways, depending on the type of chemicals used to cook the woodchips:
  - » The sulphite method is an acidic method where the chemical reagent is a cooking acid (a solution of calcium hydrogen sulphite and sulphuric acid). The cooking takes several hours at about 110-140 °C.
  - » The kraft method is alkaline, where a cooking liquor (a solution of sodium hydroxide and sodium sulphide) is used to cook the wood. This method cooks the wood for up to 5 hours at 180 °C.

Chemical, mechanical, and chemical-mechanical fibers belong to the so-called commercial fibers, sometimes called primary fibers. Approximately 75 % of all commercial fiber production is bleached kraft pulp. The next in order is sulphite pulp, followed by mechanical and chemical-mechanical fibers, and the least production is for unbleached kraft pulp. A special group comprises rag pulp used to produce specialty papers in limited quantities and recycled fiber (Bučko et al., 1988).

6.2.2.2 Bioethanol production

The production and use of biofuels are associated with various environmental impacts. The current use of fossil fuels has resulted in a critical environmental situation. Their combustion produces carbon dioxide, methane and significant amounts of nitrogen oxides. Most of these harmful gases are formed due to incomplete combustion. Using of ethanol as a fuel in internal combustion engines reduces exhaust emissions, thus reducing air pollution. Biofuels do not contain sulphur and do not contribute to acid rain. The combustion of biofuels can increase nitrogen oxides up to 10%, but lower combustion temperatures and proper engine tuning can lead to a decrease in these emissions. Unlike some gasoline containing up to 45% aromatics, ethanol does not contain aromatic compounds (Bučko et al., 1988).

Biofuels from different biomass types can be solid, liquid or gaseous. Depending on the type of biomass used, they can be divided into four generations:

- **The first generation** is made of biofuels directly from food crops. Bioethanol is produced by fermenting wheat, corn, or sugar beet. At the same time, biodiesel is produced by transesterification of oils from rapeseed.
- **The second-generation** biofuels are produced from non-food crops such as wood, organic waste, and food waste. Developed to outperform 1st generation biofuels and compete with existing fossil fuels.
- **The third generation** is represented by biofuels made from algae and other aquatic plants. Algae are believed to have the potential to produce more energy than conventional crops. They have the advantage of being grown in water instead of soil for food.
- **The fourth generation** of biofuels focuses on producing and using genetically modified organisms (GMOs) or advanced biochemical processes and procedures. These include, for example, algae for energy production (the principle is based on the photosynthesis of algae in photobioreactors), solar technology producing biofuels (the principle of artificial photosynthetic devices), and genetically modified biomass feedstock for biofuel production.

The production of bioethanol is based on the following technological operations (Kočan, 2009):

- **Feedstock storage**, the production technology depends on the feedstock used and its structure. Factors to be monitored to obtain the maximum yield are the amount of the main components, the composition and structure of the main components, and the size and method of splitting of the feedstock.
- **Cleaning and treating biomass**, depending on the type and form of biomass delivered, the delivered feedstock needs to be debarked and prepared into chips of the appropriate size.
- **Biomass pretreatment** is a step in which the crystalline structure of cellulose is disrupted, the lignin envelope is disrupted, and the hemicelluloses are partially removed. This process increases the accessibility of enzymes to the crystalline structure of cellulose and parts of hemicelluloses. The pretreatment methods may be

mechanical, physical, and chemical. Pretreatment using water is the most suitable alternative, whereas the so-called steam explosion is the most suitable alternative. The temperature and time of action of the key factor of the selected method influence the release of as much carbohydrate as possible from the biomass. They reduce sugar yields and cause inhibition of enzymatic hydrolysis. Therefore, it is necessary to find the appropriate combination of temperature and pretreatment time to maximize the release of sugars and minimize their degradation.

- **Enzymatic hydrolysis** of cellulose and viscosity reduction involves liquefying the impregnated and pretreated biomass in Stage I of two-stage reactors to reduce the mixture's viscosity. The aim is to obtain fermented carbohydrates of steady-state concentration.
- **Detoxification of inhibitors**, before the fermentation itself, is a process of detoxification of inhibitors formed during pretreatment and hydrolysis. This step is carried out to make the fermentation process more efficient. It is carried out using chemical agents (e.g., lime), physically (e.g., ion exchange), or biologically (in situ).
- **Fermentation**, ensures the conversion of simple carbohydrates into ethanol. It can be carried out alone or simultaneously with hydrolysis.
- **Ethanol purification, distillation, and dehydration** are the last steps in bioethanol production. It involves its isolation from the medium by distillation, which produces an azeotropic mixture containing 4% water and 96% ethanol. The residual water in the azeotropic mixture can be removed using, for example, molecular sieves.
- **By-product treatment**, carbon dioxide is the main component of emissions from fermentation and distillation. In addition to carbon dioxide, the production process produces highly volatile fractions of acetaldehyde, ethyl acetate, methanol, higher alcohols, volatile fatty acids, a mixture of higher alcohols, solid residue, lignin, etc.

6.2.2.3 Chemical modification of wood

Although wood is a renewable raw material, it must be protected from many external factors for optimal use. Various methods of modification are used to do just that. These methods are mainly used to preserve their favourable properties, such as strength, flexibility, and lightweight. At the same time, they are also used to eliminate harmful properties, such as dimensional instability due to moisture, low biological resistance, flammability, etc. The most effective and currently used methods are chemical and thermal modification (Sjöström, 1993).

Chemical modification is based on the reaction of the functional groups of the chemicals used with the reactive parts of the wood cell wall polymers, which can cause new properties of the modified wood. Chemical modification forms a simple covalent bond with one -OH group or crosslinking between two or more -OH groups, Figure 39. Several compounds are used for the chemical modification of wood, the most used being carboxylic anhydride, acyclic and cyclic anhydrides, ketones, carboxylic acids, carboxylic acid halides, aldehydes, and others.

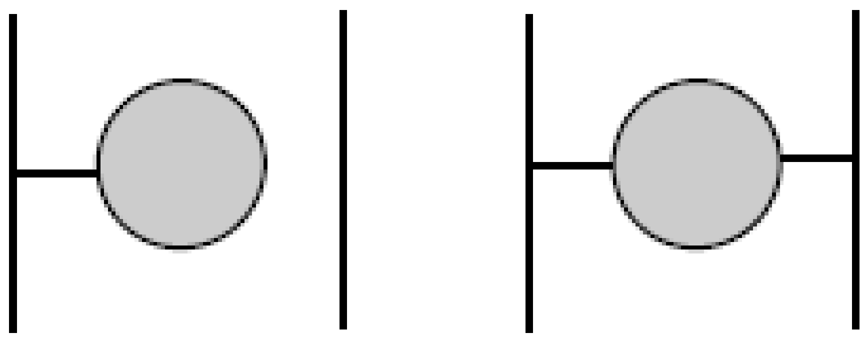


Figure 39: Schematic representation of bond formation during chemical modification of wood

Chemical modifying agents targeting wood structural components should meet good penetration ability to penetrate the wood cell wall microcapillaries, sufficient reactivity with -OH groups of wood in neutral or weakly acidic environments even at temperatures below 120 °C and the formation of stable covalent bonds with wood components (Hill, 2006).

6.3 INNOVATIVE TECHNOLOGIES

6.3.1. Material utilization of lignin

The material use of lignin in comparison with energy use represents a better appreciation of lignin, up to a thousand times.

There is a wide range of products that can be made from lignin. If we restrict ourselves to products in the woodworking industry, lignin can be used to make adhesives, coatings or impregnating agents. This is a very diverse range of products, with some resins containing lignin only inertly as a filler and others as a reactive component. Lignin is extracted from cell walls during the production of cellulose. Depending on the origin of the lignin and its specific use, it is processed by various condensation, repolymerisation, depolymerisation or stabilisation processes. A very interesting route is the enrichment of lignin with phenol (an organic compound widely used in the chemical industry), which produces lignin fragments that are more reactive than the lignin itself and therefore more suitable for further chemical processing.

Lignin is also obtained in the production of second-generation biofuels from lignocellulosic materials (e.g. wood chips or straw) and lignin is also used in conventional biorefining for energy purposes. However, modern fractionation can also be used in the production of biofuels, where only hemicelluloses are used, and the cellulose itself is then used to produce fibres or nanofibres - i.e. very valuable materials. The lignin and other substances contained in the wood are not burned, but used in a material way in higher value-added products. Figure 42 shows dried alkaline lignin from pulp production. This material in powder form can be used directly for further processing.

Currently, the Faculty of Forestry and Wood Sciences of the Czech University of Life Sciences Prague (FLD) is developing a method of pelletization of powdered lignin, not for the purpose of burning pellets, but for easier handling and transport of lignin. In the production of such pellets, it is an essential requirement that the lignin does not sinter during pressing. For further processing (production of lignin-based resins), it is important that the lignin pellets are soluble in water or other solvent. These resins can then be used in the production of high-pressure laminates, plywood, fibreboard or other wood-based composite materials.

Figure 40: Dried alkaline lignin

6.3.2 Composite materials from recycled wood

Recycled wood is wood that comes from wood products or wood-based materials at the end of their useful life and is a valuable raw material for the production of other materials. Suitable materials that are already commercially produced from recycled wood are particleboard and OSB. For these panel materials, recycled wood from the following products is used: packaging material (pallets, wooden packaging, crates), construction timber (beams, boards, planks), joinery residues (raw, laminated and veneered boards), furniture. Wood recycling, especially in the form of multi-stage cascade wood recovery, can significantly help to address the ruthless estimate that the European Union will be short of over 300 million m^3 of wood in 2030 (Hýsek, Hýsková, Habán, 2021). Such a high deficit will be mainly due to the increasing use of raw wood for energy purposes. It can therefore be expected that the production of composite materials from recycled wood will increase in the future and the percentage of wood recyclate in various wood-based materials will also increase.

An example of multi-stage wood recycling is shown after Figure 43. The raw wood is not immediately burned, but is first used for the production of solid wood structures such as trusses, furniture or pallets. At the end of the basic lifetime of the solid wood products, they are disintegrated and made into particle board (particleboard, OSB). These particleboards can then be used to produce valuable chemical products (paper or pulp). Only as a final, i.e. fourth, step can the energy recovery of end-of-life products be included. Of course, the ash from this burning can also be used as an additive in building materials.

There are also several bridges throughout the cascade directing the flow of raw timber material directly to the second or third stage of the cascade. Due to the insufficient quantity of recycled wood available or to ensure the quality of the products at the second and third stages (particleboard and chemical production), it is possible to partially satisfy the demand for raw material directly with raw wood. However, it is certainly not necessary to direct the flow of raw wood directly to energy recovery, without prior use in the higher stages of the cascade. The second type of bridging is the use of by-products from sawmill processing of raw wood at the first stage of the cascade (chips, sawdust) directly in the production of wood-based materials or chemical products (paper, cellulose). The existence of feedback loops can also be identified in Figure 43. These loops are applied at the second and third stages, where the end-of-life products from these stages can be successfully recycled and used to produce the same product (wood-based composite materials, paper).

Of course, the whole system implies a consistent sorting of wood and wood-based products. However, this is where the Czech Republic has a weakness. The legislator is also aware of this fact, both at national and European level. A key provision to be taken into account in this context is Section 21(7) of the Waste Act, as amended with effect from 2020, which stipulates, among other things, that it is forbidden to landfill recyclable and recoverable waste. The Czech Republic was ready to meet this ambitious plan, but due to the EU-wide shift of this target (Directive 2018/850/EU), the effectiveness of this ban has been postponed until 2030. It is thus clear that some activity is being undertaken in relation to this shortfall, but its effectiveness will not take place until 2030 at the earliest. In the meantime, it is of course possible to continue using wood, as has been the case for several years in Belgium, where several times more recycled wood is processed than raw wood, and in Germany, for example, where wood recycling is regulated by special legislation. It is certainly interesting that since 2003, wood waste has not been landfilled in Germany. It is therefore not necessary to wait for the ban to be established by a new law and it is possible to act immediately. Indeed, we have already seen similar efforts in the Czech Republic.

The pioneer in the use of recycled wood and the largest processor of this raw material in the Czech Republic is Kronospan CR, spol. s r.o. This manufacturer of wood-based composite materials already uses recycled wood in the production of particleboard, up to 50% by weight. In addition, the production of OSB boards was launched in mid-2022, also with up to half of the wood recycled content in the whole board. The company is thus finding a market for this material, but despite its best efforts to obtain wood from salvage yards, it is unable to meet its demand for recycled wood in the Czech Republic and has been forced to import more than 50% of the required wood recyclate from abroad, especially from Germany, in recent years. This is despite the fact that any shape, size, surface finish or age of a once-used wood product can be supplied from the recycling yard, because Kronospan CR, spol. s r.o. is able to process this material to a condition that allows further use.

