WHAT WILL ESTONIA'S BIOECONOMY LOOK LIKE IN 2050?[1]

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In recent decades, global societal, economic, environmental and climate trends have been marked by a number of unexpected or previously overlooked developments and events, which have been met with extraordinary measures. The ratio of international trade to global GDP, which characterises globalisation, has been fairly stable since the economic crisis of 2008–2009, after having grown rapidly in previous decades. In many large countries, however, the question of whether globalisation as it is currently developing is even beneficial to humanity, has become increasingly acute.

At the same time, solutions to the challenges of global warming and preservation of biodiversity are being sought worldwide. Furthermore, mRNA vaccines, which have been placed on the market at an extraordinary pace in the fight against the Covid-19 pandemic, point to entirely new scientific and technological opportunities associated with synthetic biotechnology. These opportunities can thoroughly change our understanding of how to live a healthy and fulfilling life, how healthy food is prepared and what products can be made from biological raw materials.

In this scenario analysis, we look at four global development paths of bioeconomy, all of which are equally possible, depending on societal, environmental, climate, economic, energy and political developments in the world, but are characterised by very different dynamics. We analyse the opportunities offered by a more open and a more self-centred economic environment for the development of the Estonian bioeconomy. We also discuss how to embrace the completely new technological and socio-economic opportunities associated with biorevolution, and what to do if, for some reason, novel opportunities related to life sciences and biotechnologies do not materialise.

1. The **bioeconomy scenario of secure self-sufficency** is underpinned by global economic uncertainty and the need to ensure self-sufficiency in respect of essential products. For Estonia's bioeconomy, this implies the continuation of the current specialisation, including the development of food self-sufficiency and the continued widespread use of timber as a building material and as a locally managed energy source. Information technology solutions and adherence to the principles of circular economy and cascading use of bioresources will be essential to increasing the added value of the Estonian bioeconomy. It will be difficult to attract substantial investments to support structural changes in the economy, and productivity will grow slowly.
2. In the **globalised and traditional bioeconomy scenario**, open trade and capital flows will offer opportunities for the Estonian bioeconomy to seek a better place in the global division of labour. In particular, Estonia will develop products and activities in the value chains of food and timber that are more sophisticated than today, including the chemical processing of timber. The production of pharmaceutical products will be a new promising avenue for specialisation. Major investments will be made in Estonia's bioeconomy to acquire the best available technologies and to make better use of low-value raw materials (cereals, milk, timber and grasslands).

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[1] This is a summary of the scenario and foresight work for the Project **project 'ADDVAL-BIOEC: Adding value and making more efficient use of raw materials in the bioeconomy and its sectors'** that analyzed the current developments of the Estonian bioeconomy and the main value chains thereof, as well as the opportunities for using biological resources to increase competitiveness. The study was commissioned and funded by the Estonian Research Council through Action 1 'Support of strategic R&D activities' of the 'Reinforcement of Sectoral Research and Development Activities' (RITA) programme supported by the European Regional Development Fund. See more: *www.taltech.ee/biomajandus*.

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3. In the s**cenario of a global economy shaken by biorevolution**, biotechnologies will fundamentally change the current practices of using biomass, leading to entirely new industries, products and services of the bioeconomy. Estonia will be looking for opportunities to enter new product areas related to bio-based materials, health promotion and food production that will emerge from the global biorevolution. The development of the Estonian bioeconomy will be featured by a widespread uptake of biotechnologies, including cell factories and synthetic biology, and the introduction of the resulting novel bioproducts on the market.
4. In the **scenario of adaptation to environmentally conscious and community-based biorevolution**, Europe will seek a balance between the application of novel biotechnologies and the preservation of traditional ecosystems and food systems. Estonia will advance traditional food production and community-based business models alongside the production of high-tech bio-based materials. The local bioeconomy will follow the biorevolution in a selective way, in particular in the areas of new bio-based materials and energy. Artificial intelligence solutions underpinned by big data will be widely used to develop traditional food production.

Bioeconomy has a significant potential to increase Estonia's prosperity and raise living standards. This will require a targeted shift towards much more complex product groups with a higher added value and a better land-use and CO_2 emission ratio. However, we do not yet know how fast biotechnologies will be taken up or what global agreements on climate neutrality, biodiversity conservation and economy will be reached in the coming decades. **It would therefore be imprudent to try to decide at this point which scenario we would prefer to see materialise**. Nevertheless, below we will identify the main strategic breakthrough directions that will enable the Estonian bioeconomy to grow successfully under any circumstances.

- For the labour productivity and living standard of Estonia to approach that of the Nordic countries or Germany, the share of more complex products in Estonian exports, including those of the bioeconomy, needs to increase significantly. In the context of Estonia's bioeconomy, this is expected to require billions of euros of investment in the development of chemical processing of timber, the biopharmaceutical industry, and information and communication technology (ICT) solutions and machinery supporting the bioeconomy.
- The development of specialised suppliers supporting the development of bioeconomy (including those supplying ICT and electronics applications, machinery, chemical products, biotechnology intermediates, and technologies) has even better prospects in a globalised economy than the direct valorisation of biomass.
- Estonian research and higher education must, as an absolute minimum, follow what is happening at the forefront of life sciences and biotechnologies, and develop capabilities to swiftly take up and further develop technologies created elsewhere.
- To attract major research and technology investments, Estonia should seek strategic partnerships with countries at the forefront of technology.
- Maintaining and developing effective cooperation with the Nordic countries, Germany, Poland and the Baltic States is essential for Estonia to ensure mutual market access, security of supply for the (bio) economy, energy security and investment protection.
- It is of utmost importance for Estonia to play an active role in shaping international agreements, standards and development paths concerning climate goals, biotechnology and the (bio)economy through the European Union and international organisations.

