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Bioeconomy during the COVID-19 and perspectives for the post-pandemic world: Example from EU

Ewa Woźniak*, Agata Tyczewska

Institute of Biorganic Chemistry Polish Academy of Sciences, Poznań, Poland



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ABSTRACT

The COVID-19 pandemic has had a significant impact on human lives around the world. A report from the World Health Organization (WHO) dated 10 May 2021 indicates that the pandemic has resulted in almost 3.2 million deaths globally, with over 157 million confirmed cases. The pandemic crisis may be the driving force for the global integration related to bioeconomy, especially to the implementation of the Sustainable Development Goals, development of national and regional bioeconomy strategies, enhancement of the importance of circular economy, assurance of food security as well as sustainable food production, and protection of biodiversity. However, the COVID-19 pandemic has interfered with the achievement of economic, environmental, and social targets in many EU and global initiatives. This article presents the challenges and threats during and after the COVID-19 pandemic, as well as opportunities that can be brought by for bioeconomy development.

Initiatives for the development of bioeconomy

The COVID-19 pandemic has impacted not only the EU economy but the global economy as well in terms of sustainable development and has revealed the importance of bioeconomy. Bioeconomy comprises those parts of the economy that use renewable biological resources from land and sea—such as crops, forests, fish, animals, and microorganisms—to produce food, materials, and energy (Bioeconomy Strategy, 2018). In 2017, bioeconomy generated 4.7% of gross domestic product (GDP) of the EU-27 and employed 8.9% of the labour force. The turnover of the European bioeconomy accounted for €2.2 trillion, with half of this contributed by the food, beverage, and tobacco industry and 19% by agriculture. In 2017, bioeconomy employed 17.5 million people, more than half of whom worked in the agricultural sector (53%) and a quarter in the food, beverage, and tobacco industry (25%) (Ronzon et al., 2020).

Several initiatives related to bioeconomy development started before the COVID-19 pandemic. The health crisis occurred at the same time when the EU policy agenda was undergoing a transformation towards the development of the bioeconomy (Fritsche et al., 2021). From 2012 the EU introduced or adopted many long-term initiatives supporting the development of bioeconomy, which include:

- Sustainable Development Goals - adopted from United Nation (UN) (SDGs);ⁱ
Bioeconomy Strategy in 2012 (Bioeconomy Strategy, 2012);
Updated Bioeconomy Strategy in 2018 (Bioeconomy Strategy, 2018);

European Green Deal;ⁱⁱ

Circular Economy Action Plan (EC, 2015);

Farm to Fork Strategy (Strategy, 2020); and

Biodiversity Strategy for 2030 (Biodiversity Strategy, 2020).

SDGs were adopted by all the Member States of the UN in 2015.ⁱ The 17 SDGs have been defined, with 169 associated targets (The Sustainable Development Report, 2020). The general orientation provided by the UN SDGs is of special interest and is a call to action to end poverty, to protect the planet, and to ensure that all people enjoy peace and prosperity by the year 2030 (Messerli et al., 2019). To achieve the SDGs, it is required to balance three dimensions of sustainable development: economic growth, social inclusion, and environmental protection (Heggen et al., 2020).

The first EU bioeconomy strategy was presented by the European Commission (EC) in 2012 (Bioeconomy Strategy, 2012). The aim of this strategy and its action plan was to create a more innovative, resource-efficient, and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes while ensuring that the environment is protected (Bioeconomy Strategy, 2012). In 2018, the EC published the Updated Bioeconomy Strategy, the aim of which is “to accelerate the deployment of a sustainable European economy so as to maximise its contribution towards the 2030 Agenda and its SDGs, as well as the Paris Agreement” (Bioeconomy Strategy, 2018).

The most ambitious and challenging goal set by the EC is the European Green Deal, which aims to make the EU, the world’s second-largest economy, climate-neutral by 2050.ⁱⁱ The EC had adopted the European

* Corresponding author.

E-mail address: ewozniak@ibch.poznan.pl (E. Woźniak).

Green Deal before the COVID-19 outbreak and defined its eight policy areas as follows: increasing climate action; clean, affordable, and secure energy; industry for a clean and circular economy; energy- and resource-efficient buildings; sustainable and smart mobility; sustainable food chain (farm to fork); biodiversity and ecosystems; zero pollution and toxic-free environments (The European Green Deal, 2019). The bioeconomy and biotechnology sector have huge opportunities to lead most of the transformation.

The next initiative—The Circular Economy Action Plan—was set in 2015, and is one of the main blocks of the European Green Deal, which is Europe's new agenda for sustainable growth. The EU's action plan aimed "to boost jobs, growth, and investment, while promoting the transition to a carbon-neutral, resource-efficient, and competitive economy" (Circular Economy, 2020). Its goal (EC, 2015) is to maximise the use of resources and materials keeping them in the economy for as long as possible while minimising waste. Among the five priority sectors, two were recognized in the EU's action plan: plastics and food waste (EC, 2015). According to the plan, plastic recycling is a crucial part of a circular economy and less than 25% of the collected plastic waste is currently recycled while about 50% goes to landfill (EC, 2015).

The Farm to Fork Strategy is the core of the European Green Deal. It aims to make food systems fair, healthy, and environmentally friendly (Strategy, 2020). According to the 2020 "Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system" of the EC, "new innovative techniques, including biotechnology and the development of bio-based products, may play a role in increasing sustainability, provided they are safe for consumers and the environment while bringing benefits for society as a whole" (Strategy, 2020). National policies should facilitate the transition to the bioeconomy and support the new essential biotechnologies. The implementation of The Farm to Fork Strategy in the EU countries is especially important in the context of food security, which was put at risk during the COVID-19 crisis.

The Biodiversity Strategy for 2030 is "a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems" (Biodiversity Strategy, 2020). A central part of the European Green Deal will also support a green recovery after the COVID-19 pandemic. According to the World Economic Forum (2019), more than half of the world's GDP (€40 trillion) depends on nature. Three key economic sectors that are nature-dependent are construction, agriculture, and food and drink, which generate close to €8 trillion of gross value added (World Economic Forum, 2019). The main elements of Biodiversity Strategy (2020) are as follows: establishing protected areas (for at least 30% of the land in Europe and 30% of the sea in Europe); restoring degraded ecosystems at land and sea across the whole of Europe (for instance, by reducing the use and harmfulness of pesticides by 50%, by planting 3 billion trees by 2030); unlocking €20 billion each year for biodiversity (for instance, through EU funds); and making the EU a world leader in addressing the global biodiversity crisis.ⁱⁱⁱ

Several executed Foresight Exercises have a significant input to bioeconomy as well. These are an instrument for strategic planning and public policy building. In the Report of the 5th SCAR Foresight Exercise Expert Group (2020) the targets for a safer, fairer planet by 2050 were indicated, such as zero CO₂, reduced pesticides use by 75%, health protection, keeping freshwater use at recent levels, etc. The COVID-19 crisis has highlighted the urgency and interconnection of all these issues.^{iv}

All presented initiatives are crucial to develop the world after COVID-19, which will ensure food security, save biodiversity, help mitigate climate change, practice the circular bioeconomy, use bioenergy, etc.

Socio-economic and environmental impact of COVID-19

The COVID-19 pandemic began to spread in Europe in March 2020 (Ladi and Tsarouhas, 2020). Its impact on the economy and environment cannot be fully measured at the current stage due to the lack of data. For

the present work, available data sources from the EU were used to show the short-term impact of COVID-19 on the environment and economy.

According to De Vet et al. (2021) the euro area¹ has encountered a larger hit in 2020 (compared to the global economy) and will experience a slower recovery in 2021. By mid-2022, real GDP is expected to reach pre-crisis levels (De Vet et al., 2021). In mid-2019, the prevalence of unemployment decreased to the lowest levels since 2008 for the euro area and since 2000 for the EU as a whole (Eurostat, 2019). The current pandemic and economic shutdown have led to an unprecedented rise in the number of employees who are absent from work and increased job loss (EC, 2020a). According to the estimated data from EC (2020a), the loss for median employment income at the EU level was -5.2% in 2020 compared to 2019. The national governments of EU countries have introduced short-term work programs to address the economic challenges posed by COVID-19, in particular job preservation policies (see the next paragraph).

In the second quarter of 2020, the employment rate in the EU dropped to 72.0%, which is lower by 1.3% compared to the second quarter of 2019. The employment rate decreased on an annual basis in all EU countries, except in Croatia (+0.7%) and Malta (stable). The strongest decreases were recorded in Bulgaria and Spain (-3.2% for both) as well as in Austria and Ireland (-2.4% for both) (EC, 2020a). Young employees and low/medium educated workers accounted for the strongest decrease in the employment rate. The "wholesale and retail trade, transport, accommodation and food service activities" sector showed the strongest year-to-year decline in the third quarter of 2020 (EC, 2020a).