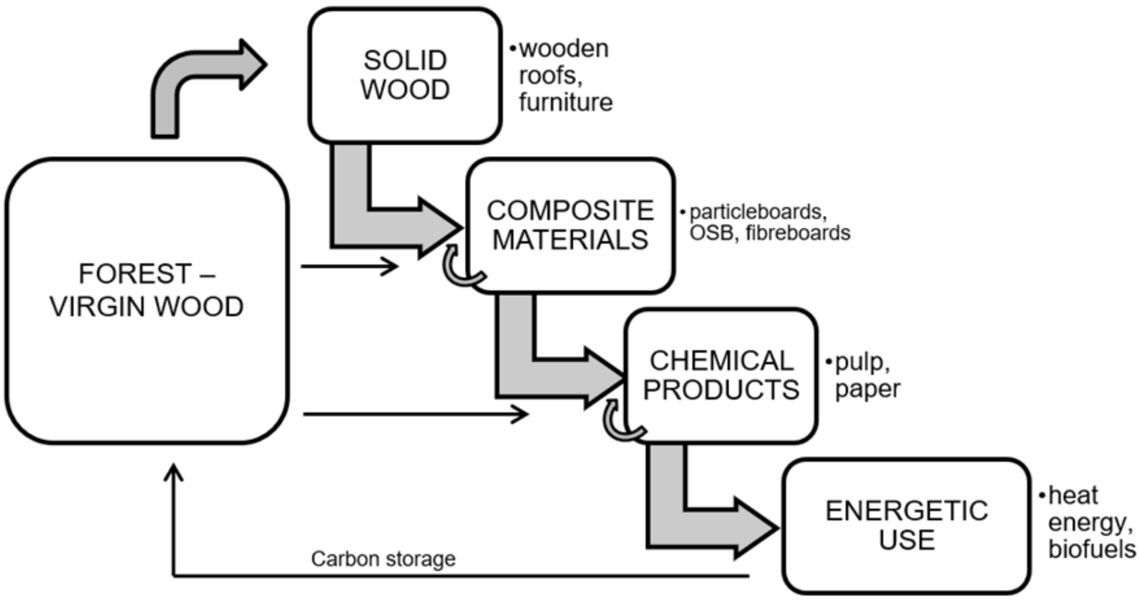


Figure 41: Example of cascading wood use

6.3.3 Wood-plastic composite materials

Wood-Plastic Composites (WPC) are made from a mixture of very fine wood elements (usually flour or fibres) and polymer. The main motivation for mixing these two different materials is to produce products that have properties combining the advantages of both feedstocks. While the wood elements act as filler and reinforcing material, the polymer is a matrix that fills the spaces between the wood elements, protects the wood elements from the environment and transfers the forces acting on them. Thermoplastics with a melting point of less than 200 °C (most commonly polyethylene, polypropylene or polyvinyl chloride) are used for the matrix. The low temperature at which wood-plastic composites can be produced precludes the use of e.g. polyethylene terephthalate (PET). The wood/plastic ratio is most often in the range of 40-70% wood and 25-55% polymer. Up to 5% is made up of additives such as pigments, stabilisers, UV stabilisers, lubricants, biocides, catalysts, wetting agents and flame retardants.

Figure 42: Example of feedstock for WPC production

Properties

Wood-plastic composite materials have better dimensional stability than solid wood. With a wood content of less than 50%, soaking and swelling is very low. However, water absorption and swelling increases with the gradual ageing (UV degradation) of the material. Compared to wood, wood-plastic composites are almost maintenance--free and are not subject to cracking and buckling. The optimum wood/plastic ratio depends on the end use of the product. A high wood particle content causes increased water absorption and lower rot resistance, on the other hand it reduces the cost of the input material. The wood/plastic ratio also affects the manufacturing parameters and the physical and mechanical properties of the composite. As the wood content increases, the flexural modulus, tensile modulus, toughness and density increase. With increasing thermoplastic content, flexural and tensile strength, elongation and swelling decreases. Due to the thermoplastic content, wood-plastic composites have lower strength and stiffness and higher creep than solid wood. Composite material properties such as strength, water absorption and resistance to biological attack (especially rot) are also influenced by the size of the wood elements. In general, these properties improve with decreasing wood particle size. However, very small particles tend to clump together and it is difficult to mix the mixture of wood and plastic so that each wood particle is coated with the polymer. The high weather resistance of wood-plastic composites is to be guaranteed by thoroughly coating the wood element with the polymer. However, numerous studies have shown that this is not the case, especially in the surface layer. Wood elements in the surface layers can easily reach moisture contents in excess of 30%, which is suitable for fungal and mould attack. The rotting of particles from the surface layer leads to surface roughening and the progression of moisture and rot deeper into the WPC profile. This phenomenon, together with UV degradation of the polymer, can cause a significant weight loss of the material associated with a deterioration of other physical and mechanical properties of the composite. However, the aging and degradation process of WPC is very slow and most manufacturers guarantee a warranty of more than 10 years.

Utilisation

The wood-plastic composite industry is a fast-growing sector and WPC products are finding ever wider applications. Almost half of the world's WPC production is in North American markets, with China accounting for one-third and Europe accounting for 10%. Due to their good weather resistance and good mechanical properties, WPCs are mainly used outdoors for patio flooring, roofing, railings and fences, door and window frames, window sills, mouldings, garden furniture and wall cladding. They are also widely used in structures that come into contact with seawater. In particular, thanks to European Union legislation, WPC mouldings are widely used in Europe in the form of various parts in the automotive industry (dashboards, door and floor mouldings). WPC mouldings have been used for longer in the form of pallets and shipping boxes, flower pots, garden decoration items, mailboxes and various small items such as clothes hangers, handles, golf clubs, etc. A promising sector is the production of toys made of health-safe, fully recyclable or biodegradable wood plastic. Polyvinyl chloride-based wood-plastics are used for lining chimneys or other hot pipes, as PVC has flame retardant properties.

At this point, it should be noted that wood-plastic composite materials can only be described as promising materials of the future if their recycling is fully resolved and consistently applied in practice. In the manufacture of wood-plastic composite, two completely different components, wood and plastic, are brought together in such a way that they can no longer be separated. Therefore, the only way to recycle wood-plastic composites is to re-manufacture the wood-plastic composite. Otherwise, when wood-plastic products are burned or landfilled at the end of their life, this is not a rational use of either wood or plastic.

6.4 ENERGY USE OF WOODY BIOMASS

Energy is a measure of the motion performed by matter. This motion is virtually impossible to stop or destroy, because the only condition under which matter does not perform any motion is its cooling to 0 degrees Kelvin. Energy expresses the ability of a system to do work and takes various forms. For example, we distinguish between mechanical energy (e.g., the rotation of a shaft driving a wheel on a car), chemical energy (the energy of the bonds between atoms in a compound that hold those atoms together), physical energy (nuclear), electromagnetic waves, thermal energy (heat), and electrical energy (electricity). Since energy can neither be created nor extinguished, we cannot even talk about its production. But we can change the form of energy, so we can produce heat or electricity (from other forms of energy).

When we talk about heat production, most people think of combustion, so-called thermochemical processes. Combustion is the conversion of energy from chemical to thermal energy, which occurs by breaking the stable bonds between individual atoms to release their energy. To initiate this process we first need to supply some energy to the system, then (under the right conditions) the process runs virtually without the need to supply external energy until all the fuel is burned. Biomass with a water content of less than 50 % is suitable for use in thermochemical processes. This is because the water must be removed (evaporated) from the fuel before combustion, which requires a significant amount of heat and thus reduces the amount of usable heat.

Especially in the last few centuries, primarily non-renewable sources have been used to generate heat and electricity. These were mainly fossil resources, in the form of coal, petroleum products or natural gas. These resources were used mainly in the thermochemical processes mentioned above and enabled the rapid development of mankind in the industrial revolution. Their nature created the precondition for the production of heat in concentrated, industrial production technologies, making its production considerably more efficient. Industrial heat production then made it possible to achieve parameters in the heat transfer medium (usually water) at which electricity could be generated and distributed through the transmission system to homes or factories. However, the disadvantages of fossil fuels are their effects on human health and pollution of virtually all components of the environment - water, soil, air. Although technologies exist today to reduce some of the undesirable impacts of fossil fuel energy production, a significant part of these impacts are inherent in their consumption and cannot be avoided.

Therefore, more and more emphasis is being placed on the development of technologies using renewable energy sources (RES). Renewable energy sources are those that are replenished or recycled within a timeframe usable by humanity. In the forest bio-economy, the most common form of energy, similar to fossil sources, is the conversion of chemical energy from RES to thermal energy, which is then converted into electrical energy, e.g. the conversion of biomass, i.e. phytomass and dendromass. However, other RES that do not use chemical energy conversion are becoming increasingly popular, e.g.:

- Solar,
- windy,
- geothermal,
- tidal energy,
- hydropower, etc.

Even today, non-renewable sources are used for energy production much more than RES. Non-renewable sources account for about 86% of the primary energy supply, of which 81% are fossil sources and 5% fission sources (sources for heat and power generation in nuclear power plants). The remaining 14 % is accounted for by RES, of which biomass accounts for about 70 %. It can thus be seen that replacing conventional, fossil energy sources is a challenging task and biomass has an irreplaceable place in this process. In particular, it can serve where the efficiency of using stochastic RES, e.g. solar, wind power plants, is questionable. The advantage of biomass is the predictability of production, so that biomass technologies can be used to smooth out deviations in the transmission system and thus stabilise the electricity supply.

Dendromass is one of the oldest sources of energy ever used by mankind. Except for isolated cases where man has harnessed geothermal energy by finding shelter in a „geothermal heated cave" or taking advantage of available thermal springs, wood is clearly the oldest purposefully used heat source - man has used the properties of wood to start and sustain fires in his dwellings as far back as 1.7 to 2 million years ago (James, 1989).

Even today, dendro-timber, or firewood, is a popular source of heat and electricity. In the European Union, the share of RES in total energy consumption was almost 19% in 2018, of which biomass accounted for 58%. The share of different forms of energy in total biomass consumption in the EU is shown in Figure 44. Dendro-forest origin dendro-wood is mainly used for energy purposes in the EU (more than 60%), with 32.5% of dendro-forest supplied directly from European forests and a further 28.2% supplied indirectly as waste, for example from wood production (Knowledge Centre for Bioeconomy, 2019). Even in developed countries, dendro-forest is used in addition to industrial heat and power generation also in households and local heating systems. About 18% of biomass consumption for heat production in the EU is accounted for by the residential sector.

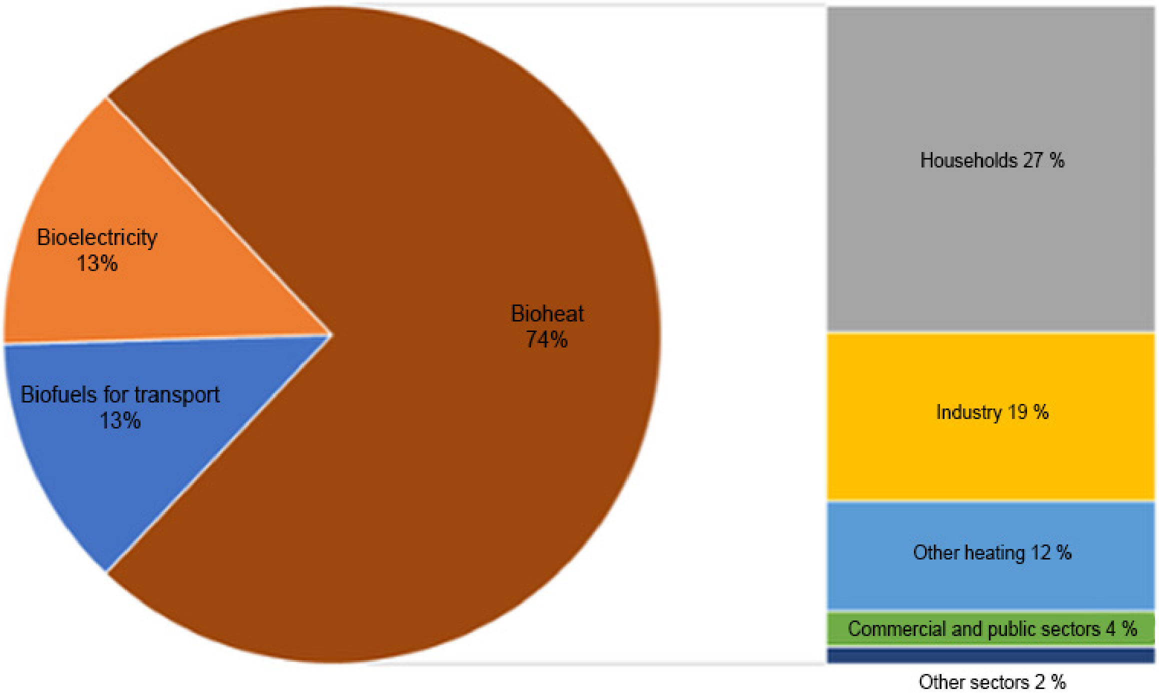


Figure 43: Total biomass consumption in heat, electricity and transport energy production
Source: European Technology and Innovation Platform Bioenergy factsheet 2020.