SCENARIO ANALYSIS AND STRATEGIC PLANNING

The EU's Green Deal and the green transition in general are one of the most ambitious undertakings of recent decades, requiring a rethinking of the current economic models in terms of both substance and form. One of the prerequisites for achieving the green ambitions is the transition from the current linear economic model to **circular bioeconomy**, i.e. replacing as much fossil raw materials as possible with biological raw materials and using and refining these raw materials as effectively and sustainably as possible. This transition requires setting, sustaining and implementing a **long-term vision for the decades ahead**.

In today's world, strategic planning and public policy-making are characterised by two opposing trends. On the one hand, the development of business strategies and public policy-making has become increasingly **knowledge-driven** and the importance of new data sources has grown over the last decades. On the other hand, the world has experienced extraordinary events in recent years. The coincidence of the end of the economic cycle and the global public health crisis resulting from the COVID-19 pandemic, coupled with increased **political uncertainty**, have made it extremely difficult to anticipate future trends.

Deutsche Bank has described today's world as an **age of disorder**, marked by sharp confrontation and the questioning of many previously widely accepted understandings and agreements. In such a world, automatically extending current trends to the coming decades can be a major mistake[4]. The National Security Council of the United States has also stressed in its analyses[5] that the world is increasingly being characterised by the so-called **paradox of progress**. In other words, the developments that have hitherto underpinned our success have now become potential obstacles to future resilience; this means that nothing in today's world should be regarded as self-evident. A similar conclusion has been reached in scientific research on the sustainable development of humanity[6].

Looking to the future, we can predict that the global population will grow to around 10 billion by 2050 and that Europe will be aging, but we do not yet know how the population growth, combined with technological development, changing lifestyles and preferences, will

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4 Jim Reid, Nick Burns, Luke Templeman, Henry Allen & Karthik Nagalingham, *The Age of Disorder – Long-Term Asset Return Study*, Deutsche Bank, September 2020.
5 NIC, *Global Trends*: Paradox of Progress, 2017, *https://www.dni.gov/index.php/global-trends-home*.
6 William Clark & Alicia Harley, Sustainability Science: Towards a Synthesis, *Annual Review of Environment and Resources*, 45, 331–386, 2020, *https://bit.ly/3luJYzg*.

affect, for example, the demand for different types of food (meat vs. plant-based food; soil-based vs. soil-free food) and products (from clothing to medicines and housing), or how international migration and trade flows will develop. While we see the Western political elites trying to advocate the ambitious Paris climate goals, we do not know for sure how well these international agreements will hold up and be implemented through national policies as Asia (especially China and India) is growing in influence.

In periods of high uncertainty, when many important factors are changing rapidly, longer-term detailed projections usually prove to be very inaccurate. Therefore, modern foresight methods do not attempt to predict developments in the coming decades as accurately as possible. What is considered more important is the **qualitative analysis of different future scenarios**, which helps policy makers, entrepreneurs and others to reflect on possible future events in good time and, on this basis, to consider their longer-term strategic objectives and action plans[7].

In the analysis of the scenarios of long-term development opportunities for the Estonian bioeconomy, we look at four global development trajectories of bioeconomy, all of which are equally possible, depending on societal, environmental, climate, economic, energy and political developments in the world, but are characterised by very different dynamics. We proceed from the premise that the main scientific and technological trends influencing longer-term development tend to emerge from technologically advanced major economies and global innovation networks[8]. The economic prospects of a small country, on the other hand, largely depend on its ability to compete in export markets and keep pace with countries at the forefront of technology. Then again, broader societal, environmental, climate and other developments play an important role in shaping the market demand. We analyse the opportunities offered for the development of the Estonian bioeconomy by a more open and a more self-centred, regionalised economic environment. We also discuss how to embrace the completely new technological and socio-economic opportunities associated with the revolutionary development of biotechnologies[9], and what to do if, for some reason, novel opportunities related to life sciences and biotechnologies do not materialise.

CURRENT STRUCTURE AND COMPETITIVENESS OF ESTONIA'S BIOECONOMY

Economic activities are quite different in terms of their potential to generate added value or cause an environmental impact. The central question to be answered in the scenario analysis concerning the Estonian bioeconomy is, therefore, which activities Estonia should specialise in if it wants to increase the added value of the bioeconomy over the period 2030–2050. This straightforward question of the economic development strategy, however, entails broader considerations of nature conservation and balanced regional development, which are now intertwined in the EU's Green Deal in the notions and priorities of sustainable competitiveness, biodiversity, etc. and which seemingly carry conflicting values.

According to the European Bioeconomy Action Plan, the EU's bioeconomy is estimated to generate an annual turnover of around 2 trillion euros and an added value of around 621 billion euros[10]. Around two thirds of the added value of the bioeconomy is generated by the manufacturing industry. The added value of agriculture amounted to 182 billion euros and that of forestry to 27 billion euros in the EU in 2018.

According to the classification of the bioeconomy used in the ADDVAL-BIOEC study, the sales revenues of Estonian bioeconomy companies amounted to around 5 billion euros in 2017 (10% of Estonian companies' total sales revenues) and exports to 2.1 billion euros (17% of Estonian companies' total exports). The added value generated in the Estonian bioeconomy amounted to 1 billion euros in 2017, representing 11% of the total added value generated by Estonian companies. Estonian bioeconomy companies employed 46,000 people in 2017, or 12% of the total workforce[11].

Estonian bioeconomy companies active in the value chains of forestry and timber and of agriculture and food contribute relatively equally to the added value generated by the Estonian bioeconomy. Together, these two main value chains generate around 90% of the added value of the Estonian bioeconomy:

- the sales revenues of forestry, timber and paper industry companies account for around 50% of the total sales revenues of companies active in the bioeconomy, while their exports represent around 60% of the bioeconomy exports;
- agriculture and food and beverage production account for around 40% of the sales revenues of bioeconomy companies and around 25% of bioeconomy exports.