After the peak observed in July 2020, the unemployment rate in the EU and the euro area slightly decreased over the last months. In October 2020, the unemployment rate was 7.6%, whereas in March 2021 it was 7.3% (EC, 2020a; Eurostat, 2020). Based on OECD data, the unemployment rate in the US declined from 9.9% in October 2020 to 6.0% in March 2021. In Japan the unemployment rate was stable during this time and oscillated within 3%.^v

In 2020, the EU agricultural sector faced unprecedented challenges due to the COVID-19 pandemic and its consequences (EU Agricultural Outlook, 2020). The pandemic will be a major influencing factor for the development of the world economy over the next two years. In the EU agricultural outlook report (2020), two scenarios were prepared based on alternative economic recovery pathways, including a "slow recovery" and a "green recovery."

According to Eurostat the annual inflation rate of the euro area was 1.3% in March 2021 (one year earlier, the rate was 0.7%), while that of the EU was 1.7% (one year earlier, the rate was 1.2%) (Eurostat, 2021). The lowest annual rates were registered in Greece, Ireland and Malta (from -2.0% to 0.1%), whereas the highest were in Romania, Hungary, and Poland (from 2.5% to 4.4%). Rising prices of a number of basic products, such as rice, flour, milk, as well as services - hospitals, vets, public transport have contributed to the high inflation.

It has been estimated that the EU economy will grow from 4.2% in 2021 to 4.4% in 2022. For comparison, the recovery forecasts for China is 7.8% growth for 2021 and decline to 4.9% in 2022. For the US a decline of real GDP from 6.5% in 2021 to 4.0% in 2022 has been estimated, whereas for India a decline from 12.5% in 2021 to 5.4% in 2022 has been forecasted (OECD Outlook, 2021; ^{vi}).

The economic development will be determined by how successful vaccination programmes will be and how quickly national governments will lift restrictions. Moreover, the EU is expected to gradually decline private consumption from 19.4% in 2020 to 13.6% in 2022. ^{vi}

Tourism is one of the sectors most affected by the COVID-19 pandemic, with an impact on travel and demand (Nicola et al., 2020). The World Tourism Organization (UNWTO) monitors short-term trends of global tourism. In 2020 there was a 74% decrease in international tourist arrivals, with only 381 million arrivals, whereas in 2019 1.5 bil-

¹ The euro area includes 19 countries. The EU includes 27 countries

lion arrivals were recorded.^{vii} In Europe, a 70% decline was noted in 2020 when compared to 2019. The scenarios presented by the UNWTO for 2021–2024 indicated that it could take between two-and-a-half and four years for international tourism to return to 2019 level.^{viii} The data showed that the estimated loss in global GDP accounts for US \$2 trillion. The biggest decline in the international tourist arrivals was in Asia and The Pacific (84%) and Middle East (75%).^{vii}

Another difficult-to-estimate issue at this time is the production of plastics and waste and their recycling. The pandemic has led to a sudden increase in the global demand for masks, gloves, and bottled hand sanitisers, called personal protective equipment (PPE), as well as the need for plastic packaging for delivery services. In March 2020, the WHO called on industry and governments to increase manufacturing by 40% to meet the growing global demand.^{ix}

On the other hand, the pandemic-related lockdown may have some direct, short-term positive impacts on the environment, particularly regarding the emission and air quality at both global and EU levels. In the transport sector, which is an important source of greenhouse gases (GHG), the demand for passenger transport (via air and roads) has declined due to restrictions in traveling.^x

The air quality and COVID-19 viewer of the European Economic Area (EEA) tracks the average weekly and monthly concentrations of nitrogen dioxide (NO₂) and particulate matter (PM 10 and PM 2.5). Data show that the NO₂ concentration, which is associated with road transport, has decreased in many European cities where lockdown has been implemented.^{xi} A significant variation is observed in the scope of depletion, with the largest reductions of up to 70% seen in urban centres in the countries that are most affected by COVID-19 at that time, such as Milan and Madrid.^{xi} According to [Menut et al. \(2020\)](#), a resolution of 20 km shows a decrease in NO₂ concentrations ranging from -30% to -50% in all western European countries. In turn, the ozone concentrations have increased in urban areas throughout Western Europe due to lockdown measures.

The COVID-19 pandemic has both positive and negative impacts on environmental degradation ([Shakil et al., 2020](#); [Rume and Didar-Ul Islam, 2020](#)). The GHG emission, NO₂ concentration, water pollution (especially pollution in beaches), and noise pollution have reduced significantly due to full or partial lockdowns ([Chakraborty and Maity, 2020](#); [Saadat et al., 2020](#); [Wang and Su, 2020](#); [Zambrano-Monserrate et al., 2020](#)). However, the findings do not support a long-term reduction in GHG, because once the lockdown is removed the economic activity and energy consumption are likely to return to normal as a majority of industrial activities will be resumed ([Wang and Su, 2020](#)).

EU actions to fight COVID-19 and recovery plan

The COVID-19 pandemic has affected the global economic downturn. Several production systems are expected to face challenges with the realization of the potential of bioeconomy to produce more efficiently and maintain value chains that sustain jobs and livelihoods, while ensuring the sustainable use of land in the face of climate change.

In order to repair the economic and social damages caused by the pandemic, the EC agreed on a recovery plan including the EU's long-term budget and the NextGenerationEU initiative - a €750 billion temporary recovery instrument. It is estimated that a total of €1.8 trillion will be needed to rebuild a post-COVID-19 Europe. On November 10th 2020, an agreement was reached between the European Parliament and the EU countries in the Council for the years 2021–2027.^{xii} It has been agreed that more than 50% of the fund will support modernisation through three sectors: research and innovation (via Horizon Europe); fair climate and digital transitions (via the Just Transition Fund and the Digital Europe Programme); and preparedness, recovery, and resilience (via the Recovery and Resilience Facility, rescEU, and a new health program called EU4Health).^{xiii}

The European Central Bank (ECB) established the pandemic emergency purchase program, with a total fund of €1850 billion for stabilising and strengthening the euro area through the pandemic.^{xiii}

In the fight against COVID-19, the EC is working with the WHO, to ensure access to medical supplies and support vaccine deployment. They take actions to support national health administrations by organising training for medical and laboratory staff.^{xiv} Moreover, the EC offers financial support for small and medium-sized enterprises (SMEs), as well as self-employed not only in the EU member countries.^{xv} To slow the spread of the virus EC restricted unnecessary travel to EU countries, introducing a map showing the risk zones. This lets people know the epidemiological situation region by region.^{xvi} The most important measure to slow the spread of COVID-19 is providing safe and effective vaccines. According to the European Centre for Disease Prevention and Control (ECDC) the number of total doses of vaccines distributed to EU/EEA countries accounted for 209 million (as at 12.05.2021). Almost half (47,3%) of the doses were distributed to Germany, France and Italy. About 65% of doses were a Comirnaty product (Pfizer).^{xvii}

The EU also supports the most hit economic sectors such as agriculture and fisheries. These sectors are the base for the bioeconomy development ([Woźniak et al., 2021](#)). Rural development beneficiaries, such as farmers, will be able to take advantage of loans or guarantees to cover operational costs of up to €200,000 at favourable terms, such as very low interest rates or favourable payment schedules. Moreover EU members can offer support of up to €7,000 per farmer and €50,000 per SME.^{xviii}

In order to diminish the economic and social impacts of the COVID-19 pandemic, national authorities initiated measures that give partners in the public-private partnership (PPP) some form of relief and financial compensation.^{xix}

One of the actions to facilitate safe free movement in the EU during the COVID-19 pandemic is The Digital Green Certificate. European Commission proposed it in March 2021. The document will attest that a person has been vaccinated against coronavirus or had a recent negative test result or have recovered from infection. In April the proposal for the Digital Green Certificates was adopted by European Parliament.^{xx}

Establishing and updating policies

Bioeconomy strategy is an important part of national and regional policy. Almost 60 countries around the world have implemented bioeconomy-related policies such as research and innovation, biotechnology, bioenergy, and bio-based economy. Different countries might adopt different official policies for the COVID-19 pandemic, for example countries including Portugal, Canada, and Finland are specializing in certain aspects of bioeconomy, namely blue bioeconomy or the forest-based bioeconomy ([Global Bioeconomy Policy Report, 2020](#)).

The bioeconomy-related strategies/action plans of Costa Rica, Italy, and Japan were released in the aftermath of the pandemic ([Global Bioeconomy Policy Report, 2020](#)). In the documents, special attention has been paid to the impact of the pandemic. In the Italian action plan, bioeconomy is seen as an area for accelerating the post-COVID-19 departure, while Japan's updated strategy highlights the role of bioeconomy in the post-COVID-19 period in the development of measures against future public health crises and in building an efficient supply chain ([Global Bioeconomy Policy Report, 2020](#)).