Renewable energy technologies for the production of heat and electricity from forest-based renewable energy sources

Heat production by thermochemical process is possible at local level in various types of heating systems, from fireplaces, solid fuel stoves to sophisticated boilers for wood briquettes or pellets. The principle of transformation is virtually identical to that of industrial production technologies, with the difference, of course, being the complexity of the operating technologies and systems for controlling the combustion process. A typical local heating plant can be seen in Figure 45.

Figure 44: Left: Wood-burning fireplace, room stove, pellet boiler,
Source: Needforspeed888, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons; LacZ, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons; ÖkoFEN, CC BY 3.0 <https://creativecommons.org/licenses/by/3.0>, via Wikimedia Commons

However, from the point of view of the forest bioeconomy, industrial energy production is particularly important, as it ensures higher production efficiency and lower emissions of pollutants into the environment. The most common industrial power generation technology is the thermal power plant. In thermal power plants, the energy of chemical bonds is converted into the thermal energy of flue gases, water and steam. The thermal energy of the water vapour is then converted back into mechanical energy as it drives the turbine blades. The turbine is connected by a shaft to a generator, in which the form is again converted, this time into electrical energy. With each of these changes of form, losses (leakages of energy outside the system) occur. The principle of operation of a thermal power plant is described in Figure 46. Water enters the boiler K, in which it is heated and changes its state to steam. The latter passes through the steam superheater PP to the condensing turbine KT, where it is injected through nozzles and by its expansion on the blades turns the shaft of the turbine, which is connected to the generator G producing electricity. The temperature of the steam at the inlet to the turbine reaches temperatures of up to 550 °C, and can be reheated by additional superheated steam to the optimum temperature in various segments. After the steam has given up its energy in the turbine, it is discharged from the CT to the condenser, where it is led either to the cooling tower for further cooling or to the chemical water treatment plant and then back to the boiler via the feed pump and water heaters. The heating plant works on practically the same principle, with the difference that the turbine is not condensing but back-pressure and instead of the cooling tower the heat consumers (households, industry requiring steam or hot water supply, etc.) are connected to the system. Thus, the heat is recovered in the heating plants, thus increasing the efficiency of the use of the energy supplied in the fuel. Typically, condensing plants have an energy conversion efficiency of around 30-40 %, whereas a CHP plant operating in combined heat and power (CHP) mode can achieve efficiencies of up to around 80 %.

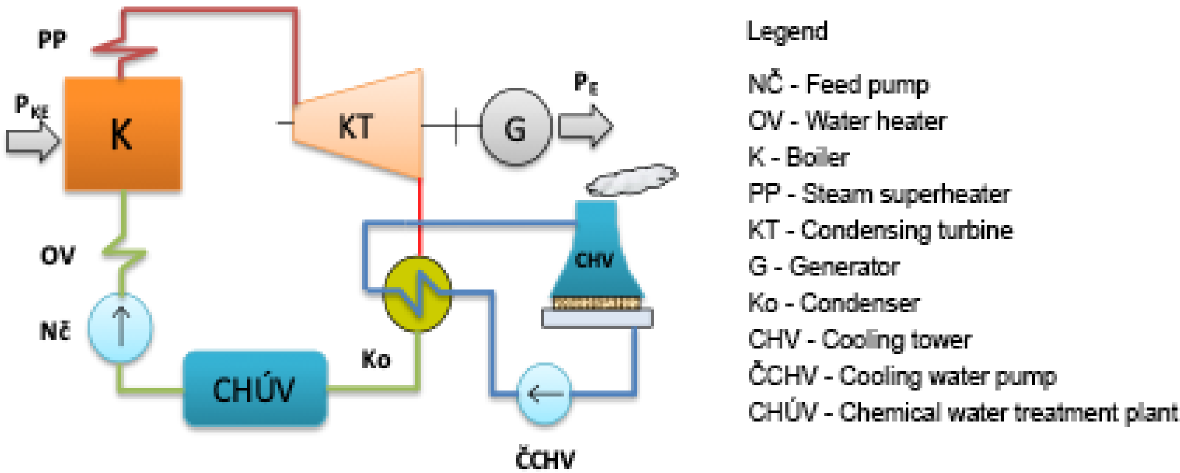


Figure 45: Condensing power plant circuit diagram

Thermal power plants and power plants are able to use disintegrated dendro-mass in various forms - typically wood chips, or pellets, or torrefied wood. In order to use non-thermally processed disintegrated dendroforestry, special equipment must be installed in the boiler to enable the combustion of biomass, which must be suitably prepared for efficient combustion (dried, chipped to a suitable fraction). In the torrefaction process, the wood undergoes a heat treatment (roasting). This process results in a change in the properties of the wood, which in an ideal state are virtually identical (in terms of fuel properties) to those of solid fossil fuels (coal). It is therefore also possible to treat torrefied wood as coal and to use it instead of coal in the virtually untreated boilers of coal-fired power stations. This method of wood treatment is therefore a very promising way of reducing CO_2 emissions from the energy sector.

Figure 46: From left: Biomass heating plant in the UK and the Czech Republic

Chapter Summary

From a technological point of view, wood is a versatile material that can be processed mechanically, thermally, hydrothermally, chemically and biotechnically. Recognising that fossil fuel resources are not inexhaustible and that their extraction, processing and combustion have a negative impact on the environment, the use of biomass offers one of the environmentally friendly fuel alternatives that have a lower environmental impact. Energy waste generated in wood production is a suitable type of biomass for its potential to be efficiently converted into energy. There are a large number of conversion methods and new processes are constantly being developed and improved. Biomass processing and the production of renewable energy is a very dynamic field. It is necessary to continue to communicate about the issue, to conduct active awareness-raising and quality environmental education, and to stimulate consumers to responsible consumption.For the purpose of energy use of disintegrated dendro-mass, it is possible to use especially lower grades and waste resulting from timber production and processing - non-wood, damaged wood, sawdust, shavings and chips. This will reduce the volume of landfill waste, mitigate the negative effects of uncontrolled biomass decomposition in the forest, and benefit a previously unused, indigenous, renewable energy source. The energy use of disintegrated dendro-mass should be the last stage in the cascading use of wood. Innovations in the wood processing industry are focused on the use of lignin in high added value materials (adhesives, coatings, resins); the production of composite materials from recycled wood (particleboard and OSB) and wood-plastic composite materials.

Control questions:

1. Explain the concepts of technology, mechanical technology of wood.
2. What is the difference between first-stage and second-stage wood processing?
3. List the products of sawmilling and characterize each group.
4. How do we process the by-product of wood production?
5. What are the most important areas of chemical wood processing?
6. Briefly describe the mechanical method of fibre production and its advantages and disadvantages.
7. What are the two types of chemical method of pulp production, briefly describe both.
8. What is the advantage of biofuels compared to normal fuels, how do these fuels differ from each other?
9. What positive properties are preserved by chemical modification and what negative properties are eliminated by chemical modification.
10. What is recycled wood?
11. What are wood-plastic composite materials and what are they made of? What are their uses?
12. Why is a thermal power plant a more efficient technology than a condensing power plant?
13. Why is biomass classified as a carbon-neutral fuel?
14. List all the constituents of wood, and divide them into macromolecular and low molecular weight.
15. What are the most important areas of chemical processing of wood?
16. What are the two most common types of chemical pulping, briefly describe both.
17. What is the advantage of biofuels over normal fuels, how do these fuels differ from each other?
18. What are the positives of chemical modification and at the same time what negative characteristics does chemical modification eliminate?

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7 ASSOCIATED PRODUCTION

The aim of the chapter is to introduce the reader to non-timber forest production. The chapter deals with the most commonly used forest fruits in Central Europe and their processing and quality assessment of these resources in the food industry. Attention is paid to the difference between the terms medicinal plant and drug. The next part of the chapter deals with zoomasa, or animal biomass, which is used in forest management. In more detail, this subchapter deals with game hunting, game production and beekeeping, especially in the conditions of the Czech Republic.

Keywords: non-timber forest products (NTFP), nutrition, drug, pharmacognosy, phytotherapy, animal biomass; game farming; hunting; hunting; beekeeping

7.1 FOREST FRUITS, MEDICINAL PLANTS AND OTHER USES OF PHYTOMASS

In addition to timber, forests also provide man with other renewable biological resources that can then be used in various ways - non-timber forest products (NTFPs). These include various types of phytomass, forest fruits, mushrooms, medicinal plants, but also resins, essential oils, bark, game, fish, etc.

Forest fruits

Berries were the main source of fruit in the human diet. Today, the resources of wild crops would no longer be sufficient to meet our needs, so man has gradually developed new, more fertile varieties through selection, breeding and cross-breeding. Gradually, it was proven that some berries not only have a better aroma and taste, but also contain more important nutrients for the proper functioning of the human body than some cultivated fruits. Many species, such as raspberries, strawberries, blackberries, blueberries and cranberries, have become organoleptically attractive fruit raw materials.

People are accustomed to calculating the energy ingested in food in joules, or kilocalories. In terms of the nutritional value of food, however, such a calculation is insufficient, and therefore we speak of a complex of components important for human nutrition. Almost universally, forest fruits are more valuable than cultivated fruits (Table 8). Fruit solids contain mainly monosaccharides, especially fructose and glucose, and small amounts of sucrose, which are less easily digestible. In addition to these macronutrients, berries also contain micronutrients such as vitamins A, B1, B2, K and especially C, as well as indigestible pectin and cellulose (soluble and insoluble fibre), which are important for proper digestion and proper intestinal peristalsis (Lukáč, 1980). Thus, berries have their place in today‘s world. They also deserve attention because they grow freely in forests, without the need for human intervention, and practically the only costs are spent on their collection and processing, or extraction. Forest fruits are currently collected to a limited extent by forest enterprises and are used more by visitors to the forest for self-collection, but if the potential of forest fruit production is exploited consistently, they can be an interesting source of income for forest enterprises.

Table 3: Nutritional value of selected forest biomass compared to conventional foodstuffs

Food	Energy in kJ	Protein (g)	Fats (g)	Carbo-hydrates (g)	Calcium (mg)	Phospho-rus (mg)	Iron (mg)	Vitamins				
								A (m.j.)	B_1 (mg)	B_2 (mg)	PP (mg)	C (mg)
Mushro-oms fresh	870,80	20,80	3,20	30,40	56	560	4,00	-	0,880	2,800	48,00	16,00
Dried mushro-oms	12351,10	367,00	27,00	414,00	700	5000	35,00	-	10,700	37,45	-	-
Blue-berries	2344,60	7,00	7,00	133,00	160	150	8,00	2800	0,200	0,200	3,00	160,00
Rasp-berries	2386,50	12,00	10,00	124,0	170	200	9,00	2000	0,400	0,400	4,00	210,00
Arrows	4898,60	41,00	4,00	279,00	500	1070	98,00	83000	0,500	0,700	-	6000,00
Potatoes	3131,7	17,00	1,70	170,80	94	510	5,95	425	0,765	0,425	14,45	102,00
Beef	4961,3	153,0	58,50	0,80	60	1140	24,75	150	0,750	1,650	51,25	-

Source: Demko, Lukáč, 1990

If the forest enterprises do harvest berries, they mainly focus on raspberries, cranberries and blueberries. Other well-known native berries include the red elder (*Sambucus zacemosa L.*), black elder (*Sambucus nigra L.*), cranberry (*Vaccinius vitis idaea L.*), bird cherry (*Cerasus avium L. Moensch.*), cranberry *(Vaccinium myrtilus L.)*, dogwood (*Cornus mas L.*), hawthorn *(Crataegus oxyacantha L.)*, pear (*Pirus communis L.*), apple (*Malus silvestris /L./ MILL.*), strawberry (*Fragaria vesca L.*), rowan (*Sorbus sucuparia L.*), hazel (*Corylus avollana L.*), blackberry (*Rubus frutcosus L.*), raspberry (*Rubus idaeus L.*), rosehip (*Rosa canina L.*), sloe (*Prunus apinesa L.*).

Only forests without a protection regime can be harvested without restrictions. In these forests, it is possible to collect berries both for personal use and for commercial use. Harvesting should be carried out gently in order to maintain the quality of the product. Similarly, conditions should be maintained during harvesting, transport, storage and processing of the berries so that excessive deterioration of the product does not occur. Also, the time from harvesting to processing should be minimised, as berries are perishable - most are soft, easily squashed, release juice that quickly ferments, etc. It is best to pick berries at the beginning of the day when they are not overheated by the sun. Collect in large enough woven baskets made of natural materials or plastic - metal containers deteriorate the quality of the fruit. Use leak-proof plastic containers if the fruit you are picking is leaking juice.

Grochowski (1976) recommends that the following principles should be followed when harvesting and processing forest fruits:

- Careful handling of the fruit during harvesting,
- Take care to preserve the protective waxy layer of the fruit,
- Reduce the time from fruit picking to processing to a minimum,
- To ensure that the quality and nutritional value of forest fruits are maintained during harvesting, storage and transport,
- With appropriate technologies and quickly secure the processing and storage of fruits.