Since "The Wealth of Nations" penned by Adam Smith[12], classical economic thinking is based on the notion that increasing trade in goods creates opportunities for deeper specialisation, which in turn supports productivity growth in the economy. **However, a recent analysis of international trade shows that not all economic activities are the same in terms of their contribution to economic competitiveness and rising living standards. Poor countries**

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7 See the scenario building methodology of the Riigikogu's Foresight Centre, as well as Meelis Kitsing, *The Political Economy of Digital Ecosystems: Scenario Planning for Alternative Futures*, Routledge, 2021; Luke Georghiou *et al., The Handbook of Technology Foresight*, Edward Elgar, 2008.

8 Christian Binz & Bernhard Truffer, "Global Innovation Systems – A conceptual framework for innovation dynamics in transnational contexts", *Research Policy*, 46(7), 1284–1298, 2017.

9 McKinsey estimates that the direct economic impact of biotech applications already seen today could reach 2–4 trillion euros per year (up to 5% of global GDP) in the next 10–20 years.

10 For more detailed information see European Commission, "Bioeconomy: the European way to use our national resources", 2018, https://bit.ly/3dLKYul. More recent analyses have suggested that the added value generated by the bioeconomy, taking into account the tertiary sector, could be as high as 1.4 trillion euros. See Kuosmanen, T., Kuosmanen, N., El Meligi, A., Ronzon, T., Gurria Albusac, P., Iost, S. and M`barek, R., How big is the bioeconomy, EUR 30167EN, Luxembourg: Publications Office of the European Union, 2020.

11 For a more detailed analysis and an overview of the classification of the bioeconomy see Urmas Varblane *et al*., "Eesti biomajanduse väärtusahelate kvantitatiivne analüüs". Interim analysis of ADDVAL-BIOEC study, work package 1.2, Tallinn & Tartu, 2021.

12 Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, W. Strahan and T. Cadell: London, 1776.

specialise in goods that are intensive in unskilled labour and land use, whereas richer countries specialise in goods requiring infrastructure, institutions, qualified labour and capital[13].

Labour productivity in Estonia's wood and timber products sector and food and beverages sector is comparable to that of Latvia or Lithuania, but 2–3 times lower than in Finland, Sweden, the Netherlands and other advanced industrialised countries. The significantly lower competitiveness of the Estonian bioeconomy is largely explained by the lower complexity of Estonian export products compared to the products exported by Nordic countries.

The product groups with the largest net export volumes produced by Estonian companies active in the bioeconomy[14] include prefabricated buildings (9406), wood carpentry for construction (4418), fuel wood (including pellets, 4401), wood shaped along its edges (4409), wheat and meslin (1001), and furniture and parts of furniture (9403). Foodstuffs exported in larger quantities also include cheese and curd (0406) and non-concentrated milk and cream (0401). Prefabricated buildings and wood carpentry for construction, as well as furniture components are medium-complexity products which are important for Estonian bioeconomy exports and for which it is worth looking for ways to maintain and increase a share in the global market (Figure 1).

By contrast, exports of wood in the rough (4403), wood sawn lengthwise (4407) and other low-complexity products are rather wasteful from the point of view of the resource efficiency of the Estonian economy. For the products with a complexity index below zero, the key question is whether significant scientific, technological or other breakthroughs or novel market niches can be foreseen which would allow Estonian products to secure a unique qualitative advantage. If such new technologies or market niches are unlikely to be found,

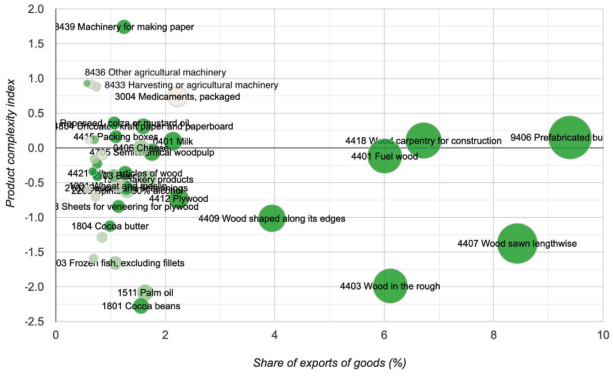

FIGURE 1. Complexity of the key export products of the Estonian bioeconomy.

Note: the darker the green, the more competitive (higher RCA) Estonia is in the respective product group.

Source: Harvard University, 2020; Tiits & Kalvet, 2020.

opportunities to add value to bio-resources in other ways should be sought. At the same time, it is also worthwhile looking for opportunities to enter completely new technology-intensive and high value-added product groups, such as pharmaceuticals, chemical or biotechnological refining of timber, etc.

In summary, in order to make new leaps of development from the current structure of the Estonian bioeconomy, it is necessary to **increase the technological and innovation capacity of the Estonian bioeconomy** on the one hand, and to be sufficiently **resilient to adapt to wider developments in international economic relations** on the other. In the following scenario analysis, we will look at Estonia's opportunities and challenges in the context of possible global developments in the bioeconomy.

A RAPIDLY CHANGING WORLD

POPULATION AND SOCIETY

The world's population will grow to around 10 billion by 2050. Half of the world's population growth will come from Africa and a third from Asia. Meanwhile, Europe and the Americas will be aging rapidly due to the diminishing working-age population. In Estonia, there will be just half a million 24–64 year-olds or less than two people of working age for every older person by 2050[15]. If current population trends continue, the population of Harju and Tartu counties will remain at around today's levels, while the population of the remaining counties will decline by 20–25% by 2040.

With the growing population and continuing urbanisation, food demand is expected to increase by as much as 50–200% according to different estimates[16]. However, the area of agricultural land cannot be increased, as the world will need forests for CO_2 sequestration and climate stability purposes. The world's food supply will therefore primarily depend on increasing agricultural productivity and reducing food wastage throughout the supply chain i.e. "from farm to fork".

The growing urbanisation of Asia and the aging of Europe's population will lead to labour shortages in rural areas which – depending on societal attitudes – could be addressed by a more favourable attitude to migration or by investment in technological development, including artificial intelligence and robotics. At the same time, it is not clear how the aging of the population (e.g. in Europe and Estonia) and the potentially accompanying growing multiculturalism of society will affect people's preferences for food, transport, energy, etc.