Biotech sector opportunity

In the conference report 'New Perspectives on the Knowledge-Based Bio-Economy', it was noted that 'bioeconomy is one of the oldest economic sectors known to humanity, and the life sciences and biotechnology are transforming it into one of the newest' ([EC, 2005](#)). Biotechnology is an 'important pillar of Europe's economy, indispensable to sustainable economic growth, employment, energy supply and to maintaining the standard of living' ([EC, 2007](#)). Therefore biotechnology is one

of the foundations for innovative bioeconomy. In the past decade, advances in molecular biology (genetic engineering methods, new breeding techniques) have stimulated a wide range of changes in bioeconomy, for instance in food production, forestry, and production of third-generation biofuels (Woźniak et al., 2021; Tyczewska et al., 2018). The sudden outbreak of the COVID-19 pandemic has led to a demand for combined efforts of various parties of the biotechnology industry. As Shahzad Malik, general partner at London-based Advent Life Sciences, indicated, “had this crisis hit a less-well-capitalized, and less mature biotech sector 15 years ago, it would have been catastrophic” (Senior, 2020).

COVID-19 pandemic

The COVID-19 outbreak has caused a global health alert due to its high rate of infection (rapid human-to-human transmission) and mortality (1–3%), in addition to generating complex clinical conditions. This has forced the scientific community to explore various strategies for combating the viral infection as well as treating life-threatening systemic responses to the infection. Within the last year, the joint efforts of scientists all around the world brought out the full potential of the biotechnology sector in the fight against COVID-19 (Lobo-Galo et al., 2021; Uthaya Kumar et al., 2021). The efforts undertaken can be divided into several domains as follows.

Diagnostics

Diagnostics plays an important role in the management of infectious diseases as it allows preventing the spread of infections between persons and communities. The first step in managing COVID-19, given its high contagiousness and expeditious spread, is the rapid and accurate detection of SARS-CoV-2 in nasopharyngeal fluids (Chen et al., 2021; Kevadiya et al., 2021; Bostan et al., 2020; Zhu et al., 2020; Lobo-Galo et al., 2021; ^{xxi}). Two types of tests have been developed for the diagnosis of COVID-19: nucleic acid tests and antibody tests. Recently, in the document prepared by EC, a total of 471 available genetic tests for SARS-CoV-2 have been listed. ^{xxii} Of these, 365 are already commercialized and the remaining are in the process of validation or under development. At present, in the FIND database, ^{xxiii} 1129 SARS-CoV-2 diagnostic devices are mentioned, under categories such as immunoassays, molecular assays, sample collection/inactivation, digital solutions, and other diagnostics. It should be emphasized that in the pandemic outburst many scientists who were engaged on a daily basis in basic research, from various institutions including the Pasteur Institute (France) and Institute of Bioorganic Chemistry PAS (Poland) and various groups including the SONAR team, worked to help in the development of diagnostic tests for SARS-CoV-2 ^{xxiv,xxv,xxvi}

Vaccines

Given the urgency to develop an effective vaccine against COVID-19, several previously developed strategies such as complete but attenuated virus strategy, complete recombinant antigenic viral proteins as subunit vaccine or as part of adenoviral vector, and finally novel nucleic acid (DNA, mRNA) delivery technology (Hume and Lua 2017, and work cited within), have been used. Besides, in an ongoing effort, certain companies and research groups around the globe are working on the development of plant-based vaccines (Uthaya Kumar et al., 2021; Machhi et al., 2021). The search of research groups for a COVID-19 vaccine has been successful so far, as currently there are four vaccines approved by the European Medicines Agency (EMA) for use in the EU: Comirnaty (Pfizer/BioNTech), COVID-19 Vaccine Moderna, Vaxzevria (COVID-19 Vaccine AstraZeneca), and COVID-19 Vaccine Janssen. ^{xxvii} The first two are mRNA-based, and the later two are adenovirus-based vaccines. Additionally, four vaccines CVnCoV (CureVac AG), NVX-CoV2373 (Novavax CZ AS), COVID-19 Vaccine (Vero Cell) Inactivated (Sinovac Life Sciences Co., Ltd), and Sputnik V (Gam-COVID-Vac) (Russia’s Gamaleya National Centre of Epidemiology and Microbiology) are under rolling

review. ^{xxviii} Furthermore, as many as 97 and 183 vaccines are in the clinical and preclinical development phase, respectively. ^{xxix}

Therapeutic strategies

To date, five therapeutic COVID-19 treatments were approved in the EU: dexamethasone, monoclonal antibody combination bamlanivimab/etesevimab, monoclonal antibody combination casirivimab/imdevimab, monoclonal antibody regdanvimab, and sotrovimab (VIR-7831). ^{xxx} In addition, therapeutic administration of convalescent sera is advocated for the treatment of patients with COVID-19 (Lobo-Galo, 2021). However, reports present conflicting data on the effectiveness of such treatments. Some suggest that, when administered early in the infection, the treatment diminishes severe COVID-19 symptoms by reducing the viral load and preventing significant pathological damage associated with the infection, whereas others indicate that the treatment is not very beneficial (Samad, 2020; Lobo-Galo, 2021).

Since the beginning of the pandemic, there has been an intense global effort to repurpose existing approved drugs for the treatment of COVID-19 (De Savi, 2020; Zhou et al., 2020; Delre et al., 2020; Zhang et al., 2021; Singh et al., 2020; Lobo-Galo et al., 2021). This approach allows for a reduction in development timelines as well as overall costs compared to the de novo drug discovery process. The techniques used include in silico, in vitro, and in vivo methods, in both cell cultures and animal models. As reported by Zhou et al. (2021), “artificial intelligence (AI) and network medicine offer cutting-edge application of information science to defining disease, medicine, therapeutics, and identifying targets with the least error.” In a large-scale repurposing survey, 12000 known drugs were analysed, and 30 of them were found to show antiviral activity against SARS-CoV-2 (Riva et al., 2020). In a virtual screening to identify covalent and non-covalent inhibitors of the SARS-CoV-2 papain-like protease (PLpro), 688 drugs in phase III and 1702 drugs in phase IV clinical trial were included and 24 out of them were identified as potential therapeutics (Delre et al., 2020). To date, a number of drugs such as remdesivir, favipiravir, ribavirin, lopinavir, ritonavir, darunavir, arbidol, chloroquine, hydroxychloroquine, tocilizumab, and interferons have been found to show inhibitory effects against SARS-CoV-2 in in vitro as well as in clinical conditions (Rosa and Santos, 2020). Other examples of repurposing approaches have been described by Singh et al. (2020), Lobo-Galo et al. (2021), and De Savi et al. (2020). Apart from repurposing known drugs, increasing attention is paid to the use of natural products (from plants and marine environments) against COVID-19 (Hassan, 2020; Ang et al., 2020; Mani et al., 2020; Joshi et al., 2020; Xian et al., 2020; Verma et al., 2020; Huang et al., 2020; Khan et al., 2020).

Nanotechnology

Nanomaterials represent a powerful tool against COVID-19. So far, many reports have detailed the development of nano-based materials, such as disinfectants, PPE, and diagnostic systems (Rangayasami et al., 2021; Cardoso et al., 2020; Sportelli et al., 2020; Campos et al., 2020; Lobo-Galo et al., 2021). Alternatively, nanomaterials can be used as nanocarrier systems for treatment against COVID-19 or in the development of vaccines against SARS-CoV-2 (Machhi et al., 2021; Heinrich et al., 2020; Shin et al., 2020; Lobo-Galo et al., 2021).

Pandemic and post-pandemic challenges of the biotech sector

Biotech and pharmaceutical sectors play a pivotal role in the fight against the COVID-19 pandemic. However, they cannot be entirely decoupled from the rest of the global economy (Senior, 2020; Reilly, 2020; Rosales-Mendoza et al., 2020; Ayati et al., 2020). The COVID-19 pandemic has significantly affected the conduct of clinical trials of medical products as thousands of trials have been suspended or stopped due to the difficulties in their execution under lockdown conditions (Bacchieri et al., 2020; van Dorn, 2020; Xue et al., 2020). Some of the challenges associated with performing clinical trials are quarantines,

site closures, and travel limitations for site personnel and/or trial subjects. Specific guidelines on clinical trials with recommendations on data management, statistics, and medical writing-related matters have been issued by the EMA and Food and Drug Administration (FDA) for the countries/regions impacted by COVID-19 (EMA, 2020; ^{xxxii}).

The COVID-19 pandemic has not just disrupted the undertaking of clinical trials in the biotech sector. Due to the limited presence of research personnel in the laboratories, most academic research groups and biotech research facilities around the world had to either stop or drastically modify their activities. Additionally, some resources, apart from highly specialised personnel, such as professional equipment or laboratory spaces, have been used to help fight the pandemic. According to Noubar Afeyan, the founder and CEO of Flagship Pioneering, the current productivity of many research-based biotech companies was only at 30–50%. This causes not only time delays but also massive economic losses (Senior, 2020).