The quality of fruit is assessed on the basis of several quantitative characteristics such as nutritional properties (energy content, mineral content, vitamin content, etc.), sensory characteristics (appearance, taste, aroma) and the presence of anti-quality characteristics (presence of toxins, harmful substances, sensory defects). Shelf-life is demonstrated by the ability to maintain the balance of metabolism after harvesting. Fruits with a good shelf-life have a slow life cycle and ageing and death of the skin is more gradual. Disease resistance during storage is another important factor. This must be ensured by preventive measures to protect the crop from pathogens during harvesting, sorting, transport and storage. To prevent disease, it is necessary that the surface of the fruit is not mechanically damaged (Pražienková, 2012).

Table 4: Fruit storage

Type of fruit	**Storage time in h at temperature**		
	4 °C	**15 °C**	**20 °C**
Raspberries, strawberries	48	18	12
Blackberries	50	24	18
Plums	100	48	36
Sprouts, pears, viburnum	75	40	24
Apples on fire	300	170	100
Blueberries	75	40	24
Cranberries, currants	150	70	60

Source: Zvara et al., 1963

Most often, forest fruits are processed for food purposes, the primary processing into a semi-finished product may be drying, preservation with organic acids or biological treatment, or freezing. The resulting semi-finished product will then be (Lukáč, 1980):

- Fruit pulp - sorted, washed, de-stemmed or de-baked fruit covered with preservative brine,
- Pulp - steamed and pressed fruit, preserved with a preservative, or by increasing or decreasing the temperature,
- Succulent - the liquid portion of the fruit, usually obtained by pressing or extracting the juice, which is chemically preserved
- Frozen fruit - Freezing fruit is very convenient because it can be stored for a long time without the use of chemical preservatives.

7.1.1 Mushrooms

Mushrooms are also an important component of non-timber forest products that can be harvested in associated forest production. The body of the fungi is the stalk, which can be unicellular or multicellular, and is made up of overstretched, variously branched filaments called hyphae. The fine hyphae of the higher fungi form a thinner or denser tangle called a mycelium. Mycelium grows either in or on the substrate under suitable conditions. It draws nutrients from the substrate. The mycelium is the actual vegetative body of the fungus and under certain conditions forms fruiting bodies. The fruiting bodies are of different sizes, shapes and colours and are used for reproduction (they form spores). The spores are either unicellular or multicellular and vary in shape, colour and size.

Although mushrooms do not have a very high energy value (Table 10), they are not negligible in the human diet because they contain various substances that the human body needs for its normal functioning. These include various proteins, amino acids, vitamins, minerals and other trace elements (Table 11). In addition to their high water content, mushrooms also contain 5-30 % protein. This content depends on the age and type of mushroom. On the other hand, when harvesting mushrooms, care must be taken to select the right species, as many mushrooms have negative effects on humans (ranging from highly poisonous to those containing allergens that cause allergic reactions).

Table 5: Basic chemical composition of some fungi species

Name	Water in %	% on dry matter						Energy kj.kg^{-1}
		Crude protein	Fat	Coal-Wire	Nitrogen-free carbohydrates	Fibre	Ash	
Champagne	89,5	26,3	1,8	59,5	49,5	1,04	12,0	1444
Ear	89,1	4,2	8,3	82,8	63,0	19,8	4,7	1469
Dung beetle	92,2	25,4	3,3	58,8	51,5	7,3	12,5	1448
Shiitake	90,0	17,5	8,0	67,5	59,5	8,0	7,0	1620
Mushroom	90,8	30,4	2,2	57,6	48,9	8,7	9,8	1443
Truffle	77,1	23,3	2,2	66,2	383,	27,9	8,3	1138
Kukmak	88,4	30,1	6,4	50,9	39,0	11,9	12,6	1414
parasol mushroom	87,3	29,7	3,1	59,7	57,7	8,0	7,5	1515
Fox	91,4	21,5	5,0	64,9	53,7	11,2	8,6	1477
Bolete	84,0	20,4	3,6	69,0	62,1	6,9	7,0	1561

Source: (Ginterová, 1992)

Table 6: Amino acids in mushroom and mushroom protein expressed in mg per gram of adjusted protein nitrogen

Amino Acid	Mushrooms	Naked
Protein % in dry matter	24,3 - 34,8	21,6-30,4
Essential amino acids		
Lysine	357-527	250-326
Histidine	0-179	87-131
Arginine	268-529	258-419
Tryptophan	186-340	56-87
Phenylalanine	91-143	125-233
Methionine	41-126	11-97
Treonin	243-366	255-290
Leucin	329-580	275-610
Isoleucine	200-366	210-363
Valine	112-420	275-326

Source: (Ginterová, 1992)

When picking mushrooms, we take care to pick the mushrooms with the stem. Although cutting the mushrooms just above the ground is allowed for the smaller, well-known species, pulling the mushrooms out brings more benefits. Many signs can be observed on the caliper to correctly identify the mushroom found (Demko and Lukáč, 1990). The packages in which it is advisable to collect mushrooms are illustrated in Fig. 49. As far as subsequent processing is concerned, mushrooms are always processed fresh and, in almost all species, young, i.e. before botanical maturity. The mushrooms must then be properly chopped, which is important not only in terms of not burdening the digestive organs but also in terms of good utilisation of the contents.

If the mushrooms must be stored before processing, they must be stored in suitable conditions. Because of their structure, mushrooms easily absorb odours from the environment, so storage conditions include suitable packaging and respect for the rule that they are not stored with other odour-producing materials (Demko and Lukáč, 1990).

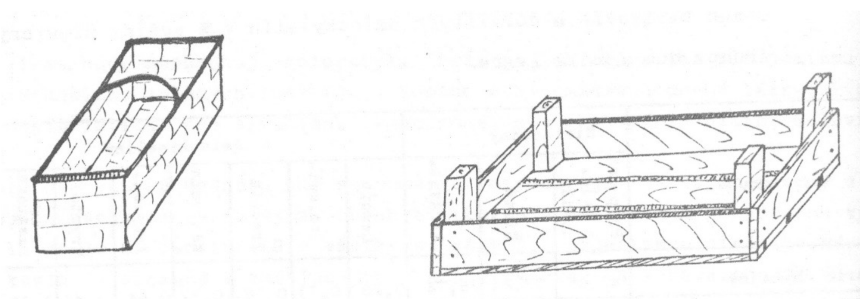

Figure 47: Suitable packaging for collecting and transporting mushrooms
1 - auricular basket, 2 - platon

Mushrooms for food purposes are processed mainly by drying, salting, preservation in organic acids, freezing or lactic fermentation. Drying is the oldest and most common method of preserving mushrooms. This method of preservation preserves the appearance, aroma, flavour and nutritional value compared to the fresh food reference. Drying is an attempt to remove the water from the mushroom, and can result in a decrease of about 70% in the water content of the food. For drying we use only fresh and mechanically or otherwise undamaged mushrooms. Before drying, we do not wash the mushrooms with water, but only clean them thoroughly and then cut them into slices. Salting is also a very old method of preserving food. If the salt concentration exceeds 12,5 %, the mushrooms will not be able to develop micro-organisms. However, salting alone does not stop the enzymatic processes, which, if the technological procedure is not followed, will shorten the shelf life of the mushrooms preserved in this way. In order to maximise the shelf life of salted mushrooms, the mushrooms must be baked before salting. This stops the enzymes and removes some of the water, which is also beneficial. Another popular way of preserving mushrooms is to sterilise them in brines, especially vinegar brines. Vinegar, creates a very acidic environment that is unsuitable for bacterial growth. It therefore acts as an excellent preservative. Other suitable brines are salty, sour, sweet and sour, or wine.

Figure 48: From left: dried mushrooms, salted mushrooms, lactic fermentation of mushrooms, pickling mushrooms in pickling brine
Source: Rankito, 2020; Mushrooms-Bigbadmole, 2023; RecipesOnline, 2023; Foreign Fork, 2021

7.1.2 Medicinal plants

In addition to their use in the food industry, non-timber forest products, mainly medicinal plants, but also mushrooms and berries, can also be used in natural medicine. The effects of medicines of natural origin are dealt with *in pharmacognosy*. In Europe, about 1 000 species of medicinal plants are known, of which about 800 are used in folk medicine and about 300 in official medicine. For the treatment of diseases, we can either use the whole plant or only the most effective parts. Furthermore, they can be used either directly for the treatment of diseases or as raw material for the preparation of medicines or for the isolation of pure active substances.

We rarely use medicinal plants in phytotherapy in their raw state. Most often, they are used in a dried state, which aims to keep the active substances stable for longer and prevent their decomposition. Of course, we can preserve these plants in other ways, but these often result in the isolation of the pure form of the active substance. By processing the medicinal plant, we create a so-called *drug*, which contains a mixture of chemically and therapeutically different substances. Which substances are present in the drug will then influence its overall effect on humans - in addition to the main active substance, there may be various secondary active substances in the drug that modify the effect. These ‚coefficients' may enhance or inhibit the effect of the main substance and may also affect the stability of the drug. Even natural drugs used in phytotherapy need to be used safely. The pharmacopoeia is used for this purpose, in which all official drugs are listed and must meet the various criteria set out in the pharmacopoeia or other standards for medicinal drugs.

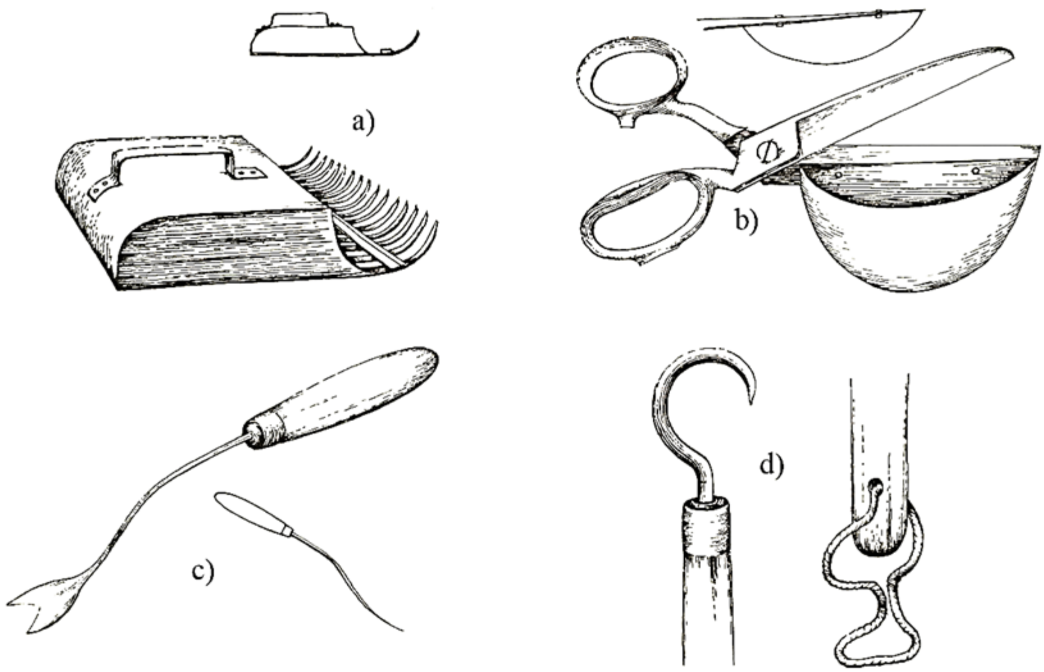

Figure 49: Tools for collecting medicinal plants
(a) comb, (b) scissors with trays, (c) rose petal cutter, (d) hook with loop
Source: (Kresánek, 1988).

The effectiveness of the drug depends on various factors - the time of collection, the place or method of collection. Clean, healthy and fresh material must be used to obtain the drug. Therefore, when collecting medicinal plants, we are careful to preserve the shape and consistency of the collected material. We never tear or squeeze the plants, but cut, cut, and place them in baskets and bags. We collect the plants in such a way that we use healthy, fresh, clean and flawless material to obtain the drug. If possible, we collect the different parts of the plants separately, and we also try to sort the different types of medicinal plants we collect as soon as they are collected. We leave some of the plants in the habitat to ensure reproduction and preservation of the species. After collection, we can proceed with the treatment of the medicinal plants, called *dressing*. The actual process of obtaining the drug can vary considerably from species to species, but some of the processes of dressing are common. For example, it is always advisable to remove organic and inorganic impurities (soil, dry leaves, stems, pest-infested plant parts, etc.) before preservation. Several authors have described in detail the possibilities of treating medicinal plants (Table 7), e.g. Kresánek (1988), Brabenec (1984), Thurzová et al. (1968), Habán (1996). Specific procedures depend on the amount of material and the technical equipment of the collectors or growers.