ENVIRONMENT AND CLIMATE

In order to limit global warming to 1.5–2°C, the world needs to radically reduce (net) greenhouse gas emissions already by 2030. The European Union has committed itself

[13] Cesar A. Hidalgo *et al.*, The Product Space Conditions the Development of Nations, Science, 317(5837), 482–487, 2007, https://doi.org/10.1126/science.1144581.

[14] Here, the bioeconomy covers the two-digit CN chapters 01–05 (animals and products of animal origin), 06–15 (vegetable products), 16–24 (foodstuffs), 30 (pharmaceutical products), 41–43 (raw hides and skins and leather goods), 44–49 (wood and timber products), 47–49 (pulp, paper and printed matter), 51–53 (wool, cotton, vegetable textile fibres), 94 (furniture and prefabricated buildings). Please note! In addition to wooden furniture and prefabricated buildings, CN code 94 also includes furniture made from metal and other materials. For a more precise delimitation of bioeconomy products, a CN code consisting of at least six digits should be used.

[15] *World Population Prospects 2019, Online Edition*, United Nations, 2019, https://population.un.org/wpp/.

[16] European Parliament, Megatrends in the agri-food sector: global overview and possible policy response from an EU perspective, 2019, p. 30, https://bit.ly/38YeVEj; OECD-FAO Agricultural Outlook 2020–2029, OECD Publishing, Paris/FAO, Rome, 2020, https://doi.org/10.1787/1112c23b-en; Agata Tyczewska et al., Towards Food Security: Current State and Future Prospects of Agrobiotechnology, *Trends in Biotechnology*, 36(12), 1219–1229, 2018, https://doi.org/10.1016/j.tibtech.2018.07.008.

to becoming climate neutral by 2050[17]. Similarly, China has also set a target to become carbon neutral by 2060[18]. The US has rejoined the Paris climate agreement. However, achieving the climate goals will require the cooperation of a wider range of countries with large populations and/or fossil fuel production, including Indonesia, Nigeria, oil producing countries in the Middle East, etc. Changes outside the energy sector, such as reducing and replacing the use of cement and steel, are equally important.

No less important an environmental challenge than climate ambition is the preservation of biodiversity worldwide. The global population of various vertebrate species has declined by 68% in the last 40 years, mainly due to land-use changes (50%) and overexploitation (24%), as well as invasive species and diseases (13%). The rapid decline in the area of tropical forests has been the decisive element in the change in global land use patterns over the last century. Around 60% of land formerly covered by tropical forests is now being used for the production of beef, soy and palm oil[19].

In this context, oceans, seas, coastal and inland water systems, which cover about 75% of the Earth's surface, are seen as an important source of biomass (alongside agricultural and forest land), which has been underexploited so far, especially in Europe. For example, the oceans mission of the European Horizon programme (Mission Starfish 2030) sets the goal of increasing the consumption of low-trophic aquaculture products (such as algae, shellfish, other invertebrates) from European waters and seas by 70% by 2030, which in turn would lead to significant reductions in carbon dioxide emissions[20].

Today, it is far from clear how quickly the world will be able to slow down the climate change and what the impacts of the climate change will be on different geographical regions. In Estonia, for example, rising temperatures will extend the growing season, but this will not necessarily have a positive impact on the quality of biomass (the need to increase adaptability to various disturbances, etc.) or on processing (e.g. forest harvesting in warmer weather and with softer soil). And what will happen to soil quality and nutrients in soils as the climate warms? Will there be major unexpected changes in the natural environment or in the functioning of ecosystems, such as disasters, spread of parasitic pests or invasive species, which will significantly alter the conditions in which we live and manage our resources?

ECONOMY AND ENERGY SUPPLY

Based on the parity of purchasing power, China's economy is already larger than that of the US and will overtake the US also in nominal GDP terms by 2030 if current economic growth rates are sustained. India will overtake the US in terms of GDP by 2050. Asia, which is internally very diverse, will thus become by far the world's most powerful economic region by mid-century, encompassing knowledge- and technology-intensive regions, as well as regions specialising in relatively labour- and resource-intensive activities.

According to the US Energy Information Administration, global energy consumption is projected to grow by nearly 50% by 2050, while McKinsey estimated in 2020 that energy consumption could even double[21]. The increase in global CO_2 emissions so far has been primarily driven by the energy sector, but the energy sector also has the potential to rapidly become carbon neutral. The global supply of solar and wind power will exceed that of coal or gas already by 2024. As a result of rapid technological development, solar energy is also about to become the cheapest energy source in the world's history.

Biomass, on the other hand, is a rather inefficient source to meet the world's growing energy needs. The world's total production of biomass (timber, plants, animals, etc.) in 2010 could cover only 20% of global primary energy needs in 2050. It is therefore only appropriate to use biomass for energy production according to the cascading use principle and in cases where other energy sources are not available or the low quality of the raw material does not allow for more sustainable products to be made.

Due to the dynamics of wood maturity, Estonia's wood resources will decrease significantly by 2050 compared to the current level. Plant biomass, meat and dairy production, on the other hand, have the potential to grow[22]. As beef production requires significantly more grassland and generates more greenhouse gases than the production of other foodstuffs, it would not be surprising if stricter climate and environmental requirements resulted in a significant reduction in the production and consumption of beef and an increase in the consumption of plant-based food. The reduction in beef production in turn would also free up grassland for other uses[23].

Today, it is far from clear what the dynamics of global economic development will be in the face of a deepening ecological crisis and the already very high debt burden of developed countries. To what extent will the European Union be able to sufficiently harmonise its technology, climate, economic and regional development policies and even out the hitherto very unbalanced development at regional level? How will the issue of integration and comprehensive management of Estonia's and Europe's energy systems be resolved in the context of the increasing share of distributed wind and solar energy production and electricity consumption?