Notably, the pandemic is also a catalyst for change, innovation and investment. Some of the expected long-term effects of the current pandemic in the biotech sector are: i) increasing the share of telemedicine in health care, constituting opportunities and challenges for the providers, ii) re-evaluation of geographical diversification of biotech companies' supply chains and clinical trials, iii) boom for diagnostic manufacturers as a remedy for future pandemics, iv) increased interest in funding innovative and mission-critical solutions and biotech companies, v) advances in information technology and investments in IT infrastructure. ^{xxxii,xxxiii,xxxiv}

As a result of shifting resources from agriculture to medical COVID-19 research, the agriculture research is declining in some countries; the projected decline in funding in 2021 by USDA is 0.2 billion \$.^{xxxv} This trend may not be long-drawn and the public sector agricultural research could increase in the next few years as, for example, the EU plans to allocate billions of euros for the EU bioeconomy sector. The technological progress made during the pandemic is also creating opportunities for agricultural and energy research as the lessons learnt from the COVID-19 pandemic on the understanding of the genomics of a virus, breaking virus transmission and diagnostics can be applied for livestock and plant viruses and epidemics. Furthermore, the pandemic disruptions of food supply chains increased the demand for vegetable-based meat and e-commerce. It also highlighted growing shortages of agricultural labor (which may indicate the need for farms' mechanization), and of resources like water and environmental services.^{xxxv}

Communication and social perception

The transition toward bioeconomy depends not only on the attempts and enthusiasm of experts and policymakers but also on the acceptance and involvement of society (Woźniak et al., 2021). In mid-2020, about 39% of Europeans believed that one of the three biggest challenges in their countries is access to healthcare and health services, while 67% indicated economic and financial challenges and 47% indicated climate change (EIB Climate Survey, 2020).

At present, the prevention of the spread of COVID-19 in society, mainly with vaccines recommended by appropriate authorities like the EMA (2020), is a crucial issue. The current pandemic has caused widespread mistrust about the safety and effectiveness of vaccines around the world (de Figueiredo et al., 2020). Negative attitude toward vaccines and uncertainty or aversion to vaccination among people have become the major obstacles to managing the COVID-19 pandemic in the long term (Paul et al., 2020).

In 2020, several research works have been conducted across the world with a focus on gathering the opinions of people about the COVID-19 pandemic. At the end of 2020, Kantar Company conducted a survey among 7000 people from Australia, France, Germany, Great Britain, Italy, Singapore, and the US to know their opinions on vaccination against COVID-19.^{xxxvi} Across these countries, only a minority of people said that they will definitely take a COVID-19 vaccine when it becomes

available. The survey showed that people in France were the most reluctant to take a vaccine, whereas people in Australia and Great Britain were the most accepting. In Singapore and France, people expressed a significant level of concern related to the speed at which the COVID-19 vaccines are being developed and produced. In contrast, in Great Britain and Australia, 75% of the survey participants perceived vaccines as safe. Regarding the trust in public authorities and government, the respondents from the USA and France indicated that the most reliable sources of information on the COVID-19 vaccine were family doctors (50% and 43%, respectively). Health authorities were considered the most reliable sources by people in Singapore and Italy (66% and 63%, respectively). In contrast, doctors appearing in the media were not considered as a reliable source of information by people in all the countries surveyed. In Singapore, 56% of respondents indicated that the country's government is a reliable source of information, whereas in the USA only 14% indicated that they trusted their government. In France, 48% of citizens declared that they did not trust the government to make the right decision about making a vaccine against COVID-19 available.^{xxxvi}

According to the Public Opinion Survey commissioned by the European Parliament in 2020 (Report EP, 2020), three out of four European citizens (76%) have heard about the various EU measures proposed to fight the consequences of the COVID-19 pandemic. Of those, 49% stated that they were satisfied with the proposed measures, while about 53% of the respondents across the EU were not satisfied with the solidarity shown in the EU Member States. Moreover, 56% of Europeans believed that the EU should have greater financial means to be able to overcome the effects of the pandemic. Sixty-eight percent of respondents agreed that "the EU should have more competences to deal with crises such as the Coronavirus pandemic," while the least number of respondents in the Czech Republic, Sweden, the Netherlands, Finland, and Croatia indicated the same (Report EP, 2020).

At this point, it is impossible to predict how the public will react or how supportive or participating they will be in a recovery and resilience plan. However, this is the right moment to start discussing the advancements of science, new technological solutions that help not only in the face of the current pandemic but also in our daily lives. The pandemic, which has been going on for more than a year, exposed gaps in public knowledge and a moderate level of confidence in scientists. Unchecked, and even worse, untrue information is disseminated at an alarming rate, contrary to recognized scientific facts, which are not only often ignored by society, but also ridiculed. Now it is time to act. The trust in science and scientists can be rebuilt through education, and campaigns informing and engaging the public.

Concluding remarks and future perspectives

The outbreak of COVID-19 has caused a worldwide crisis with immense proportions being propelled by weak health systems, lack of clean water and sanitation, poverty, hunger, limited access to education, and global cooperation. The pandemic has also inflicted devastating effects on most aspects of the global economy. Hence, the success of SDGs is now at stake, as it depends on sustained economic growth and globalisation (Heggen et al., 2020; Editorial, 2020; Ng, 2020; Naidoo and Fisher, 2020). It has been estimated that all the 17 SDGs are threatened or partially threatened by the COVID-19 outbreak and that two-thirds of the 169 SDG targets are either under threat due to the pandemic or not well placed to alleviate its impacts (Naidoo and Fisher, 2020). As stated in *The Sustainable Development Goals Report 2020*, the progress made since the adoption of the SDGs in 2015 was insufficient and SDGs are now facing a regressive impact (*The Sustainable Development Report, 2020*). However, according to the EC, bioeconomy can contribute to economic recovery as it can stimulate the EU recovery from the COVID-19 crisis by aligning the economy with the biosphere (EC, 2020b). Although, limited data on the impact of the pandemic on the bioeconomy is currently available, the link between the bioeconomy

and post-COVID-19 recovery is still discussed by many experts, not only in the light of impacts, but also possible responses (Fritsche et al., 2021).

COVID-19 has uncovered the weaknesses in global food supply chains (COVID-19 and SDGs, 2021), which may have a negative impact (can be measured in the next few years) on eliminating hunger and poverty (SDG1 and SDG2). According to the Department of Economic and Social Affairs of the United Nations (2020), 6% of the global population would still be living in extreme poverty in 2030, and thus the target of ending poverty would be missed. It is estimated that due to the COVID-19 pandemic 71 million additional people will be living in extreme poverty (The Sustainable Development Goals Report, 2020). Failure to achieve SDG1 and SDG2 is connected to poor access to water and sanitation (SDG6), which remains a major health issue during the pandemic. The goal of ensuring good health and well-being (SDG3) mainly by reducing maternal and child mortality, HIV/AIDS cases, and malarial deaths is also threatened because of interruptions in the vaccination campaign in 70 countries. Moreover, around the world, health services that were functioning for screening cancer and non-COVID-19 infectious diseases have been disturbed, to say the least (Editorial, 2020; The Sustainable Development Goals Report, 2020).

The fourth SDG aims at ensuring that by 2030 all young people receive an inclusive and equitable quality education. However, according to The Sustainable Development Goals Report (2020), more than 200 million children will still not be receiving education by 2030. Moreover, most of the children in the world have been deprived of opportunities to study during the lockdown. As reported by the United Nations Educational, Scientific and Cultural Organization (UNESCO), nearly 1.6 billion learners in more than 190 countries, which account for 94% of the world's student population, were affected by the closure of educational institutions at the peak of the crisis. As many as 100 countries have yet to announce a date for schools to reopen (UNESCO, 2020).

The SDG8 dedicated to decent work and economic growth was also hit by the pandemic, as according to the International Labour Organization (ILO) working hours equivalent to 495 million full-time jobs were lost around the world due to lockdown. In addition, estimates (before taking into account the income support measures) suggest a global labour income loss of 10.7% during the first three quarters of 2020 (compared with the corresponding period in 2019), which amounts to US \$3.5 trillion, or 5.5% of global GDP in the first three quarters of 2019 (ILO, 2020).

The Sustainable Development Goals Report (2020) also indicates that the environmental sustainability goals described under SDG7, SDG9, and SDG11–15 may also be hard to achieve by 2030. At the beginning of the COVID-19 pandemic, when many international borders were closed and populations were confined to their homes, there was a reduction in global energy use and CO₂ emissions (by 8.8%) (Le Quééré et al., 2020; Liu et al., 2020). Although there is an opportunity for a green recovery that will revive economies and advance climate goals^{xxxvii}, the post-pandemic emissions could boomerang and exceed the pre-pandemic levels (Kuzemko et al., 2020). This is due to the fact that the observed alterations do not reflect structural changes in the economic, transport, or energy systems. The key to durable decarbonisation is switching from non-renewable sources to renewable ones by replacing fossil fuels with renewable fuels, introducing recyclable materials, and replacing petroleum-based products with plant-based alternatives. Furthermore, reduction in the GHG footprint of agriculture can be achieved with improved plant varieties created using modern technologies.