Table 7: Selected species, collection and processing characteristics of medicinal plants

Type of plant	Relationship to the current Pharmacopoeia	Collected part of the plant	Collection time	Drying and storage conditions of the drug
Contryhella *Alchemilla xantichlora Rothm.*	Redeemed	Flowering inflorescence or ground leaves	V.-IX.	Natural or artificial heat to 40 °C
Angelica officinalis *Archangelica officinális Hoffm.*	Redeemed	Root, stem, flowers, leaves, fruit	According to plant parts V.-IX.	Temperature up to 35 °C. Hermetically sealed container
Arnica shower *Arnica mongana L.*	Redeemed	Rootstock, leaves, stem, flowers	By plant parts spring - autumn	Dry with artificial heat 40-50 °C. Crown to 70 °C. Protect from light
Without black *Sambucus nigra L.*	Official (flower)	Flower with short stalk	V.-VII.	Temperature up to 45 °C Protect from light and moisture
Birch birch *Betula varrucosa Ehrh.*	Redeemed	Young sticky leaves.	IV.-V.	Temperature up to 35 °C. The drug is fragile and dries quickly.
Blueberry *Vaccinium myrtillus L.*	Official (fruits)	Fruits, young leaves	VII.-VIII.	Dry at a temperature of up to 40 °C. Store on $CaCO_3$
Fennel *Foeniculum vulgare Mill.*	Official	Fruits	2-3 times a year	Temperature up to 35 °C. Protect from light and moisture
Lily of the valley *Convallaria majalis L.*	Redeemed	Leaves, flowers, flowers	V.-VI.	Temperature up to 40 °C. Decomposes with moisture. Poisonous
Swallowtail greater *Cholidonius majus L.*	Official	Flowering young stem, root	III.-IX.	Temperature up to 35 °C. Protect from light and moisture. Poisonous.
Small-leaved lime tree *Tilia cordata Mill.*	Official	Young flowers	VI.-VII.	Temperature up to 35 °C. Beware of scalding.
St. John's wort *Hypericum perforatum L.*	Official	Flower, flower bud	V.-VIII.	Temperature up to 35 °C. Need to preserve the original colour
Ruler's bugle *Atropa bella-donna L.*	Official (sheets)	Leaves, root, stem	Gradually as they grow up	Temperature 50-60 °C. Leaves must be green. Poisonous.
Common thyme *Thymus vugaris L.*	Official	Flowering flower bud	V.-VI.	Temperature up to 35 °C. Silica drug
Peppermint *Mentha piperita L.*	Official	Nail before flowering	V.-VI.	Temperature up to 35 °C. Storage in two-litre paper bags
Wormwood *Artemisia absinthium L.*	Official	The tops of the flowers before flowering	VI.-VII.	Temperature up to 35 °C. Silica drug. Dries slowly
Chamomile true *Matricaria chamomilla*	Official	Flower	V. -IX.	Temperature up to 40 °C. No turning
St. John's wort *Platago lanceolata L.*	Official	Leaves at flowering time	V.-IX.	Temperature up to 40 °C. No turning
Licorice bald *Glycyrrhiza glabra L.*	Official	Root and outcrops	Spring, autumn	Temperature 35 °C. Well-sealed packaging
Clary sage *Salvia officinalis L.*	Official	Leaves, inflorescence before flowering	V.-VI.	Temperature 30-35 °C. Silica drug. Dries slowly
Valerian *Valeriana officianlis L.*	Official	Underground with roots	From autumn to spring	Temperature 35 °C. Silica drug. Protect well.
Stinging nettle *Urtica dioica L.*	Redeemed	Nail, leaves	Multiple times a year	Temperature 60 °C - dries quickly
Medical dandelion *Taraxucum officinale Web.*	Redeemed	Root	Autumn	Temperature 50 °C. We protect against rodents and insects

Source: Thurzová *et al.,* 1968

7.2 ZOOMASS

Zoomass (animal biomass) can be defined as the animal mass of individuals, populations, or other parts of a biocoenosis over a certain area (e.g. m^2 , ha, km^2) or space (litre, m^3 , etc.). One of the defined criteria of bioeconomy at EU level is food security and the related topic of edible non-timber forest products.

The forest is a place that provides mankind not only with wood but also with food. Many animals live there and they are often hunted. Hunting is a field of human activity that is constantly evolving in line with the development of society and the exploitation of nature. Most peoples have a long history of hunting, with subsistence being the primary goal in the past. Hunting activities in different countries have not only focused on mammals, but also on birds, fish, reptiles, and insects. In European countries, hunting is now not primarily for food security but is a tool for managing wildlife populations. In the context of forest-based associated production, fish farming can be included among the products of animal origin.

7.2.1 Wildlife and hunting in the Czech Republic

In the Czech Republic, game refers to populations of wild animals that are or have been important from the point of view of hunting. A comprehensive list of animal species whose wild populations are considered game is given in Section 2 of the Hunting Act No. 449/2001 Coll. The Hunting Act also distinguishes between game species that can and cannot be managed by hunting. The same law also defines game as a renewable natural resource. Hunting, of which game hunting is also a part, is a set of various activities carried out in the countryside in relation to wild game as part of the ecosystem, as well as an association activity aimed at maintaining and developing hunting traditions and customs as part of Czech national cultural heritage. Hunting is an integral part of landscape management. The users of hunting grounds make considerable efforts to create suitable living conditions for wild game species and to maintain game populations at optimum numbers. For small game, this is mainly a matter of encouraging and trying to increase numbers, and for cloven-hooved game species it is a matter of reducing them to a socially acceptable level, particularly in relation to damage to forestry and agriculture.

Game hunting in the Czech Republic

Game hunting is one of the activities carried out in the exercise of hunting rights and is part of game breeding. Game hunting may only be carried out in a manner consistent with the principles of hunting, nature conservation, and the principles of protection of animals against cruelty. The Hunting Act No 449/2001 Coll. defines prohibited hunting methods. Thus, in our country, hunting can be carried out by shooting, for the purpose of obtaining game, possibly also trophies and other economically important raw materials (e.g. skins), or by trapping, which serves to seize live game. The trend in the number of furbearers and game birds taken in the Czech Republic over the period 2012-2021 is shown in Figures 50 and 51. Game in the Czech Republic is kept and hunted in free hunting grounds (so-called *extensive game breeding*), but also in game preserves and pheasant farms (so-called *intensive game breeding*). However, intensive game breeding does not include game farms, as farmed game is considered to be livestock under the legislation. In 2022, there were 5 787 hunting areas in the Czech Republic, of which 201 were game preserves and 286 pheasant farms.

The total production of meat from hunted game in the Czech Republic in 2021 was 2 309 tonnes of deer, 997 tonnes of fallow deer, 250 tonnes of mouflon, 1 611 tonnes of roe deer, 11 545 tonnes of wild boar, 87 tonnes of hare, 357 tonnes of pheasant, and 167 tonnes of duck (mallard).

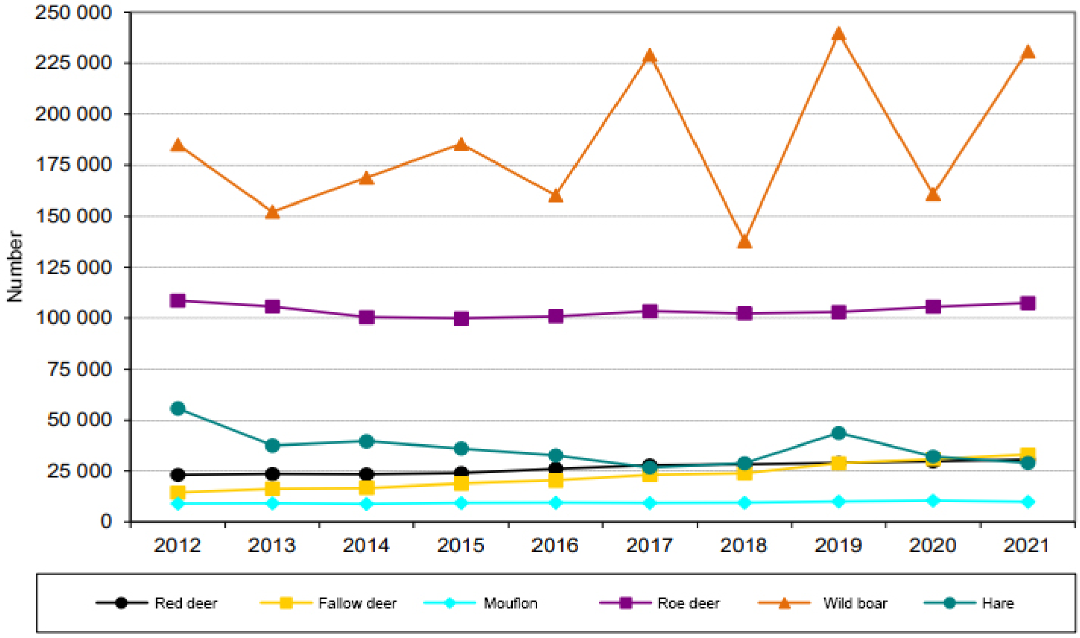

Figure 50: Evolution of the game harvest in the Czech Republic, 2012-2021
Source: CZSO, 2022.

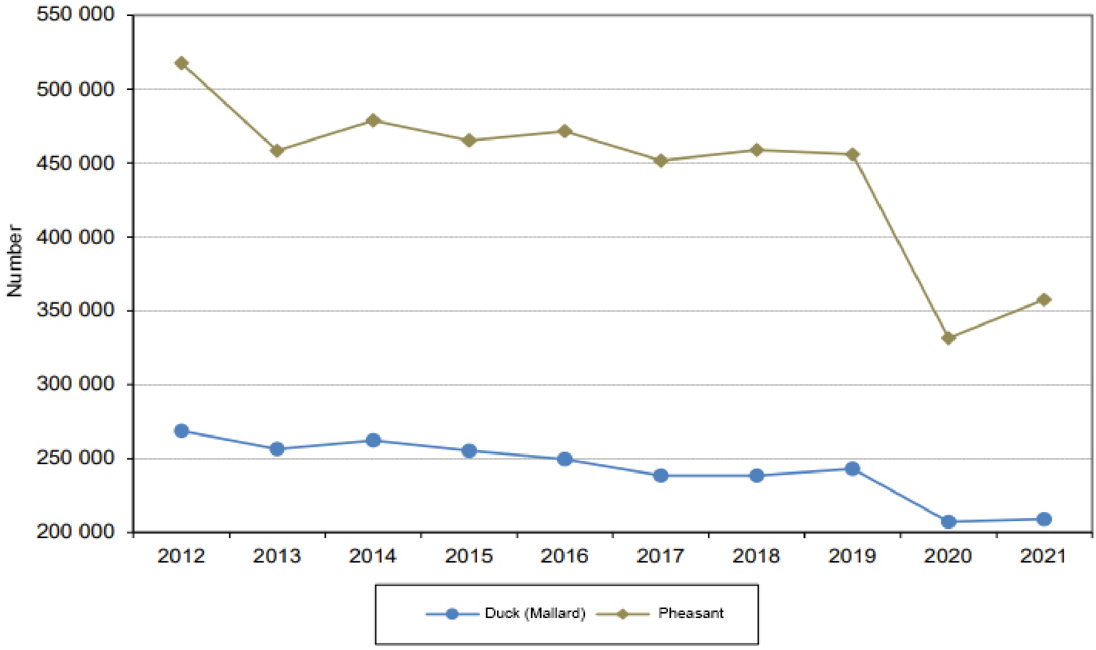

Figure 51: Evolution of game bird harvest in the Czech Republic, 2012-2021
Source: CZSO, 2022

Quality of game meat

As a product of game breeding, game meat is one of the highest quality foods. In its procurement, treatment, storage and processing, qualitative and quantitative losses must be eliminated as far as possible and all veterinary and hygiene rules for the handling of game meat as food for human consumption must be observed. Due to its composition, game meat is rightly one of the most nutritionally valuable foods as it is characterised by its high protein content and a very low fat content. However, this fat has a significant proportion of very valuable unsaturated fatty acids for humans. Game meat is considered to be a highly valuable food; hence its price is often higher. Game meat is also very well suited to dietary cuisine.

Other wild game products

In addition to meat, other animal by-products are also obtained from the processing of hunted game. These products can be, for example, hides, feathers, horns, and antlers. All these products can also find other uses in society, for example in the production of knife blades, clothing, or decorative items. Over 90,000 foxes, more than 11,000 martens, and almost 5,000 badgers were hunted in the Czech Republic in 2021. These hunted animals can thus represent a great potential for the use of their fur. This potential has also increased in view of the ban on breeding animals mainly for fur, which has been in force in the Czech Republic since February 2019.

7.2.2 Beekeeping

Beekeeping is perceived as a very important sector in the field of agriculture, but also in forestry. Honey bees provide pollination of insect-bearing plants and play a very important role in maintaining the biodiversity of the landscape in natural ecosystems. Bee keeping is an important and irreplaceable contribution to society as a whole. The contribution of this sector is often compared to the yield from the sale of honey. However, these values are incommensurable and incompatible, especially in terms of the benefits of pollination and the overall importance to society. The production of honey and bee products is only a small part of the importance of beekeeping as such. Bees produce biologically valuable and beneficial substances – honey, pollen, propolis, royal jelly, bee venom, and wax. Within the European Union, the benefits of beekeeping to society are estimated at EUR 14.2 billion per year. At the same time, it is important to remember that 84% of plant species and 76% of food production depend on bee pollination. Beekeeping makes a major contribution to promoting economic stability, maintaining ecological balance in the landscape, and protecting biodiversity. One of the factors adversely affecting Czech beekeeping is the relatively low consumption of bee products, especially honey. In the Czech Republic, honey consumption is around 0.9 kg per capita per year. Honey production has not changed significantly in recent years, reaching around 8 000-9 000 tonnes per year. The plant colouring agents contained in the sap of woody plants cause honey obtained from pollination of woody plants to be darker than honey obtained from the flowers of meadow plants. In 2020, 64 105 beekeepers with 694 086 hives were registered in the Czech Republic (MoA, 2022).