SCIENCE AND TECHNOLOGY

The rapid development of IT has been described since the 1960s by Moore's law, according to which the number of transistors in a microchip doubles every two years, while the price of a computer falls by a factor of two. However, using the cost of human genome sequenc-

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17 *The European Green Deal*, European Commission, COM(2019) 640 final, 2019, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN.

18 *China carbon neutrality in 2060: a possible game changer for climate*, EEAS, 2020, https://bit.ly/37dE8JY.

19 Hannah Ritchie, *Drivers of deforestation*, Our World in Data, 2021, https://bit.ly/2TJzReg.

20 See the EU's Mission Starfish 2030 initiative: https://ec.europa.eu/info/publications/mission-starfish-2030-restore-our-ocean-and-waters_en.

21 Ari Kahan, *EIA projects nearly 50% increase in world energy usage by 2050*, led by growth in Asia, September 2019, https://bit.ly/3y59Y8g; Paolo D'Aprile *et al., How the European Union could achieve net-zero emissions at net-zero cost*, McKinsey, 2020, https://mck.co/3or4OOm.

22 Jaan Kers *et al*, "Eesti biomajanduse pikaajalised bioressursi potentsiaali prognoosid: 2030 ja 2050", interim analysis of ADDVAL-BIOEC study, work package 2.1, Tallinn & Tartu, 2020.

23 Permanent grassland accounts for around a third of Estonia's agricultural land. The European Union's common agricultural policy (Article 45) provides for the obligation to maintain permanent grassland. The minimum ratio of permanent grassland in Estonia must not decrease by more than 5% compared to 2015. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02013R1307-20190301.

ing as an example, it can be stated that the development of biotechnology has been even faster in the last few decades. The development of IT and biotechnologies is also characterised by a symbiotic relationship[24].

One of the most important breakthroughs in biotechnology in recent years is the CRISPR-Cas9 technology[25], which makes it relatively easy to modify DNA sequences and gene functions. Future developments in biotechnology, which will open up the possibility of "programming" living organisms in the coming decades, can in many ways be compared – in terms of their potential economic and societal impact – to the first Intel microprocessors of the early 1970s, which laid the foundations for the modern era of personal computers.

Rapidly evolving biotechnology capabilities have the potential to make a significant difference to both the economy and wider society[26]:

- technologically, **60% of the world's inputs could be produced from biomass**, while obtaining materials that are more eco-friendly and have better properties;
- technological breakthroughs will also make the **development of various bio-based products much faster and more precise**, paving the way for, for example, the development of more accurate personalised medicine, the use of new information on plants and soils to increase agricultural productivity, the development of personalised diet plans based on genetic testing, etc.;
- the **ability to modify and reprogram human and other organisms** – for example, to create genetically modified plants with higher yields or better weather tolerance, to prevent the spread of vector-borne diseases, etc, will grow;
- the ability to **develop various new interfaces between biological organisms and computers** – for example, to restore lost vision, etc. will also grow.

McKinsey estimates that the direct economic impact of the biotechnology applications already seen today could amount to 2–4 trillion euros per year (up to 5% of global GDP) in the next 10–20 years. In other words, biotechnology has the potential to become a key driver of global economic growth, as has been the case with information and communication technologies in recent decades.

Biorevolution entails a number of technological, economic, health and environmental risks. It is currently not clear what additional international regulation will be needed to address the risks associated with a widespread uptake of new biotech-intensive products, or how favourably policy-makers' will view the widespread development and introduction of biotechnologies. For example, will the European Union decide to take a more favourable stance towards the use of GMOs and CRISPR technology in relation to food, and if so, when[27]?

POLITICS AND THE GEOPOLITICAL BALANCE

In recent decades, international politics has been characterised above all by the pursuit of ever greater openness and economic freedom. This has been accompanied by the rise of Asia's economic power and growing political rivalry with the US and Europe. Having experienced the vulnerability of the global economy, the US, Europe and China are striving for greater *strategic autonomy* in securing both key economic inputs and production capacities.

We are entering a new multipolar world. At this point, it is difficult to foresee in detail the rules that will govern international relations or the ways of solving economic and ecological problems. If the US, China, Europe or countries exporting fossil fuels, which are strongly influenced by global climate goals, were to unilaterally impose restrictions on trade and/or capital movement due to changes in the economic and geopolitical balance, it is quite likely that the whole international trade regime would change significantly. Within the larger regional trading blocs, including Europe and Asia, a relatively free business environment may be maintained, but increasing restrictions and political risks in economic relations between trading blocs cannot be ruled out. This, in turn, could result in the need for new agreements on international economic and climate cooperation, as well as on a new security architecture.

In the coming years, it will certainly be very important to monitor the impact of the green transition and the deployment of renewable energy sources on the geopolitical weight of countries. To what extent will the economic and geopolitical confrontation between the US and China spill over into economic relations between the EU and China? How will the relationships between Europe, China and Russia develop? What will be the weight and role of multilateral cooperation organisations in the world?

BIOECONOMY DEVELOPMENT SCENARIOS UP TO 2050

FRAMEWORK OF THE SCENARIO ANALYSIS

Many of the aspects of the external environment referred to above are characterised by uncertainty about future developments. The future prospects for the climate, the environment and the economy largely depend on the willingness of groups of countries and companies, as well as generations to cooperate and the ability to establish rules that are beneficial to all parties. The dimension of **global openness vs. regionalisation of the bioeconomy** has therefore been chosen as one of the main axes of the scenario analysis. On this axis, the alternative to global openness is growing rivalry between and within continents, leading to the prioritisation of community needs at the levels of

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[24] Ewen Callaway, It will change everything: DeepMind's AI makes gigantic leap in solving protein structures, *Nature*, 30/11/2020, https://doi.org/10.1038/d41586-020-03348-4.

[25] Emmanuelle Charpentier and Jennifer Doudna who developed the CRISPR-Cas9 method were awarded the Nobel Prize in Chemistry in 2020; see https://www.nobelprize.org/prizes/chemistry/2020/press-release/.