The COVID-19 pandemic has endangered the implementation of the European Green Deal, and thus the development of regional and national strategies for the growth of bioeconomy. In the EU countries, the authorities are changing their priorities and putting the health and welfare of their citizens first, postponing actions related to the development and establishment of National Energy and Climate Plans.^{xxxviii} The EC needs to revise the legislative proposal for the 2021–2027 financial framework and consider the global economic situation caused by the COVID-19 pandemic. According to the current proposal, 25% of the EU budget would

be dedicated to climate action plans (Erbach, 2020; Elkerbout et al., 2020). As indicated by Becchetti et al. (2021), the EU Green Deal must learn some lessons from the COVID-19 pandemic, which underlined the strong relationship between the environment, health, and economy. There is a need for a new paradigm aimed at limiting the disclosure of economic value creation to environmental, pandemic, and social risks. The COVID-19 pandemic has revealed a vicious circle of the following: unsustainable development, environmental degradation, new pandemic threats, lockdown, economic downturn, and job losses (Becchetti et al., 2021).

The paper published by the Ellen MacArthur Foundation showed how policymakers can pave the way for a low-carbon and prosperous economic recovery (Ellen MacArthur, 2020). It underlined the circular investment opportunities across five key sectors: built environment, mobility, plastic packaging, food, and fashion. The actions taken by the government today will shape the post-COVID world for generations to come. The pandemic has highlighted the ineffectiveness of single-use packaging as during the pandemic the PPE, used especially by hospital workers, was mostly made of plastics (de Sousa, 2020). Hence, there is an urgent need to replace the plastic items with materials that can be safely reused, recycled, or composted. By replacing just 20% of single-use plastic packaging with a reusable substitute, it is possible to gain an economic opportunity worth at least US \$10 billion, and about 6 million tons of materials can be saved (Ellen MacArthur, 2020). The global packaging market size is expected to grow from US \$909 billion in 2019 to US \$1.013 billion by 2021, with the plastic segment leading the market.^{xxxix} The circular economy can play an essential role in managing plastic waste, a problem that existed before the pandemic, and in shaping the economic recovery, which will not only save cost and materials but also protect the environment from waste and pollution (Ellen MacArthur, 2020). The COVID-19 pandemic highlights the need for the development of bioeconomy and biotechnology, as well as the necessity of social acceptance of new breeding techniques in sectors related to health and plants. Regulatory changes must be made to ensure the prosperity of biotech companies. The present crisis allows the politicians and stakeholders to see the opportunities for the development of the biotech sector; however, consumer acceptance is needed.

Authors' contributions

EW conceived the general idea and concept of the article. EW and AT drafted the manuscript. EW described the EU initiatives toward bioeconomy, and analysed the socio-economic and environmental impact of COVID-19. EW described the policy and public opinion aspects. AT analysed and described the opportunities in the biotech sector during and after the pandemic. EW and AT wrote the concluding remarks and future perspectives section. Both the authors have reviewed and approved the final manuscript.

Resources

- ⁱ SDGs EU, https://ec.europa.eu/international-partnerships/sustainable-development-goals_en [accessed 01 March 2021].
- ⁱⁱ EU Science Hub, <https://ec.europa.eu/jrc/en/publication/thematic-reports/tracking-eu-citizens-interest-ec-priorities-using-online-search-data-european-green-deal> [accessed 01 March 2021].
- ⁱⁱⁱ EU Biodiversity strategy for 2030, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/eu-biodiversity-strategy-2030_en [accessed 02 March 2021].
- ^{iv} Report of the 5th SCAR Foresight Exercise Expert Group, <https://scar-europe.org/images/FORESIGHT/FINAL-REPORT-5th-SCAR-Foresight-Exercise.pdf> [accessed 10 April 2021].
- ^v OECD, <https://www.oecd.org/newsroom/unemployment-rates-oecd-update-april-2021.htm> [accessed 10 May 2021].
- ^{vi} EC Spring 2021 Economic Forecast: Rolling up sleeves, <https://ec.europa.eu/info/business-economy-euro/economic->

performance-and-forecasts/economic-forecasts/spring-2021-economic-forecast_en [accessed 02 May 2021].

^{vii} UNWTO World Tourism Barometer, Tourism data dashboard, <https://www.unwto.org/unwto-tourism-dashboard> 2021 [accessed 26 Feb 2021].

^{viii} UNWTO Barometer, World Tourism Barometer and Statistical Annex, <https://www.e-unwto.org/doi/abs/10.18111/wtobarometereng.2021.19.1.1> [accessed 26 Feb 2021].

^{ix} WHO- Shortage of personal protective equipment endangering health workers worldwide, <https://www.who.int/news/item/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide> [accessed 03 March 2021].

^x EEA- COVID-19 and Europe's environment, <https://www.eea.europa.eu/post-corona-planet/covid-19-and-europes-environment> [accessed 26 Feb 2021].

^{xi} EEA- Air quality and COVID-19, <https://www.eea.europa.eu/themes/air/air-quality-and-covid19> [accessed 26 Feb 2021].

^{xii} Recovery plan for Europe https://ec.europa.eu/info/strategy/recovery-plan-europe_en [accessed 15 Feb 2021].

^{xiii} ECB - Pandemic emergency purchase programme (PEPP), <https://www.ecb.europa.eu/mopo/implement/pepp/html/index.en.html> [accessed 01 March 2021].

^{xiv} EU response to the coronavirus pandemic, https://ec.europa.eu/neighbourhood-enlargement/news_corner/eu-response-to-the-coronavirus-pandemic_en [accessed 15 May 2021].

^{xv} Supporting European business during the pandemic, https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/jobs-and-economy-during-coronavirus-pandemic/supporting-european-businesses-during-pandemic_en [accessed 15 May 2021].

^{xvi} 10 things the EU is doing to fight COVID-19 and ensure recovery, <https://www.consilium.europa.eu/en/policies/coronavirus/10-things-against-covid-19> [accessed 15 May 2021].

^{xvii} COVID-19 vaccine tracker, <https://gap.ecdc.europa.eu/public/extensions/COVID-19/vaccine-tracker.html#distribution-tab> [accessed 15 May 2021].

^{xviii} Supporting the agriculture and food sectors amid Coronavirus, https://ec.europa.eu/info/food-farming-fisheries/farming/coronavirus-response_en [accessed 20 May 2021].

^{xix} Clarification on the implications of COVID-19 measures on the statistical treatment, https://ec.europa.eu/eurostat/documents/10186/10693286/PPPs_methodological_note_COVID-19.pdf [accessed 10 May 2021].

^{xx} COVID-19: Digital green certificates, https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/safe-covid-19-vaccines-europeans/covid-19-digital-green-certificates_en [accessed 27 May 2021].

^{xxi} European Centre for Disease Prevention and Control. Diagnostic testing and screening for SARS-CoV-2, <https://www.ecdc.europa.eu/en/covid-19/latest-evidence/diagnostic-testing> [accessed 27 May 2021].

^{xxii} European Commission (EC). Current Performance of COVID-19 Test Methods and Devices and Proposed Performance Criteria, <https://ec.europa.eu/docsroom/documents/40805> [accessed 27 May 2021].

^{xxiii} FIND. Sars-cov-2 diagnostic pipeline, <https://www.finddx.org/covid-19/pipeline/> [accessed 27 May 2021].

^{xxiv} Operation and reliability of RT-PCR tests in the detection of Sars-cov-2, <https://www.pasteur.fr/en/home/press-area/press-documents/operation-and-reliability-rt-pcr-tests-detection-sars-cov-2> [accessed 10 Feb 2021].

^{xxv} Medicofarma, <https://medicofarma.pl/coronavirus-test/> [accessed 02 March 2021].

^{xxvi} Nencki Institute of Experimental Biology, <http://www.nencki.gov.pl/article/masowa-diagnostyka-koronawirusa->

[dzieki-naukowcom-z-instytutu-nenckiego-pan](https://www.nencki.gov.pl/article/masowa-diagnostyka-koronawirusa-dzieki-naukowcom-z-instytutu-nenckiego-pan) [accessed 02 March 2021].

^{xxvii} COVID-19 vaccines: authorised, <https://www.ema.europa.eu/en/human-regulatory/overview/public-health-threats/coronavirus-disease-covid-19/treatments-vaccines/treatments-vaccines-covid-19-authorized-medicines> [accessed 27 May 2021].

^{xxviii} COVID-19 vaccines: under evaluation, <https://www.ema.europa.eu/en/human-regulatory/overview/public-health-threats/coronavirus-disease-covid-19/treatments-vaccines/vaccines-covid-19-covid-19-vaccines-under-evaluation> [accessed 27 May 2021].

^{xxix} Draft landscape and tracker of COVID-19 candidate vaccines, <https://www.who.int/publications/m/item/draft-landscape-of-covid-19-candidate-vaccines> [accessed 27 May 2021].