7.2.3 Consumption of insects

Insects can generally be included among forest zoomasses with food provisioning potential. These have historically been considered as food in many areas of the world. In Europe, the consumption of insects is uncommon, but recently interest in edible insects has been growing among both consumers and food producers. According to Regulation (EC) No 2283/2015, insects can be considered as a new type of food from 1 January 2018. However, edible insects are still rarely used in the European food industry and the potential microbiological, chemical, and physical risks associated with the use of insects in food production have therefore not all been sufficiently investigated. Facilities for rearing insects as food or feed must comply with the relevant regulations applicable to the rearing of livestock. These include controlled rearing and feeding conditions that prevent microbial and chemical contamination. For this reason, the importance of insects as food produced from forests cannot yet be realistically considered.

Chapter Summary

From the above, it can be seen that timber, or dendro-mass, is not the only forest product we can use. Forest enterprises have various options for securing yields, for example through associated forest production from non--timber forest products. It is clear from the term ‚associated forest production' itself that the yields achieved in this way will not be equal to those from timber sales,; but, on the other hand, this production can help enterprises to bridge periods of lower harvesting volumes. From the point of view of the forest bioeconomy, it is desirable to replace mineral (fossil) resources with renewable biological resources wherever possible. Phototherapy is one of the ways of replacing these resources in the pharmaceutical sector.

Zoomass, or animal biomass, is made up of animals in the forest environment. Some of them have been hunted for a very long time all over the world. In our country, we obtain zoomass from forest stands most often as game hunted under the Hunting Act, and also in the form of fish or bees. From hunted game we obtain a very high-quality product in the form of meat from hunted game. In 2021, for example, we obtained 11 545 tonnes of meat from wild boar hunting alone. Other animal products such as fur, horns, and antlers can also be used from hunted game. Bee keeping is also closely linked to forestry and the role of bees for the landscape and for people is irreplaceable. Within the European Union, the benefits of beekeeping to society are estimated at €14.2 billion per year. On average, 8 000-9 000 tonnes of honey are produced in the Czech Republic each year. The topic of edible insects is also currently being addressed globally. However, due to the current conditions for the production of insects as food, this animal product cannot yet be counted on in the forestry sector.

Control questions

1. What are non-timber forest products?
2. What types of non-timber forest products can be used in associated forest production?
3. In which forests can we fully exploit the potential of berry production?
4. How can coefficients influence the effects of a drug?
5. How can we process medicinal plants if we want to use them in phytotherapy?
6. What all can be included in the zoomass we use in forest management?
7. What is the average amount of game meat produced annually in the Czech Republic (main game species)?

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8 ELEMENTS OF CIRCULARITY, BIOMASS CASCADING

The aim of the chapter is to present information on the circular economy and the relationship between the circular economy and the bioeconomy. Another aim is to provide information on the principle and benefits of the cascade and to place this information in the context of the current socio-economic situation in the Czech Republic.

Keywords: circularity, biomass, energy, cascade, waste

8.1 CIRCULARITY

Circularity is a term most often encountered in the literature in direct connection with economy or economics. Circular economics is a school of thought, one of the currents in economics; Circular economics is a relatively new concept, encountered since the beginning of the 21st century. The main impetus for its development has been the spread of environmental ideas and ecological approaches, in close connection with the problems associated with the sustainability of consumption in the future, as well as with the issue of waste management. However, the principles to which circular economy refers have a much broader historical context. For example, as early as the 18th century, Thomas Malhus addressed the unsustainability of consumption in the context of a growing population.

Circular economics is based on the theoretical construct of efficient use of raw materials and the creation of qualitatively new production cycles. It is about replacing *linear* production chains (in which raw materials are used to produce a product and then waste) with *circular* chains, which ensure the circulation of materials already used and their return to production; there is a change of view on the production of waste, which should be minimised not only at the end of the product life cycle, but also during the product life cycle itself. The so-called *cradle to grave* principle is to be replaced by the *cradle to cradle* principle (Kislingerová et al., 2021). The product life cycle itself represents the ‚life' of a product from the extraction of raw materials to its removal from the system. Often, the environmental impacts/impacts of a product are assessed, and it is in this context that product development stages are assessed - the environmental assessment of the development stages of a future product is already included. In this context, we are talking about the so-called *LCA analysis* (Life Cycle Assessment, which is also linked to ISO standards related to environmental management, specifically ISO 14040).

It is clear that a complete circular system does not exist, but a circular approach can effectively mitigate environmental impacts while reflecting an economic and social approach that reflects societal change. In a circular economy, energy losses are also reduced and should ideally be zero again.

Circular economy and economics are closely related to the public or global interest. It is also one of the transformative policies of *the European Green Deal,* where the circular economy is intended to help meet the goal of carbon neutrality. At European level, so-called Circular Economy Packages have also been adopted in the past - the first focusing mainly on waste issues, the second focusing on the whole life cycle. For example, directives and issues related to waste, landfill etc. are also related to circularity.

In order to talk about a circular approach, Maitre-Ekern (2017) points out the conditions to be met. These are:

- *Holistic approach* (product life cycle in the long term)
- *Durability and repairability* (material used, availability of spare parts and transport options)
- *Creating loops* (resale, recycling)
- *Consumer Involvement*

At the company level, circularity can be measured using various indicators, which can include, for example, *recycling, waste management, reuse, resource efficiency*, etc. (Kristensen, Mosgaard, 2020). At the same time, companies' approaches to environmental issues are often under the scrutiny of customers (consumers), whose behaviour often puts pressure on companies. A responsible approach to environmental protection is often part of companies' promotional activities, and can also represent an interesting competitive advantage and a guide for consumers when deciding which manufacturer to prefer.

The new Circular Economy Action Plan - A Cleaner and More Competitive Europe (EC, 2020) states in its Introduction that there will be a huge increase in consumption by 2050 (double in the case of biomass - see the *OECD/Global Material Resources Outlook to 2060* report *of 2018)* and annual waste production is expected to increase by 70% by the same period (see the World Bank's 2018 report *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*). This information logically results in efforts to find ways to address the situation as effectively as possible. In this context, the projections seem unsustainable with a major negative impact on future generations. New ways of responding to the situation are therefore being sought. One way is to increase the use of renewable resources, another is to increase recycling and to try to extend the lifetime of products. The review also looks at disposal and how to find more environmentally friendly ways of dealing with products once they have lost their functionality. The circular or circular economy is closely related to this.

Circularity and waste management

The issue of waste generation is one of the key areas of the circular economy. In May 2022, the Czech Republic updated its *Waste Management Plan for the years 2015 to 2024* (with a view to 2035). There are four main objectives, one of which is the *transition to a circular economy, followed* by *waste prevention, increased recycling and material recovery* (MoE, 2022).

The website of the Ministry of the Environment provides summary data on waste management, as well as, for example, waste management indicators. Each inhabitant of the Czech Republic produces more than 0.5 tonnes of municipal waste per year and almost 3.5 tonnes of waste in total. In the last three years (2018 to 2020), waste production per capita has remained almost constant; from a regional perspective, the Central Bohemian Region, the capital city of Prague and the South Moravian Region produce the most waste. For municipal waste, the Central Bohemian Region is again in first place, followed by the Moravian-Silesian Region and the Capital City of Prague in third place (MoE, 2022).

Circular economy and bioeconomy

Often discussed is the relationship between the circular economy and the bioeconomy. The view on their interrelationship depends mainly on the approach of a particular author. Either the circular economy can be linked to the recycling of raw materials and thus, together with the bioeconomy (in this approach, the bioeconomy is the replacement of fossil fuels with renewable resources) and the green economy (synonymous with a low-carbon strategy), it is a relatively separate concept. Another approach views the bioeconomy as a superstructure of the circular economy (Nova Institute, 2016).

Biomass and bioeconomy, circular economy

Hetemäki (2017) defines the bioeconomy as the renewable use of biomass and its conversion into materials, products and services. Therefore, biomass has a very important role in the bioeconomy (and circular economy).

Biomass has already been mentioned in previous chapters of the text; for the sake of completeness, here is the official definition - *„biomass is the biodegradable part of products, wastes and residues from agriculture (including plant and animal matter), forestry and related industries, as well as the biodegradable part of industrial and municipal waste (EU, 2001)".*

In addition to the terms mentioned in the previous chapters (phytomass, dendromass, zoomass), biomass can be divided into - *biomass grown for energy purposes* (e.g. fast-growing woody plants, such as poplars, willows, alders, etc.). However, it is also possible to find another (further) division of biomass - according to its water content into: *dry* (wood, wood residues), *wet* (wet; e.g. sewage), *special*.

Combustion is the most common method for obtaining energy from biomass, but there are other options such as liquefaction, gasification, fermentation, etc. The energy use of woody biomass is discussed in Chapter 6.4.

8.2 CASCADING BIOMASS UTILISATION

Biomass cascading is „*any resource-efficient and circular use of biomass*“ (EU, 2019). Specifically, it refers to cascading use in sectors that depend on forestry (i.e. wood processing, pulp and paper, biorefineries). However, other sectors also use woody biomass as a feedstock (e.g. chemical industry).

We‘ve been talking about cascading since the 1970s, especially with addressing environmental impacts and non-renewable raw materials. However, these were mainly linear approaches (e.g. logs -> construction timber + by-products and energy), which could subsequently be developed and replaced by more advanced approaches thanks to technological developments that significantly advanced the possibilities to process inputs (resources) more efficiently, but also to deal with waste issues in a different, qualitatively better way. In recent years, the European Commission has published several studies related to the issue of cascade recovery, namely (EU, 2019):

- *European* Wood (2010) on wood flows;
- *Indufor* (Study on the availability of biomass in the EU and the competitiveness of EU forest-based industries), published in 2014;
- Cascades - Study on optimized cascade wood utilization (2016).

The documents published are part of an overall approach to addressing non-renewable resources, in the fields of environment, agriculture, forestry, energy, climate change and research.

Cascading use is based on principles (EU, 2019):

- **Sustainability.** This principle is about balancing all aspects - environmental, economic and social - in the long term. Cascade use helps to meet the Sustainable Development Goals (specifically Goals 8, 12, 13 and 15), which are the creation of new economic opportunities, more sustainable use of biomass, and the retention of carbon storing biomass. Cascading increases the availability of renewable materials, thereby reducing the consumption of fossil fuel-based products. Increased material processing and energy production and distribution, including recycling, reduces emissions.
- **Resource efficiency**, where, among other things, the main and secondary biomass flows are utilised, waste production is reduced, and innovative uses are sought,
- **Circularity,** which is also related to the actual planning of the product life cycle with regard to the efficient sourcing of raw materials or material mix. Consumer awareness and willingness to accept new products and information about them also play a major role. The setting up of local, regional and international markets for trading raw materials and products is also related to circularity.
- **New products and new markets.** In particular, the use of woody biomass in high value-added products and new markets is promoted, in line with demand promotion and market transparency. It cannot be overlooked that, for example, demand as such is closely linked to consumer awareness (see above), which puts pressure on producers to produce products that are sustainable (see Principle 1 - Sustainability), while consumers themselves must be convinced of the benefits of such products.
- **Subsidiarity.** The principle of subsidiarity is well known, especially in the context of political decisions, and is directly one of the principles of the functioning of the European Union under the Maastricht Treaty . The principle generally means that decisions are to be taken at the lowest possible level (as close to the citizens as possible - assigning decision-making powers to municipalities and regions) so that decision-making power is in the hands of those who have relevant and comprehensive information on the issue at hand. Cascading is about respecting national, regional and local contexts, as materials are viewed differently according to the availability, processing capacity and distance of markets in a given location (country), which affects the allocation of biomass and the possibilities for its use, including for energy purposes.

Thus, cascading leads to the conservation of fossil resources, reduces greenhouse gas emissions and leads to greater efficiency in resource use, thereby leading to higher value creation. On the other hand, it should be noted that cascading requires relatively demanding logistical processes and a relatively complex network/connection of actors. The timber cascade serves to ensure a longer value chain so that first the raw material is used for higher value-added products (e.g. building materials) and finally for energy production.

The cascades by product type (pulp, construction timber, timber houses, etc.) are illustrated with concrete examples in the publication *Guidelines for biomass cascading with selected examples of best practices in the context of woody biomass - EU, 2019.* These include the use of wood residues (biochar), wood fuels with higher energy efficiency and lower emissions, wood biomass textiles, chemicals and biofuels based on hemicellulose, etc. More information on specific examples is available in the subject publication.