[26] Michael Chui *et al.*, *The Bio Revolution: Innovations transforming economies, societies, and our lives*, McKinsey Global Institute, 2020, https://mck.co/3pZxXlw

[27] Heidi Ledford, CRISPR conundrum: Strict European court ruling leaves food-testing labs without a plan, *Nature*, 572(15), 2019, https://doi.org/10.1038/d41586-019-02162-x.

continents, the European internal market and nation states (Figure 2).

Over the last two and a half centuries, the development of the global economy has been driven by five successive technological-economic paradigms, starting with the industrial revolution that began at the end of the 18th century. Each of these has been underpinned by groundbreaking new technologies and the new infrastructure, institutions and lifestyles resulting from them. On the technological development axis of this scenario analysis, biorevolution refers to the development path in which radically new **biotechnologies and the supporting infrastructure will become one of the central pillars of the next technological-economic paradigm and of changes in socio-technical systems** (energy system, food system, etc.). This biorevolution is contrasted with a much slower evolutionary development, with biotechnologies that can radically change the economic and living environments being low in numbers or their introduction being significantly limited due to societal attitudes, laws, agreements, etc.

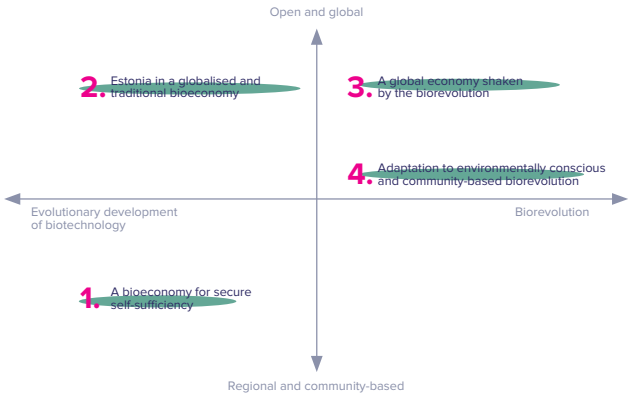

FIGURE 2. Matrix for the scenario analysis of Estonia's bioeconomy

Source: authors.

SCENARIO 1: A BIOECONOMY FOR SECURE SELF-SUFFICIENCY

International uncertainties will lead to a slowdown in globalisation and to the division of the world into regional blocs and increasing competition and confrontation between them. A lack of mutual trust will be hampering international political, climate and economic cooperation. Instead of specialisation and international exchange of goods and services that characterised the earlier era of globalisation, management decisions will largely be driven by distrust, competition for resources, self-reliance and self-sufficiency. This environment will result in international investment and cooperation for the development of new biotechnologies and bioeconomy products being stifled, as well. Rather, the aim will be to cope by fine-tuning existing capabilities and making more efficient use of bio-resources in accordance with the principles of circular bioeconomy. Estonia's bioeconomy, which is based on biomass, will remain a traditional community-based area of activity oriented towards the domestic Estonian market or markets in the neighbouring region.

The desire to ensure self-sufficiency will make it necessary to maintain a broad product portfolio (and even expand it in the food sector), while the efficient organisation of economic activities would require specialisation and significantly higher production volumes. This, in turn, will enhance the diversification of traditional rural activities (forestry, agriculture) and the entrenchment of part-time work as a way of life. There is likely to be a shortage of both local and international investment capital necessary for entering more capital-intensive areas of activity (such as chemical refining of timber, new ways of valorisation of milk, production of pharmaceuticals, substitution of fossil raw materials in the chemical industry, etc.).

The central development path for Estonia's bioeconomy: fine-tuning of the use of bio-resources. Estonia will continue along the path of mainly animal-based (food and feed), mechanical (timber) and energy-based (waste, wood) valorisation of biomass, with ICT solutions helping to make processes more efficient (including better planning, resource management, etc.). Digitisation of industry and supply chains and the uptake of imported environmentally friendly technologies will be the key sources of productivity gains.

SCENARIO 2: ESTONIA IN A GLOBALISED AND TRADITIONAL BIOECONOMY

While being open to cooperation and trade, countries will be moving at different speeds as regards the green transition in support of climate goals. Many countries are heavily dependent on either fossil fuel exports or other economic activities with a high ecological footprint and will not be able to find quick solutions to the related challenges. In the delicate balance between economic and environmental objectives, there will be a tendency to give preference to economic growth in the hope that this will in turn lead to solutions to environmental and societal challenges. Thanks to long-standing investment in environmental and energy technologies, Europe will emerge as a major developer of technologies supporting the green transition, alongside Asia. It is clear that by 2050 the green transition, clean-tech and ICT solutions will have laid the foundations for the next technological-economic paradigm.

The central development path for Estonia's bioeconomy: specialising in higher-complexity (higher-value-added) products and using investments associated with the digital and green transitions to maintain and increase the competitiveness of the current key industries within bioeconomy, i.e. production of food and beverages and timber products. The structure of Estonia's bioeconomy in terms of industries and the shift towards higher-value-added products will be influenced above all by changes in the international market demand and by the competitiveness of Estonian industries in export markets, including the capacity to increase productivity with the help of widely known cultivation practices and technologies for sourcing and processing bio-resources.

The central focus of a longer-term strategy will be on the development of new, more complex activities that are independent of local raw materials. For Estonia, given its peripheral logistical location, bioeconomy activities where both import inputs and export outputs

can be transported relatively easily will be of particular interest. This implies the development, in particular, of a research-intensive biopharmaceutical industry, high value-added biochemistry, etc., following the example of Denmark, Ireland and other small countries. Following the example of the Nordic countries, it would also be interesting for Estonian companies, as well as important for their global growth, to develop business models in which the competence and export potential of a new business (e.g. production of prefabricated buildings, food biotechnology, etc.) is developed on the basis of the local raw materials in Estonia, but the technologies and production facilities would be located close to the main raw materials and/or the main target markets in order to expand the business further.