^{xxx} COVID-19 treatments: Article 5(3) reviews, <https://www.ema.europa.eu/en/human-regulatory/overview/public-health-threats/coronavirus-disease-covid-19/treatments-vaccines/treatments-covid-19/covid-19-treatments-article-53-reviews> [accessed 27 May 2021].

^{xxxi} FDA. Clinical Trial Conduct During the COVID-19 pandemic, <https://www.fda.gov/drugs/coronavirus-covid-19-drugs/clinical-trial-conduct-during-covid-19-pandemic> [accessed 27 May 2021].

^{xxxii} The impact of the COVID-19, https://www.rbccm.com/en/gib/healthcare/episode/the_impact_of_covid19 [accessed 15 May 2021].

^{xxxiii} Covid-19: lessons learned across the life sciences, <https://www.pharmaceutical-technology.com/features/covid-19-lessons-for-life-sciences/> [accessed 15 May 2021].

^{xxxiv} Covid-19: impact and recovery for the life sciences industry, Deloitte, https://www2.deloitte.com/content/dam/Deloitte/ie/Documents/LifeSciences_Healthcare/IE_CF_COVID-19%20%20Health%20and%20Life%20Sciences_0420_FV.pdf [accessed 15 May 2021].

^{xxxv} COVID- Webinar: Covid-19 and the bioeconomy, <http://biomonitor.eu/event/webinar-covid-19-and-the-bioeconomy/> [accessed 15 May 2021].

^{xxxvi} Kantar. Infographic: Public opinion about COVID-19 vaccination. <https://www.kantar.com/inspiration/coronavirus/infographic-public-opinion-about-covid-19-vaccination> [accessed 28 Jan 2021].

^{xxxvii} Coronavirus: Tracking how the world's 'green recovery plans aim to cut emissions, <https://www.carbonbrief.org/coronavirus-tracking-how-the-worlds-green-recovery-plans-aim-to-cut-emissions> [accessed 02 March 2021].

^{xxxviii} European regions and the green transition in a COVID-19 era <https://aer.eu/european-regions-and-the-green-transition-in-a-covid-19-era/> [accessed 03 March 2021].

^{xxxix} Business Wire (2020). COVID-19 Impact on packaging market by material type, application and region - global forecast to 2021 <https://www.businesswire.com/news/home/20200511005497/en/COVID-19-Impact-on-Packaging-Market-by-Material-Type-Application-and-Region—Global-Forecast-to-2021—ResearchAndMarkets.com> [accessed 28 Feb 2021].