In the *National Forest Policy Concept 2035 (NFPC)*, the data presented are taken from NIL 2 (2011-2015), and relate to biomass and carbon information. This information can be considered with regard to the potential for biomass use in the country (see Figure 54 for more details). Support for the development and promotion of biomass, biogas and biomethane use in the Czech Republic is provided by the Czech Biomass Association (CZ BIOM).

As a regulatory instrument, the NFPC directly mentions the Forest Act („*to regulate biomass extraction in such a way that it does not endanger the state of forest ecosystems“)* and it is a tool to achieve the so-called long-term objective B, which is aimed at increasing the ecological stability of forest ecosystems (for more details, see NFPC; MoA, 2020).

Renewable energy sources

The use of biomass is part of the publications of the Ministry of Industry and Trade, which since 2003 has been publishing reports on renewable energy sources (*Renewable Energy Sources - Results of Statistical Surveys)*, where it focuses not only on the share of renewable energy sources in the energy balance of the Czech Republic, but also directly on the energy use of biomass. The most report from 2021 (published in October 2022), reports that gross electricity generation from renewable energy sources accounted for 12.6% of total electricity generation (MIT, 2022). The breakdown of electricity generation from renewable sources, including the breakdown by category of biomass is included in this report.

Renewable energy includes water, wind, solar, solid biomass and biogas, geothermal, ambient and liquid biofuels. A document called the *Biomass Action Plan for the Czech Republic (2012-2020)* was also in force until 2020.

The report also contains other information clearly published in the form of tables and graphs, including time series. At the European level, reference can be made to the European Commission website (EC, 2022), which presents data on biomass in the EU (Infographics on biomass sources and uses in the EU-27).

Summary

Circularity is associated with the efficient use of raw materials and the replacement of linear production chains to eliminate waste. Circularity is both linked to sustainability and closely linked to the bioeconomy. Of particular relevance to the forest bioeconomy is biomass that is either intentionally grown or that is waste. Biomass is also an important energy source. Cascading biomass use is the use of biomass in sectors that depend on forestry (e.g. wood or paper industry, energy industry, etc.).

Control questions:

1. Describe the circular economy and state the principles on which it is based.
2. Describe the principle of cascading and state the advantages of cascading.
3. Evaluate the role of biomass and RES in the Czech Republic.

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9 BIOECONOMY AS PART OF ECONOMIC STRATEGY

The aim of the chapter is to introduce the main bioeconomy strategies and related documents to provide an overview of the development of concepts in this area, the current status and future developments.

Keywords: bioeconomy, strategy, concept, action plan

9.1 OECD STRATEGY

The OECD strategy describes the current state of play and possible future developments. It includes institutional and societal measures to support the bioeconomy. These include:

- public research,
- regulation,
- intellectual property rights,
- social attitudes.

The next section focuses on entrepreneurship in the emerging bioeconomy. It includes current business models for biotechnology and emerging business models in biotechnology. It also includes scenarios for 2030 and suggested policies to achieve the goals.

Some policy approaches and tools for the emerging bioeconomy are listed below:

- **Research grants**. Use of public resources to generate knowledge inputs such as private and public sector R&D and human resources through training of researchers, scientists, technicians, etc. This could include mission-oriented research as well as support for specific technology and multidisciplinary research.
- **Market creation**. Putting in place an incentive structure that could include other things, procurement guidelines, production subsidies, price incentives, trade barriers (either setting them up or removing them), and competition policies.
- **Regulations/standards**. Safety mandates, product registration, advertising, environmental mandates (e.g. tradable carbon markets, life cycle assessment), etc. It can also be a market making tool.
- **Infrastructure investment**. Creates the basic framework for systems such as public healthcare, collaborative science, databases, transport, energy generation and distribution, etc.
- **Search research**. It maps the links between evolving research agendas (including focused and multidisciplinary research), regulatory frameworks, policy initiatives and the development of new technologies.
- **Public forums**. Develops public discussion, debate and education on issues such as the ethics, benefits and risks and utility of biotechnology.
- **Development commitments**. Provides financial and other support (technology transfer, university-to-university cooperation, etc.) to developing countries. This instrument includes initiatives such as the UN Millennium Development Goals.

9.2 EUROPEAN TECHNOLOGY PLATFORMS

Overview of European Technology Platforms (ETPs) active in the bioeconomy:

a) Plants for Future (focusing on plant genomics and biotechnology);

b) Forestry (forest-based platform);

c) Sustainable Chemistry (covers industrial biotechnology, the pursuit of sustainable development of chemistry);

d) Food for Life (food that supports human health);

e) Farm Animal Breeding (platform for animal breeding and reproduction);

f) Global Animal Health;

g) Biofuels.

European companies are increasingly addressing the need to create an economy based on bio-based materials.

9.3 STRATEGY AND ACTION PLAN FOR A SUSTAINABLE BIOECONOMY

The European Bioeconomy Strategy was adopted in 2012. The Europe 2020 strategy considers the bioeconomy as a key element of smart and green growth in Europe. The bioeconomy and its action plan aim to pave the way for a more innovative and efficient use of resources. A competitive society should reconcile food security with the sustainable use of renewable resources for industrial and environmental purposes. Information on research and innovation programmes in the bioeconomy sectors will be important, contributing to a more coherent policy environment, better linking national, European and global policies on biotechnology, including increased public dialogue. They will seek synergies and respect complementarities with other policy areas, instruments and funding sources that share and address the same objectives, such as the Common Agricultural and Fisheries Policies (CAP and CFP), the Integrated Maritime Policy (IMP), environment, industry, employment, energy and health.

A new strategy and action plan for a sustainable bioeconomy, „Innovating for Sustainable Growth: a Bioeconomy for Europe", was published in 2012. The strategy aims to contribute to the development of an economy based on reduced emissions, sustainable agriculture and fisheries, contributing to food security and the sustainable use of renewable bio-resources for industry. The European Union is well placed - unlike the US, it has diverse plant resources and can produce many different types of bio-based materials.

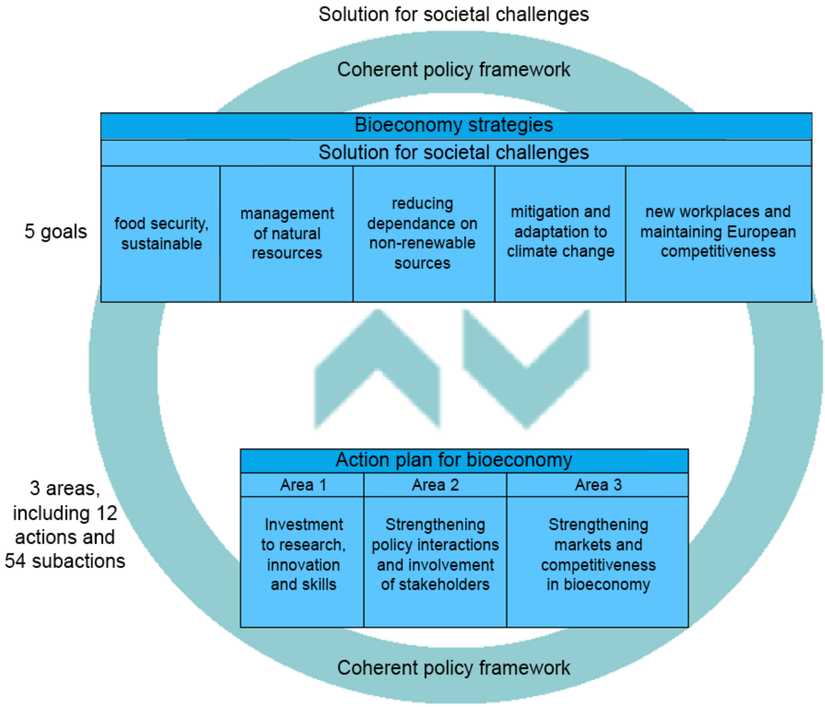

Figure 52: Illustration of the structure of the 2012 Biotechnology Strategy and Action Plan
Source: EC, 2017b

In terms of innovation, the bioeconomy strategy should focus more on how to improve productivity and logistics, including streamlining import tariffs. Customs policy should ensure the competitiveness of the European bio-industry (especially against cheaper imported products). Research should also be targeted at innovation programmes and demonstration activities. Partnerships between public institutions and private companies should be used to finance pioneering bio-based production facilities. The bioeconomy is currently being discussed in Brussels as an interplay between agricultural policy and policies in other economic sectors. A European Innovation Partnership Programme is established, which applies to agriculture as well as to other directorates in the EU. In agriculture, it is required to make the sector „productive and sustainable", to be found through collaboration between science and practice. Industry is expected to enter massively into this process.

9.4 UPDATED BIOECONOMY STRATEGY

In 2018, an updated Bioeconomy Strategy was adopted under the title A sustainable bioeconomy for Europe: strengthening the link between economy, society and environment. This document focuses, among other things, on how the bioeconomy contributes to EU priorities:

- Sustainability (Sustainable Development Goals)
- new job opportunities
- the climate goals of the Paris Convention
- modernisation and strengthening of industry (new value chains, more environmentally friendly and cost-effective industrial processes)
- renewable part of the circular economy (reduce food waste by 50% in 2030)
- promoting healthier ecosystems (plastic-free seas and oceans)
- stopping land degradation by 2030.

It was also noted that the five objectives of the 2012 Bioeconomy Strategy remain valid:

1. ensuring food and nutrition safety
2. sustainable management of natural resources
3. reducing dependence on non-renewable, unsustainable resources, whether they come from within the country or from abroad
4. mitigating and adapting to climate change
5. boosting European competitiveness and creating new jobs.

This strategy was linked to the circular economy. It includes actions towards a sustainable, circular economy:

1. Strengthen and expand biotechnology-based industries, access to investment and markets
2. rapidly expand the local bioeconomy across Europe
3. understand the ecological limits of the bioeconomy.

9.5 CHALLENGES OF THE BIOECONOMY

Specific objective: availability of safe and high quality food and bio-products, development of primary production systems using existing resources efficiently, strengthening of related ecosystem services. Also accelerating the transition towards a sustainable European bio-economy. World population of 9 billion in 2050, food needs expected to increase by 70%, agriculture's share of greenhouse gas emissions 10% (EU), global increase in emissions from agriculture up to 20% by 2030. Bio-waste - 138 million tonnes/year in the EU (40% will end up in landfill), 30% of food production in developed countries will end up as waste. Agriculture, forestry and fisheries and related bio-industries are the main sectors on which the European bio-economy is developing (20 million jobs).

Sustainable agriculture and forestry requires more efficient production, climate change mitigation, sustainability, increased productivity, adaptation of plants, animals and production systems to a changing environment and climate through lower energy consumption and less waste, less emissions - food security - use of biomass and by-products from agriculture and forestry for non-food products, higher yields of plants, animals, micro-organisms with more efficient use of water, nutrients, energy, also diversity of production systems (conventional, organic farming), conventional and modern breeding methods, better use of genetic resources.

Soil management, soil fertility, plant and animal health, integrated plant protection, animal diseases including zoonoses, antimicrobial resistance and basic research on relevant biological issues. Sustainable agriculture and forestry will focus on ecosystem services and public goods, cultural and recreational values, erosion reduction, carbon sequestration, greenhouse gas reduction, management tools, decision making, non-market value assessment.

Support to rural areas, policies, innovation for rural areas - new products, diversification of production (food, feed, materials, energy), socio-economic research, prevention of social and economic marginalisation of rural areas, knowledge exchange, participatory resource management, analytical tools, indicators, models, forecasts, data, monitoring and evaluation of strategies and policies.

Another focus is a sustainable and competitive agri-food sector and safe and healthy food. Informed consumer, consumer preferences, needs, behaviour, lifestyle, quality of life, impact on production. Healthy and safe food - nutritional needs, impact of nutrition on physiological functions, physical and mental performance. Also relationship of diet, ageing, chronic diseases (improving health through diet). Chemical and microbial contamination, risk and communication, food safety and improving standards. Sustainable and competitive agri-food industry - adaptation to change (social, environmental…), processing, packaging, process control, waste reduction, by-product recovery, product availability and quality, traceability, logistics, services, environmental impacts.

The focus is on the potential of aquatic living resources (aquaculture). Sustainable and environmentally sound fisheries, ecosystem approaches in fisheries, understanding marine ecosystems, ecosystem impacts of fisheries, socio-economic impacts, adaptation to environmental conditions, research on fish stocks are the basis. There is a need to create competitive European aquaculture, diversification, new species, interaction with the ecosystem, adaptation of the sector to climate change, innovation of production systems, social and economic dimension and orientation towards consumer demand. Marine biotechnology is very promising - harnessing the potential of marine biodiversity and biomass for new products, processes and services, applications in industry (fisheries, chemistry, pharmaceuticals, materials, cosmetics, energy ...).