SCENARIO 3: FINDING A PLACE IN THE GLOBAL ECONOMY SHAKEN BY BIOREVOLUTION

The relatively rapid and successful resolution of the COVID-19 pandemic has boosted society's faith in science and innovation and given impetus to large-scale investment in life sciences and biotechnologies. The radical breakthroughs in life sciences and biotechnologies that are expanding humanity's understanding of biology and opening up the possibility of "programming" living organisms can be compared – in terms of their potential economic and societal impact – to the first Intel microprocessors of the 1970s, which laid the foundations for the modern era of personal computers.

Major powers' national and international visions and agreements on adaptation to climate change will place a major emphasis on technology as a key tool in mitigating climate change. This will reinforce the hope and understanding that technological progress can help decouple economic growth from the growth of greenhouse gas emissions, and that humanity can embark decisively on a path to green growth. New and largely unregulated markets for new technologies will offer unexpected and controversial technological solutions and development opportunities, including for replacing fossil fuels and tackling climate change. Uneven technological and economic development will bring about new and different winners and losers.

The central development path for Estonia's bioeconomy: the development and earliest possible uptake of novel, biorevolution-inspired products. While Estonia is not able to compete with major economies in the development of new enabling technologies, it will rapidly expand its biotechnology capabilities, which will create the preconditions to compete in new high-growth industries.

SCENARIO 4: ADAPTATION TO ENVIRONMENTALLY CONSCIOUS AND COMMUNITY-BASED BIOREVOLUTION

Global biorevolution will bring about fundamental changes in the technological base of society, allowing for the restructuring of essentially the entire economy, including the replacement of most raw materials with more sustainable bio-based products to cope with climate change and preserve biodiversity, and for personalised approaches to food and medicine.

At the same time, however, the increase in the number of exceptional natural phenomena in the world and the generational change, particularly in Europe and also Estonia, will strengthen the importance of sustainability, biodiversity and valuing nature among societal values. This is why efforts will also be made to curb the spread of biorevolution, and naturalness will be valued in food production and in the cultivation of biomass in forestry and agriculture. As a result of these developments, biorevolution will be limited primarily to the medical, materials and energy sectors. Values such as localism, responsibility, organicity and wholesomeness will prevail in the food system and the natural environment, while biotechnological breakthroughs will tend to be met with caution in society (there will, however, be various niche products and a global market for them, including for the use of residues and co-products from forestry and the food system in other sectors).

The central development paths for Estonia's bioeconomy: focusing on technological development to accelerate the replacement of fossil raw materials, and on improving the sustainable use of local biomass, including the preservation of ecosystems and limiting biomass imports to ensure global access for all.

ESTONIA'S STRATEGIC OPTIONS IN THE DIFFERENT SCENARIOS

This analysis of development scenarios has identified four different development paths that the Estonian bioeconomy could take in the coming decades, depending on developments in the external environment. However, we do not yet know how fast biotechnologies will be taken up or what global agreements on climate neutrality, biodiversity conservation and economy will be reached in the coming decades. It would therefore be imprudent to try to decide at this point which scenario we would prefer to see materialise. The scenarios are intended to provide a framework to support strategic planning that will help the Estonian bioeconomy to succeed in very different worlds.

Based on the scenarios, Table 1 summarises the main options for increasing the added value generated by the Estonian bioeconomy. In analysing the expected contribution of the Estonian bioeconomy to socio-economic development, we consider, in each scenario, the likelihood of Estonia entering new, more complex product groups, including chemical processing of timber, production of biopharmaceuticals and new plant-based food and materials, as well as ICT solutions supporting the bioeconomy. In addition, we highlight the central aspects related to the achievement of environmental and climate goals for each scenario.

These four scenarios differ from each other in terms of the very different external environment in which Estonia will be making its choices for the development of the bioeconomy. They also have completely different central development logics and lead to very different outcomes in terms of land use, growth of added value, and other indicators.

TABLE 1. ESTONIA'S BIOECONOMY DEVELOPMENT SCENARIOS 2030–2050

	1. A bioeconomy for secure self-sufficiency	2. Estonia in a globalised and traditional bioeconomy	3. A global economy shaken by the biorevolution	4. Adaptation to environmentally conscious and community-based biorevolution
Main drivers in the external environment	Global insecurity: the need to ensure self-sufficiency in respect of essential products	Open trade and capital flows create the prerequisites for securing a better place in the global division of labour	Biotechnology will fundamentally change the current practices of using biomass and lead to entirely new areas of activity within bioeconomy	Europe will seek a balance between the application of novel biotechnologies and the preservation of traditional ecosystems and food systems
Specialisation of Estonia's bioeconomy	Current specialisation will continue, including food self-sufficiency and the widespread use of timber as a building material and as a locally managed energy source	Estonia's exports will move up the food and timber value chains towards more complex products, including chemical processing of timber. The production of pharmaceuticals will be a new area of activity	Estonia will be looking for opportunities to enter new product groups related to health promotion and food production that have emerged from the global biorevolution	Traditional food production and community-based business models will be promoted alongside the production of bioengineered novel materials
Central development logic for Estonia's bioeconomy to increase added value	Information technology solutions to increase self-sufficiency through the cascading use of bioresources and support to the circular economy	Large-scale investments in the acquisition of the best available technology and in the better use of low-value raw materials (cereals, milk, timber and grassland)	Widespread uptake of novel biotechnologies (including cell factories and synthetic biology) and the creation of novel bioproducts based on them	Selective participation in biorevolution (in particular in the areas of materials and energy). Data-driven solutions to support traditional food production
Contribution of bioeconomy to socio-economic development	The share of bioeconomy in the business sector will remain at 10%. Labour productivity will remain two to three times lower than in the Nordic countries	Labour productivity in Estonia's bioeconomy will be three quarters of that in the Nordic countries. Bioeconomy will account for up to 15% of the added value generated in the business sector	Thanks to new biotech-intensive industries, the added value generated by the bioeconomy will increase to 20–25% of the total added value generated in the business sector. Labour productivity in Estonia will be at a level comparable to the Nordic countries	
Contribution of bioeconomy and land use to environmental and climate goals	Afforestation and increased share of production of timber products with a long useful life (including wooden buildings) will support CO_2 sequestration	Specialisation in complex products and activities within the global economy will make it possible to cease activities with a large ecological footprint	Reduction in cattle breeding as a result of new foodstuffs will reduce greenhouse gas emissions and free up grassland for other uses, including afforestation	Environmentally conscious participation in the biorevolution will meet both economic and environmental objectives

Source: authors.