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

- Ang, L., Lee, H.W., Choi, J.Y., Zhang, J., Lee, M.S., 2020. Herbal medicine and pattern identification for treating COVID-19: a rapid review of guidelines. *Integr. Med. Res.* 9 (2), 100407. doi:10.1016/j.imr.2020.100407.
- Ayati, N., Saiyarsari, P., Nikfar, S., 2020. Short and long term impacts of COVID-19 on the pharmaceutical sector. *DARU J. Pharm. Sci.* 28, 799–805. doi:10.1007/s40199-020-00358-5.
- Bacchieri, A., Rossi, A., Morelli, P., 2020. Risk and mitigation actions for clinical trials during COVID-19 pandemic (RiMiCOPa). *Contemporary Clin. Trials Commun.* 20, 100682. doi:10.1016/j.conctc.2020.100682.
- Becchetti, L., Piscitelli, P., Distante, A., Miani, A., Uricchio, A.F., 2021. European Green Deal as social vaccine to overcome COVID-19 health & economic crisis. *Lancet Regional Health - Europe* 2, 100032 doi:10.1016/j.lanepe.2021.100032.
- Biodiversity Strategy (2020). Bringing nature back into our lives. EC, 380, Brussels. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380> [accessed 10 May 2021].
- Bioeconomy Strategy, 2012. Innovating for sustainable growth: a bioeconomy for Europe. European Commission, Brussels, Belgium Available from https://ec.europa.eu/research/bioeconomy/pdf/official-strategy_en.pdf.
- Bioeconomy Strategy, 2018. A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society, and the environment. COM, 673 final. Brussels, Belgium Available from <https://op.europa.eu/en/publication-detail/-/publication/edace3e3-e189-11e8-b690-01aa75ed71a1/language-en>.
- Bostan, M., Ataman, M., Bostan, I.S., Bleotu, C., 2020. Targets and assay types for COVID-19 diagnosis. *J. Immunology Immunochem.* 1 41 (6), 946–959. doi:10.1080/15321819.2020.1862866, PMID: 33539260.
- Cardoso, V.M.O., Moreira, B.J., Comparetti, E.J., Sampaio, I., Ferreira, L.M.B., Lins, P.M.P., Zucolotto, V., 2020. Is Nanotechnology Helping in the Fight Against COVID-19? *Front. Nanotechnol.* 2, 588915. doi:10.3389/fnano.2020.588915.
- Campos, E.V.R., Pereira, A.E.S., de Oliveira, J.L., Carvalho, L.B., Guilger-Casagrande, M., de Lima, R., Fraceto, L.F., 2020. How can nanotechnology help to combat COVID-19? Opportunities and urgent need. *J. Nanobiotechnol.* 18, 125. doi:10.1186/s12951-020-00685-4.
- Chakraborty, I., Maiti, P., 2020. COVID-19 outbreak: migration, effects on society, global environment and prevention. *Sci. Total Environ.* 728, 138882. doi:10.1016/j.scitotenv.2020.138882.
- Chen, L., Zhang, G., Liu, L., Li, Z., 2021. Emerging biosensing technologies for improved diagnostics of COVID-19 and future pandemics. *Talanta* 1 (225), 121986. doi:10.1016/j.talanta.2020.121986.
- Circular Economy, 2020. Action Plan for a cleaner and more competitive Europe. Directorate-General for Communication, EC, Brussels Available from <https://op.europa.eu/en/publication-detail/-/publication/45cc30f6-cd57-11ea-adf7-01aa75ed71a1/language-en>.
- de Figueiredo A., Simas C., Karafillakis E., Paterson P., Larson H.J. (2020). Mapping global trends in vaccine confidence and investigating barriers to vaccine uptake: a large-scale retrospective temporal modelling study. *The Lancet* 396, 10255:89908. DOI: [https://doi.org/10.1016/S0140-6736\(20\)31558-0](https://doi.org/10.1016/S0140-6736(20)31558-0).
- Delre, P., Caporuscio, F., Saviano, M., Mangiatordi, G.F., 2020. Repurposing Known Drugs as Covalent and Non-covalent Inhibitors of the SARS-CoV-2 Papain-Like Protease. *Front. Chem.* 8, 594009. doi:10.3389/fchem.2020.594009.
- Department of Economic and Social Affairs of the United Nations (2020). Impact of COVID-19 on SDG progress: a statistical perspective. Policy Brief no 81. Available at: https://www.un.org/development/desa/dpad/wpcontent/uploads/sites/45/publication/PB_81.pdf [accessed 28 Feb 2021].
- De Savi Ch., Hughes D.L., Kvaerno, L., 2020. Quest for a COVID-19 Cure by Repurposing Small-Molecule Drugs: Mechanism of Action, Clinical Development, Synthesis at Scale, and Outlook for Supply. *Org. Process Res. Dev.* 24, 940–976. doi:10.1021/acs.oprd.0c00233.
- de Sousa, F.D.B., 2020. Pros and Cons of Plastic during the COVID-19 Pandemic. *Recycling* 5, 27 doi:10.3390/recycling5040027.
- De Vet, J.M., Nigohosyan, D., Nunez Ferrer, J., Gross, A.K., Kuehl, S., Flickenschild, M., 2021. Impact of the COVID-19 pandemic on EU industries. European Parliament Available at [https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662903/IPOL_STU\(2021\)662903_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662903/IPOL_STU(2021)662903_EN.pdf).
- EC, 2005. New perspectives on the knowledge-based bio-economy – conference report. European Commission, Brussels, Belgium.
- EC, 2007. En route to the knowledge-based bio-economy (“Cologne Paper”) German Presidency of the Council of the European Union (EU) Cologne Available from https://dechema.de/dechema_media/Downloads/Positionspapier/Cologne_Paper.pdf.
- EC (2015). Closing the Loop - an EU Action Plan for the Circular Economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2015) 614 final. Brussels. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614> [accessed 15 April 2021].
- EC, 2020a. Employment and Social Developments in Europe. ESDE Q. Rev.. Available at <https://ec.europa.eu/social/main.jsp?langId=en&catId=791&furtherNews=yes&newsId=9467>. [accessed 15 April 2021].
- EC, 2020b. How the bioeconomy contributes to the European Green Deal. Directorate-General for Research and Innovation. European Commission doi:10.2777/67636.
- Editorial, 2020. Will the COVID-19 pandemic threaten the SDGs? *Lancet Public Health* 5 (9), E460. doi:10.1016/S2468-2667(20)30189-4.
- EIB Climate Survey (2020). The European Investment Bank Database. Available from <https://www.eib.org/en/surveys/2nd-climate-survey/climate-change-impact.htm> [accessed 25 Feb 2021].
- Ellen MacArthur Foundation (2020). The circular economy: a transformative Covid-19 recovery strategy: How policymakers can pave the way to a low carbon, prosperous future. Available from: <https://www.ellenmacarthurfoundation.org/publications/covid-19> [accessed 10 May 2021].
- Elkerbout, M., Ch., Egenhofer, Nunez Ferrer, J., Catuti, M., Kustova, I., Rizos, V., 2020. The European Green Deal after Corona: Implications for EU climate policy. *CEPS 2020–2026*.
- EMA (2020). International regulators provide guiding principles for COVID-19 clinical trials. Available from: https://www.ema.europa.eu/en/documents/press-release/international-regulators-provide-guiding-principles-covid-19-clinical-trials_en.pdf [accessed 28 Feb 2021].
- Erbach, G., 2020. Impact of the coronavirus crisis on climate action and the European Green Deal. Briefing. PE 649.370. EPRS. European Parliamentary Research Service.
- EU agricultural outlook, 2020. For markets, income and environment 2020–2030. *Agricult. Rural Dev.* Available from https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/agricultural-outlook-2020-report_en.pdf. [accessed 15 May 2021].
- Eurostat (2019). Euro Area Unemployment at 7.5%. Euroindicators 169/2019. Available from: <https://ec.europa.eu/eurostat/documents/2995521/10064439/3-31102019-CP-EN.pdf/20825ac8-e75f-6ca4-59ea-6b9e8d04f07c> [accessed 10 May 2021].
- Eurostat (2020). Euro area unemployment at 8.4%. Euroindicators 175/2020. Available from: <https://ec.europa.eu/eurostat/documents/2995521/10662309/3-02122020-AP-EN.pdf/3b4ec2e2-f14c-2652-80bd-2f5e7c0605c2> [accessed 10 May 2021].
- Eurostat (2021). Annual inflation up to 1.3% in the euro area. Euro indicators. 45/2021. News release. Available from: <https://ec.europa.eu/eurostat/documents/2995521/11563035/2-16042021-AP-EN.pdf/207a1c91-b8b5-4f86-5c66-d0af0a76fa98?t=1618505492050> [accessed 15 Feb 2021].
- Fritsche, U., Brunori, G., Chiaramonti, D., Galanakis, C.M., Matthews, R., Panoutsou, C., 2021. Future transitions for the Bioeconomy towards Sustainable Development and a Climate-Neutral Economy – Bioeconomy Opportunities for a green recovery and enhanced system resilience. Publications Office of the European Union, Luxembourg Borzacchiello, M. T., Sanchez Lopez, J. and Avraamides, M. eds. ISBN 978-92-76-28415-4/JRC123534 doi:10.2760/831176.
- Global Bioeconomy Policy Report (2020). A decade of bioeconomy policy development around the world. A report from the International Advisory Council on Global Bioeconomy. Available from: https://gbs2020.net/wp-content/uploads/2020/11/GBS-2020_Global-Bioeconomy-Policy-Report_IV_web.pdf [accessed 15 May 2021].
- Hassan, S.T., 2020. Shedding light on the effect of natural anti-herpesvirus alkaloids on SARS-CoV-2: a treatment option for COVID-19: multidisciplinary Digital Publishing Institute. *Viruses* 12 (4), 476. doi:10.3390/v12040476.
- Heggen, K., Sandset, T.J., Engebretsen, E., 2020. COVID-19 and sustainable development goals. *Bull. World Organ.* 98, 646 <http://dx.doi.org/10.2471/BLT.20.263533>.
- Heinrich, M.A., Prakash, Byron Martin Jai, 2020. Nanomedicine strategies to target coronavirus. *Nano Today* 35, 100961. doi:10.1016/j.nantod.2020.100961.
- Huang, J., Tao, G., Liu, J., Cai, J., Huang, Z., Chen, J.X., 2020. Current Prevention of COVID-19: Natural Products and Herbal Medicine. *Front. Pharmacol.* 11, 588508. doi:10.3389/fphar.2020.588508.
- Hume, H.K.C., Lua, L.H., 2017. Platform technologies for modern vaccine manufacturing. *Vaccine* 35 (35), 4480–4485. doi:10.1016/j.vaccine.2017.02.069.
- ILO (2020). ILO Monitor: COVID-19 and the world of work. Sixth edition Updated estimates and analysis. Available from: https://www.ilo.org/wcmsp5/groups/public/-/dgreports/-/dcomm/documents/briefingnote/wcms_755910.pdf [accessed 28 Feb 2021].
- Joshi, T., Joshi, T., Sharma, P., Mathpal, S., Pundir, H., Bhatt, V., Chandra, S., 2020. In silico screening of natural compounds against COVID-19 by targeting Mpro and ACE2 using molecular docking. *Eur. Rev. Med. Pharmacol. Sci.* 24 (8), 4529–4536. doi:10.26355/eurrev.202004.21036.
- Khan, M.T., Ali, A., Wang, Q., Irfan, M., Khan, A., Zeb, M.T., Zhang, Y.J., Chinnasamy, S., Wei, D.Q., 2020. Marine natural compounds as potential inhibitors against the main protease of SARS-CoV-2: a molecular dynamic study. *J. Biomol. Struct. Dyn.* Published online 1–11. doi:10.1080/07391102.2020.1769733, 1 Jun.
- Kevadiya, B.D., Machhi, J., Herskovitz, J., et al., 2021. Diagnostics for SARS-CoV-2 infections. *Nat. Mater.* Published online doi:10.1038/s41563-020-00906-z, 14 Feb.
- Kuzemko, C., Bradshaw, M., Bridge, G., Goldthau, A., Jewell, J., Overland, I., Scholten, D., Van de Graff, T., Westphal, K., 2020. Covid-19 and the politics of sustainable energy transitions. *Energy Res. Soc. Sci.* 68, 101685. doi:10.1016/j.erss.2020.101685.
- Ladi, S., Tsarouhas, D., 2020. EU economic governance and Covid-19: policy learning and windows of opportunity. *J. Eur. Integration* 42 (8), 1041–1056. doi:10.1080/07036337.2020.1852231.
- Le Quéré, C., Jackson, R.B., Jones, M.W., Smith, A.J.P., Abernethy, S., Andrew, R.M., De-Gol, A.J., Willis, D.R., Shan, Y., Canadell, J.G., Friedlingstein, P., Creutzig, F., Peters, G.P., 2020. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nat. Clim. Change* 10, 647–653. doi:10.1038/s41558-020-0797-x.
- Liu, Z., Ciais, P., Deng, Z., et al., 2020. Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. *Nat. Commun.* 11, 5172. doi:10.1038/s41467-020-18922-7.
- Lobo-Galo, N., Gálvez-Ruiz, J.C., Balderrama-Carmona, A.P., Silva-Beltrán, N.P., Ruiz-Bustos, E., 2021. Recent biotechnological advances as potential intervention strategies against COVID-19. *3 Biotech.* 41. doi:10.1007/s13205-020-02619-1, Published online 09 Jan 2021.
- Mani, J.S., Johnson, J.B., Steel, J.C., Broszczak, D.A., Neilsen, P.M., Walsh, K.B., Naiker, M., 2020. Natural product-derived phytochemicals as potential agents against coronaviruses: a review. *Virus Res.* 284, 197989. doi:10.1016/j.virusres.2020.197989.