The strengthening of the bioeconomy for the bioindustry can be seen in the use of terrestrial and aquatic biological resources, minimization of environmental side effects, development of bioproducts, biologically active substances with new properties, valorization of renewable resources, bio-waste and by-products. The development of integrated biorefineries with emphasis on the production of higher value-added products, strategies to ensure sufficient sources of raw materials, the expansion of biomass types for use in second and third generation biorefineries (bio-waste, industrial by-products). Development of markets for bio-based products and processes, standardisation (bio-based content, functionality, biodegradability), methodologies for life cycle assessment.

9.6 FUTURE DEVELOPMENTS

Global developments are expected to support the transformation of the economy towards a sustainable bio-economy based on the use of renewable raw materials. The bio-economy will not be a new industry, but rather a combination of forestry, chemicals, energy and buildings etc. Opportunities require renewal: new products and solutions to meet new needs, created through new inter-company partnerships. The EU and Member States share a common vision of the need for a bio-economy and circular economy. The expected developments in the timeframe corresponding to the Bioeconomy for Europe strategy are shown in Table 8.

Tab. 8. Summary of comparative economic impacts of scenarios in 2025

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Value added (bioeconomy only) in %	- 0,27 %	+ 0,61 %	+ 0,14 %	+ 0,75 %
Added value (bioeconomy only)	- EUR 4 billion	EUR 9 billion	EUR 2.4 billion	EUR 11.4 billion
Employment	×	+ 120 000	+ 11 000	+ 131 000

Source.

9.7 BIOECONOMY DEVELOPMENT STRATEGY IN THE CZECH REPUBLIC

The Czech Republic does not yet have a national bioeconomy strategy. It is generally contained in the Strategic Framework Czech Republic 2030:

- The economy of the Czech Republic is purposefully reducing its material and energy intensity. Economic growth is built on entrepreneurship, innovation, human creativity, higher value-added industries, a circular economy, a low-carbon profile, robotics and digitalisation. It is based on the principles of the social market economy, which is characterised by cooperation and coordination between the public, business and non-profit sectors.
- Agriculture, forestry and water management ensure quality and reliable production that takes account of natural limits and global climate change - improving soils, slowing water runoff from the landscape and helping to maintain biodiversity.
- Responsible use of the territory creates conditions for balanced and harmonious development of municipalities and regions, which leads to increasing territorial cohesion and ensuring all functions of settlements necessary for maintaining and improving the quality of life of their inhabitants. Settlements are adapted to climate change.

The chapter „Ecosystems“ contains:

- The ecosystem of the landscape enables the production of food, fodder and industrial crops, timber, non-timber forest products or meat from grazing domestic animals. It regulates air quality, climate, runoff and water quality, erosion, disease vector populations, waste flows and excessive nutrient inputs. More generally, it supports the life cycles of organisms, helps maintain genetic diversity and ensures nutrient cycling and soil formation. But it also creates conditions for recreation and tourism, has aesthetic values, creates cultural heritage and a sense of place, is important for scientific research and education, and can have spiritual and religious significance.
- The cause of forest soil erosion is bare-soil farming and the use of heavy machinery in harvesting and harvesting timber. The forests are also not left with sufficient wood for thinning - including logging residues, which are also removed from the forest. This, together with the over-cultivation of conifers, causes acidification and nutrient depletion of forest soils.

The strategic objectives for ecosystems include:

1. Establish a landscape policy and rules for its implementation, strengthening the protection of the value of the landscape as a complex ecosystem and its ecosystem services.
2. Increase the diversity and stability of habitats and populations of individual biological species in the landscape.
3. Improve the water regime, in particular to slow down water runoff from the landscape and improve water quality.
4. Strengthen soil protection from degradation and exploit the potential of landscapes to capture and store carbon and adapt to climate change.
5. Create conditions for greater use of domestic agricultural production and timber.

Strategy of the Ministry of Agriculture of the Czech Republic with a view to 2030 - Forestry:

- The basic goal of the state in the field of forestry is sustainable forest management, i.e. the management and use of forests and forest land in such a way and to such an extent that preserves and improves their biodiversity, production capacity and regeneration capacity, vitality and ability to perform currently and in the future the appropriate ecological, economic and social functions at the local, national and global level and which do not damage other ecosystems.
- The MoE takes into account the National Forestry Programme in its decision-making in the field of forestry, especially as regards economically, socially and environmentally oriented measures in forestry.
- The issue of the gene pool of forest tree reproductive material is addressed in the National Programme for the Protection and Reproduction of the Gene Pool of Forest Tree Species, which was announced by the Ministry of Agriculture for the period 2014-2018.
- In the new strategy of the Ministry of the Environment, the strategic priority of the forestry sector will be to create conditions for increasing the competitiveness and viability of the entire forest-based value chain and the domestic use and consumption of wood.
- The outputs of the National Forest Inventory will be essential for the direction of forest management and forestry policy in general. The second cycle of the inventory took place in 2011-2015.

Strategy of the Ministry of Agriculture of the Czech Republic with a view to 2030 - Forestry - strategic objectives:

- The main strategic priority is to increase the competitiveness and viability of the entire value chain while maintaining the principles of sustainable forest management, i.e. to create conditions for increasing the competitiveness and viability of the entire value chain based on forestry and domestic use and consumption of timber, as well as to create conditions for optimal provision of forest ecosystem services and ensuring the sustainability of forest functions in an evolving climate.
- As part of this, it is essential to ensure that all forests are managed according to the principles of sustainable forest management and that forestry and the entire downstream value chain are competitive and viable contributors to the bioeconomy and green economy (see text below).

Sustainable management of forests with continuous improvement of their condition includes the following points:

- Conservation and sustainable use of forest land.
- Protection of forest soils, water and other natural resources.
- Addressing stand dieback due to drought and subsequently fungal pathogens and insect pests.
- Conservation and reproduction of the forest tree gene pool.
- Based on the results of the second cycle of NIL, assess the state of forests in the Czech Republic and their potential to provide various products and services in a way that does not disturb the balance and ensures forest protection.
- After the completion of ecclesiastical restitution and the restoration of fragmented forest tenure, including state-owned forests.
- Outreach and education.
- Intensify the introduction of R&D results into forestry operations - especially through state-owned forest management institutions.

The competitiveness of the forest-based value chain includes the following important challenges:

- Create conditions for increased domestic use and consumption of wood and wood products.
- Remove unjustified barriers arising from legislation and technical standards that prevent greater use of wood.
- Consider changes to tax and other regulations that would favour wood as a building material.
- To strengthen the competitiveness of producers of forest tree planting material.
- Create the conditions for investment in the forestry sector and downstream value chains that will lead to the production of higher value-added wood products.
- Strengthen the competitiveness of all interest groups, including trades, along the entire forest-based value chain.
- Reduce timber exports from the Czech Republic.
- Promote research and development aimed at better use of wood and the search for new product options using wood.

The principles of state forestry policy can also be considered as principles of forestry bioeconomy (Government Resolution No. 854 of 21 November 2012):

Preamble:

1. Forests and forest land are the natural wealth of the Czech Republic, a source of wood as a renewable raw material and an irreplaceable component of the environment.
2. Forests are essential for the protection of soil, water, air and climate, for rural development and forestry performance, and for the landscape and the environment of people, animals and plants. Forests must therefore be managed and managed so that they can fulfil all these protective, economic and social roles in an equitable and sustainable manner.

General background:

1. The Czech Republic, in accordance with its obligations under international law and its membership of the European Union, strives to ensure sustainable forest management, i.e. the management and management of forests and forest land in a manner and to an extent that preserves their biodiversity, productive capacity and regenerative capacity, vitality and ability to perform in the present and in the future, and which do not harm other ecosystems.
2. The Czech Republic strives to preserve the proportion of forests left to develop spontaneously, where all vegetation levels and age categories of trees are represented and which include over-aged stands, linear stands, wetlands, vernal pools, peat bogs, etc., as these forests have a high diversity of all living and non-living things.

3. In order to balance the above-mentioned roles of forests, it is necessary to divide the rights and obligations of forest owners according to the type of ownership and category of forests and to maintain a fair balance between the interests of forest owners and public interests.

Long-term objectives of the state forestry policy:

1. Ensure the conservation of forest and forest land for future generations.
2. Increase the competitiveness of forestry.
3. Increase biodiversity in forest ecosystems, their integrity and ecological stability.
4. Strengthen the importance of forests and forestry for rural economic development.
5. Strengthen the importance of education, research and innovation in forestry.

Measures to achieve long-term goals:

A. Preserving forest and forest land for future generations;
B. Increasing the competitiveness of forestry;
C. Increasing biodiversity in forest ecosystems, their integrity and ecological stability;
D. Maintaining and strengthening the importance of forests and forestry for rural development.

9.8 BIOEAST STRATEGIES

The BIOEAST strategy began to take shape in 2017 following a joint declaration by the Ministers of Agriculture of the V4 countries, Bulgaria, Croatia, Romania and Slovenia. It is a joint strategy in the field of bioeconomy. In the context of the experience with bioeconomy in CEE countries, three main gaps were identified:

1. blocking research and innovation,
2. failed administration,
3. deadlock in biomass value chains.

The EU-13, despite the fact that there are still many problems waiting to be solved at national level, have to tackle global challenges. The EU 2030 Agenda requires knowledge support and strategic thinking. The BIOEAST initiative should provide support for the development of post-2020 EU programmes and policies, including:

- A new framework programme for research,
- a new initiative for the Common Agricultural Policy and Food 2030,
- a common forestry policy
- the Common Fisheries Policy,
- regional development strategies (Danube, Baltic Sea, Black Sea, 3 Seas, etc.) under the European Structural and Investment Funds,
- Circular economy package,
- industrial and digitisation packages.

The BIOEAST initiative should consider three priority areas that coincide with policies at EU level:

1. EU research and innovation programming: setting targets for CEE countries‘ common programming needs, focusing on emerging themes;
2. Review of the European Commission‘s bioeconomy strategy in the context of the Circular Economy Package;
3. launch of the FOOD 2030 initiative and debate on the post-2020 Common Agricultural Policy.

The BIOEAST initiative focuses on **three main macro-regional initiatives**:

1. Strategic thinking in bioeconomy;
2. food and feed for the „heart of Europe“ and the rest of the world;
3. industrial support based on bio-resources.

9.9 FINNISH FOREST BIOECONOMY STRATEGY AS AN EXAMPLE OF A NATIONAL STRATEGY

Finland has set itself the goal of a low-carbon, resource-efficient and sustainable economy. A sustainable bioeconomy plays a key role in achieving these goals. Finland is well positioned to become a pioneer of the bioeconomy in the world. The bioeconomy will strengthen the national economy and employment in Finland and improve the well-being of the Finnish population.

Finland‘s bioeconomy strategy aims to promote economic growth and job creation through the growth of bioeconomy businesses and high value-added products and services, while ensuring operating conditions for natural ecosystems. The guiding idea of the strategy is that competitive and sustainable bioeconomy solutions to global challenges will be created in Finland and that new business will be generated in both the Finnish and international markets, thereby promoting prosperity for Finland as a whole.

The vision and quantitative objectives of the Bioeconomy Strategy will be implemented through four strategic objectives:

1. Competitive environment for the bioeconomy: a competitive environment will be created for the growth of the bioeconomy.
2. New business in the bioeconomy: new business will be created in the bioeconomy through venture funding, bold experimentation and crossing sectoral boundaries.
3. A strong bioeconomy competence base: the bioeconomy competence base will be updated by developing education, training and research.
4. Availability and sustainability of biomass: availability of biomass, well-functioning feedstock markets and sustainability of biomass use.

Indicators for monitoring the implementation of the strategy are set out in Table 9 below.

Table 9: Indicators for monitoring the implementation of the strategy

Key items to be measured	Indicators
The growth of the bioeconomy and its importance in the national economy	Bioeconomy output / value added / number of employees and their share in the national economy
Value added produced for the use of natural resources	Raw material input / value added to raw material flows
Ecological benefits from the bioeconomy	Raw materials used / greenhouse gas emissions
Sustainability of the bioeconomy	Total use of natural resources / growth and harvested volumes of timber, cereals, fish, endangered species, urban waste
Sustainability of the bioeconomy	Indicators to be developed for ecosystem services, environmental and resource efficiency, and wealth and environmental assets

Source: The Finish Bioeconomy Strategy, 2014

Chapter Summary

The chapter summarises the most important strategies approved so far. This is primarily the OECD strategy, as well as the two EU strategies from 2012 and 2018. BIOEAST can also be included here, as it focuses on the adoption of bio-economic strategies in the CEE countries. The Finnish forest bioeconomy strategy is given as an example of a national strategy. The challenges of the bioeconomy are described using the EU as an example. They focus on sustainable agriculture and forestry, soil management, rural support, and the competitiveness of the agri-food sector. Global developments are expected to support the transformation of the economy towards a sustainable bioeconomy based on the use of renewable raw materials.

Control questions

1) What are the institutional and societal measures to support the bioeconomy according to the OECD strategy?
2) Which ETPs are active in the bioeconomy?
3) What bioeconomy strategies have been adopted so far within the EU?
4) How the bioeconomy contributes to EU priorities
5) What is BIOEAST?
6) What are the challenges of the bioeconomy?
7) What role can we expect the bioeconomy to play in the future?

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