Below we list the main strategic breakthrough directions that will enable the Estonian bioeconomy to grow successfully under any circumstances.

I. SPECIALISING IN MORE COMPLEX ECONOMIC ACTIVITIES AND REDUCING DEPENDENCE ON LOCAL RAW MATERIALS

- **For the labour productivity and living standard of Estonia to approach that of the Nordic countries or Germany, the share of more complex products in Estonian exports, including those of the bioeconomy, needs to increase significantly. In the context of Estonia's bioeconomy, this is expected to require billions of euros of investment in the development of chemical processing of timber, the biopharmaceutical industry, and ICT solutions and machinery supporting the bioeconomy.**
- By contrast, successful entry in resource- and labour-intensive activities, such as textiles and clothing, is increasingly unlikely as Estonia's living standards are expected to rise. Climate goals and

competition for resources in the field of chemical processing of timber are also expected to reduce the use of timber for electricity and heat generation.

- The development of chemical processing of timber or the pharmaceutical industry is very capital intensive, requiring investments in the order of 1 billion euros per project. In Finland and Sweden, for example, companies do not usually finance such projects only from their own resources, but involve international syndicates of banks, national export credit funds and other actors[28]. Similarly, proactive attraction of foreign direct investment from Western Europe, the US and rapidly-developing Asia is crucial to accelerating structural changes in the Estonian economy and creating access to new markets. As production volumes and product complexity increase, dependence on local raw materials should decrease. Depending on the area of activity, this may imply an increase in the share of imported raw materials and components, as well as relocation of production outside Estonia, close to raw materials and/or key target markets.
- **The development of specialised suppliers supporting the development of bioeconomy (including those supplying ICT and electronics applications, machinery, chemical products, biotechnology intermediates, and technologies) has even better prospects in a globalised economy than the direct valorisation of biomass.**
- Traditional sectors of bioeconomy, such as food production or timber processing, do not develop technologies themselves, but rely heavily on the technologies and equipment developed by specialised suppliers. The presence of such enabling companies provides the producers of food and timber products, among others, with a major competitive advantage. In these technology-intensive industries, business is usually easier to scale up and be more productive.
- The technological competitive advantages associated with supporting the development of bioeconomy should be sought in particular in the rapidly developing fields of cloud computing, machine learning and artificial intelligence. These are areas with lower barriers to entry and a high potential where Estonian companies can succeed on their own. On the other hand, the manufacturing of specialised food production and woodworking equipment is characterised by increasingly slower technological development and growing scale. Those entering such well-established areas should consider attracting foreign investment, as well as mergers and acquisitions.

II. BIOREVOLUTION AND PRESENCE AT THE FOREFRONT OF THE EMERGING NEW ECONOMY

- **Estonian research and higher education must, as an absolute minimum, follow what is happening at the forefront of life sciences and biotechnologies, and develop capabilities to swiftly take up and further develop technologies created elsewhere**. A comparison with the current ICT sector is appropriate to assess the potential labour needs of the Estonian biotechnology sector. The ICT sector employs around 30,000 people whose creative efforts have resulted in several companies worth over one billion euros.
- In addition to increasing labour supply, funding for applied research is needed to build up the new emerging biotech-intensive economy. Furthermore, there is a need to ensure access to venture capital for established start-ups, both domestic and foreign, that are willing to locate a significant part of their operations in Estonia.
- **To attract major research and technology investments, Estonia should seek strategic partnerships with countries at the forefront of technology**. Limited resources make it impossible for small countries to compete with large ones in the R&D needed to develop the enabling technologies that underpin biorevolution. Due to limited human and financial resources, early-stage investments in new enabling technologies related to biorevolution are far too risky for Estonian companies, as well as for Nordic companies.
- The example of Singapore's biotechnology strategy demonstrates that even a foreign investment-based biotechnology strategy would require complementary public and private investments amounting to billions of euros over a decade[29].

III. AN OPEN AND RELIABLE INTERNATIONAL BUSINESS ENVIRONMENT

- **Maintaining and developing effective cooperation with the Nordic countries, Germany, Poland and the Baltic States is essential for Estonia to ensure mutual market access, security of supply for the (bio)economy, energy security and investment protection**. This will ensure that Estonian companies have access to a sizeable market and can import those bioeconomy products or technologies, the local production of which is unfeasible or inexpedient.
- **It is of utmost importance for Estonia to play an active role in shaping international agreements, standards and development paths concerning climate goals, biotechnology and the (bio)economy through the European Union and international organisations**. European countries have so far taken a much more conservative stance than many of the major powers in the uptake of biotechnologies, while Europe is also seeking to position itself as a leader in the green transition. At the same time, developments in many sectors in Europe and the world are taking place independently of Estonia. This is creating an environment in which Estonia should be ready to rapidly deploy completely new technologies in sectors such as health care, food and novel biomaterials. However, Estonia does not control the development of these technologies and products.

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[28] See, e.g.: *Metsä Group builds a new bioproduct mill in Kemi, Finland*, https://bit.ly/3oLpzb3.

[29] See e.g.: David Finegold, Poh-Kam Wong & Tsui-Chern Cheah "Adapting a foreign direct investment strategy to the knowledge economy: the case of Singapore's emerging biotechnology cluster", *European Planning Studies*, 12, 7, 2004.