- Machhi, J., Shahjin, F., Das, S., et al., 2021. Nanocarrier Vaccines for SARS-CoV-2. *Adv. Drug. Deliv. Rev.* doi:10.1016/j.addr.2021.01.002, S0169-409X(21)00002-8 Epub ahead of print. PMID: 33428995; PMCID: PMC7794055.
- Menut, L., Bessagnet, B., Siour, G., Mailler, S., Pennel, R., Cholakian, A., 2020. Impact of lockdown measures to combat Covid-19 on air quality over western Europe. *Sci. Total Environ.* 741, 140426. doi:10.1016/j.scitotenv.2020.140426.
- Messerli, E., Murniningtyas, E., Eloundou-Enyegue, P., et al., 2019. The future is now – science for achieving sustainable development. United Nations: Global Sustainable Development Report Available from https://sdgs.un.org/sites/default/files/2020-07/24797GSDR_report_2019.pdf.
- Naidoo, R., Fisher, B., 2020. Reset Sustainable Development Goals for a pandemic world. *Nature* 583, 198–201. doi:10.1038/d41586-020-01999-x.
- Ng, M.K., 2020. Sustainable Development Goals (SDGs) and Pandemic Planning. *Planning Theory Pract.* 21 (4), 507–512. doi:10.1080/14649357.2020.1807130.
- Nicola, M., Alsaifi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Ch, Iosifidis, Agha, M., Agha, R., 2020. The socio-economic implications of the coronavirus pandemic (COVID-19): A review. *Int. J. Surg.* 78, 185–193. doi:10.1016/j.ijsu.2020.04.018.
- OECD Outlook, 2021. OECD Interim Economic Outlook, March 2021. OECD Publishing Available from <https://www.oecd.org/economic-outlook/march-2021/>.
- Paul, E., Steptoe, A., Francourt, D., 2020. Attitudes towards vaccines and intention to vaccinate against COVID-19: Implications for public health communications. *The Lancet Regional Health Europe* 1, 100012 doi:10.1016/j.lanepe.2020.100012.
- Rangayasami, A., Kannan, K., Murugesan, S., Radhika, D., Kumar Sadasivuni, K., Raghava Reddy, K., V., Raghu, A., 2021. Influence of nanotechnology to combat against COVID-19 for global health emergency: A review. *Sensors Int.* 2, 100079. doi:10.1016/j.sintl.2020.100079.
- Reilly, P., 2020. The Impact of the COVID-19 Pandemic on the Biotech Industry. *Hum. Gene Ther.* 31, 11–12. doi:10.1089/hum.2020.29124.pre.
- Report EP (2020). Uncertainty/EU/Hope. Public opinion times of COVID-19. Second Round. European Parliament 2020. Available from: https://www.europarl.europa.eu/at-your-service/files/be-heard/eurobarometer/2020/public_opinion_in_the_time_of_coronavirus_crisis_2/en-covid19-survey2-report.pdf [accessed 28 Feb 2021].
- Riva, L., Yuan, S., Yin, X., Martin-Sancho, L., Matsunaga, N., Burgstaller, S., Chang, M., 2020. A large-scale drug repositioning survey for SARS-CoV-2 antivirals. *bioRxiv* doi:10.1101/2020.04.16.044016, 2020.04.16.044016.
- Ronzon, T., Piotrowski, S., Tamosiunas, S., Dammer, L., Carus, M., M'Barek, R., 2020. Developments of Economic Growth and Employment in Bioeconomy Sectors across the EU. *Sustainability* 12, 4507. doi:10.3390/su12114507.
- Rosa, S.G.V., Santos, W.C., 2020. Clinical trials on drug repositioning for COVID-19 treatment. *Rev Panamericana de Salud Pública* 44, e40. doi:10.26633/RPSP.2020.40.
- Rosales-Mendoza, S., Comas-García, M., Korban, S.S., 2020. Challenges and Opportunities for the Biotechnology Research Community during the Coronavirus Pandemic. *Trends Biotechnol.* 38 (8), 823–824. doi:10.1016/j.tibtech.2020.04.016.
- Rume, T., Didar-Ul Islam, S.M., 2020. Environmental effects of COVID-19 pandemic and potential strategies of sustainability. *Heliyon* 6 (9), e04965. doi:10.1016/j.heliyon.2020.e04965.
- Saadat, S., Rawtani, D., Hussain, C.M., 2020. Environmental perspective of COVID-19. *Sci. Total Environ.* 728, 138870. doi:10.1016/j.scitotenv.2020.138870.
- Samad, N., Sodunke, T.E., Banna, H.A., Sapkota, A., Fatema, A.N., Iskandar, K., Jahan, D., Hardcastle, T.C., Nusrat, T., Chowdhury, T.S., Haque, M., 2020. Convalescent Plasma Therapy for Management of COVID-19: Perspectives and Deployment in the Current Global Pandemic. *Risk Manag. Healthc. Policy* 13, 2707–2728. doi:10.2147/RMHP.S281388.
- Senior, M., 2020. Biotech companies prepare for COVID-19 downturn. *Nat. Biotechnol.* 38 (6), 663–664. doi:10.1038/d41587-020-00012-0, PMID: 32415300.
- Shakil, M.H., Munim, Z.H., Tasnia, M., Sarowar, S., 2020. COVID-19 and the environment: A critical review and research agenda. *Sci. Total Environ.* 745, 141011. doi:10.1016/j.scitotenv.2020.141022.
- Shin, M.D., Shukla, S., Chung, Y.H., et al., 2020. COVID-19 vaccine development and a potential nanomaterial path forward. *Nat. Nanotechnol.* 15, 646–655. doi:10.1038/s41565-020-0737-y.
- Singh, T.U., Parida, S., Lingaraju, M.C., Kesavan, M., Kumar, D., Singh, R.K., 2020. Drug repurposing approach to fight COVID-19. *Pharmacol. Rep.* 72, 1479–1508. doi:10.1007/s43440-020-00155-6.
- Sportelli, M.C., Izzi, M., Kukushkina, E.A., Hossain, S.I., Picca, R.A., Ditaranto, N., Cioffi, N., 2020. Can Nanotechnology and Materials Science Help the Fight against SARS-CoV-2? *Nanomaterials* 10, 802. doi:10.3390/nano10040802.
- Strategy (2020). A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. EC, 381, Brussels. Available from: https://ec.europa.eu/food/sites/food/files/safety/docs/f2f_action-plan_2020_strategy-info_en.pdf [accessed 16 March 2021].
- The Sustainable Development Goals Report (2020). United Nations. Available from: <https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf> [accessed 02 March 2021].
- The European Green Deal (2019). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2019), 640 final. Brussels, Belgium. Available from: https://ec.europa.eu/info/sites/default/files/european-green-deal-communication_en.pdf [accessed 25 March 2021].
- Tyczewska, A., Woźniak, E., Gracz, J., Kuczynski, J., Twardowski, T., 2018. Towards Food Security: Current State and Future Prospects of Agrobiotechnology. *Trends Biotechnol.* 36, 1219–1229. doi:10.1016/j.tibtech.2018.07.008.
- UNESCO, 2020. Policy Brief: Education during COVID-19 and beyond. August 2020. United Nations Available from https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2020/08/sg_policy_brief_covid-19_and_education_august_2020.pdf.
- Uthaya Kumar, A., Kadiresen, K., Gan, W.C., Ling, A.P.K., 2021. Current updates and research on plant-based vaccines for coronavirus disease 2019. *Clin. Exp. Vaccine Res.* 10 (1), 13–23. doi:10.7774/cevr.2021.10.1.13.
- van Dorn, A., 2020. COVID-19 and readjusting clinical trials. *Lancet* 22 (396(10250)), 523–524. doi:10.1016/S0140-6736(20)31787-6.
- Verma, S., Twilley, D., Esmear, T., Oosthuizen, C.B., Reid, A.M., Nel, M., Lall, N., 2020. Anti-SARS-CoV Natural Products With the Potential to Inhibit SARS-CoV-2 (COVID-19). *Front. Pharmacol.* 11, 561334. doi:10.3389/fphar.2020.561334.
- Wang, Q., Su, M., 2020. A preliminary assessment of the impact of COVID-19 on environment – a case study of China. *Sci. Total Environ.* 728, 138915. doi:10.1016/j.scitotenv.2020.138915.
- World Economic Forum (2019). Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy. Available at: http://www3.weforum.org/docs/WEF_New_Nature_Economy_Report_2020.pdf [accessed 28 Feb 2021].
- Woźniak, E., Tyczewska, A., Twardowski, T., 2021. Bioeconomy development factors in the European Union and Poland. *New Biotechnol.* 60, 2–8. doi:10.1016/j.nbt.2020.07.004.
- Xian, Y., Zhang, J., Bian, Z., Zhou, H., Zhang, Z., Lin, Z., Xu, H., 2020. Bioactive natural compounds against human coronaviruses: a review and perspective. *Acta Pharm. Sin.* B 10 (7), 1163–1174. doi:10.1016/j.apsb.2020.06.002.
- Xue, J.Z., Smetana, K., Poda, P., Webster, K., Yang, G., Agrawal, G., 2020. Clinical trial recovery from COVID-19 disruption. *Nat. Rev. Drug Discov.* 19 (10), 662–663. doi:10.1038/d41573-020-00150-9.
- Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. *Sci. Total Environ.* 728, 138813. doi:10.1016/j.scitotenv.2020.138813.
- Zhang, Y., Greer, R.A., Song, Y., Praveen, H., Song, Y., 2021. In silico identification of available drugs targeting cell surface BiP to disrupt SARS-CoV-2 binding and replication: Drug repurposing approach. *Eur. J. Pharm. Sci.* 160, 105771. doi:10.1016/j.ejps.2021.105771.
- Zhou, Y., Wang, F., Tang, J., Nussinov, R., Cheng, F., 2020. Artificial intelligence in COVID-19 drug repurposing. *Lancet Digital Health* 2, e667–e676. doi:10.1016/j.lan.2020.06.002.
- Zhu, H., Zhang, H., Ni, S., Korabečná, M., Yobas, L., Neuzil, P., 2020. The vision of point-of-care PCR tests for the COVID-19 pandemic and beyond. *Trends Analyt. Chem.* 130, 115984. doi:10.1016/j.trac.2020.115984.