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Future transitions for the Bioeconomy towards Sustainable Development and a Climate-Neutral Economy

Bioeconomy opportunities for a green recovery and enhanced system resilience

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Executive Summary

The COVID-19 pandemic is causing an unprecedented global health crisis and socio-economic upheaval and led to severe consequences well beyond previous crises of the last decades which mostly were related to financial issues. COVID-19 caused sudden economic, psychological, and partly physical shocks to markets, societal sub-systems (e.g., education, food, health), and people.

As a direct consequence, today, food security and resilience are at stake. The effects on bio-based products and bioenergy (in particular: biofuels) vary and their role in the recovery (with possible changes in customer's behaviour) could differ as well.

The linkages of the bioeconomy to post-pandemic recovery with regard to impacts and possible responses are currently being discussed by many institutions and initiatives, even though there is currently limited data on the impact of the pandemic on the bioeconomy.

This report presents preliminary results based on initial analysis from the authors on knowledge synthesis on the EU bioeconomy system, trends, and perspectives of the future development towards 2030 and 2050.

The main impacts reported so far from COVID-19 in the bioeconomy relevant sectors are:

- **Food sector**: The COVID-19 pandemic hit the food system hard, putting food security at risk and causing reduced capacity of input provision to food chains. Further direct impacts concern production losses due to shortage of inputs and labour, reduced demand due to lockdown of canteens and restaurants and wastage of perishable product that could not be stored.
- **Biobased products and materials**: COVID-19 so far had mixed impacts on forestry, non-food bio-based products and chemicals. These impacts have both direct and indirect variable effects across Europe. However, in some areas, there has been significant disruption in forest management and forestry sector activities.
- **Bioenergy**: IEA analysed the impacts of COVID-19 on the energy sector, in particular to renewables, including biofuels. Electricity demand in the EU dropped significantly, and according to IEA, projected reductions in 2020 compared to 2019 will be highest for oil, followed by coal, gas, and nuclear, while renewables should slightly increase.

The COVID-19 pandemic occurred in a time when the EU policy agenda was taking a powerfully transformative shape: the European Green Deal, committed to foster sustainable development and achieving the targets of the Paris climate agreement, has specified respective goals, tools, and timelines.

Rather than deviating from this pathway, the COVID-19 crisis shows that a system change is needed. However, it has also shown that this transformation may encounter several obstacles which require combining regulatory efforts, multi-level coordination, and massive finance to be overcome.

As the EU and its Member States begin to emerge from lockdowns and plan recovery, respective strategies, and contingency plans to manage further waves of the pandemic, attention must return to addressing the climate crisis and building resilience – and in that, the bioeconomy has a role to play.

Climate action will be mainstreamed in all EU programs funded under the Multiannual Financial Framework and Next Generation EU programs, with buffers for distributive effects (Just Transition Fund). The role of bioenergy and bioeconomy investments are also part of the EU Taxonomy which aims to clarify what "green" investments are.

The enormous funds (both public and private) mobilised and significant economic stimulus packages developed to address the crisis offer opportunities to invest in the future, including in a sustainable circular bioeconomy which can put nature and restoration of natural capital at the centre of the entire process. Member States will have to develop and implement adequate governance to handle such large resources and projects.

The initial set of opportunities identified for a circular sustainable bioeconomy to contribute to a post-pandemic recovery include:

Food sector: Improving food systems to become more sustainable and resilient will allow adapting fast to extreme events, as well as ensuring that future crises will only minimally affect food chains and vulnerable people. Key to that plans is the strengthened position of farmers in the value chains. Priority is in reorganising agricultural supply systems based on the principles of agroecology, circularity, and One Health. Attention must be given to the blue bioeconomy and sustainable aquaculture as well as on urban agriculture that can improve quality of urban life. There is also significant interest from businesses and various start-ups in animal protein alternatives, bio-based fibres, and respective marketing. Viewed in the context of a global food syndemic, the interplay of food insecurity, malnutrition, and obesity based on dietary behaviours amid the COVID-19 pandemic indicate opportunities for addressing social and structural determinants of healthy eating as a strategy to improve the health of people and the planet.

Biobased materials and bioenergy: Currently, the industrial system is too linear, resource-intense, has limited provisions for biodiversity and ecosystem services and is mostly based on non-renewable resources. There are scalable innovations and viable technologies to produce sustainably sourced bio-based alternatives, though, including public goods such as bioplastics, nanocellulose, and wood-based textiles as well as services such as bioenergy, which could significantly reduce both amounts of non-renewable materials used and GHG emissions while creating durable carbon pools. Both in bio-based products and in bioenergy, possibilities to integrate biochemical and thermochemical processes gain attention, as well as the ability to valorise residues and co-products of upstream routes to improve on circularity. Also, the extraction of critical raw materials, as identified and listed by the EC, and their valorisation beyond traditional routes and products should be developed in combination with biorefining processes.

At present, it remains unclear how the COVID-19 pandemic will evolve and how it will impact daily life patterns in the long run: This applies to the 1st and 2nd waves of the pandemic and even more to possible subsequent wave(s).

However, a circular, sustainable and transformative bioeconomy, building on innovation and people's inclusion, represents great opportunities with at least partly solutions for the post-COVID-19 era and during the EU economic recovery. These cover all sectors of the bioeconomy and beyond – from agriculture, fishery and forestry to food, energy, materials, transport, and tourism as well as financing and cross-cutting options such as decentralised biorefineries, innovative bioprocessing, and stimulation of an inclusive BioWEconomy.

Concerning the recommended actions, considering the need to ensure a transition leaving no one out, both short- and long-term strategies should be immediately elaborated with dedicated measures. In that, supporting economic operators, communities, and stakeholders to overcome the crisis and preserve jobs and economic activities need to be combined with decarbonisation and sustainable production and use models.

In order to support the EU industry in its transformation towards a sustainable and circular bioeconomy, sufficient EU funds need to be leveraged to de-risk innovative projects and stimulate private investments, far beyond the €250 million which is the current target size of the European Circular Bioeconomy Fund. Furthermore, closely monitoring the effectiveness of these financial programmes is essential.

Given that the global pandemic is ongoing also in the EU and its Member States, and relatively little evidence exists yet on COVID-19 impacts and bioeconomy responses, the analysis presented here is preliminary and needs substantiation from further work, considering future results from monitoring, and scientific knowledge expected to arise in the 2021-2022 timeframe.

It should also be investigated more deeply how the circular bioeconomy can counter sustainability implications of COVID-19 in urban and rural areas, and what impacts this will have on ecosystem services and on achieving the SDGs.

1 Introduction

This report presents results from initial analysis of the ad-hoc Network of Experts on the question:

What are the most promising solutions and opportunities that the European bioeconomy can offer to support a green recovery from the coronavirus pandemic and enhance system resilience in the future?

The authors addressed resilience in a knowledge synthesis on the EU bioeconomy system, trends, and perspectives of the future development towards 2030 and 2050 (Fritsche et al. 2020). With the present report, this brief analysis is deepened to the extent possible, and open questions are summarised.

Given that the global pandemic is ongoing in the EU and its Member States, relatively little evidence exists yet on COVID-19 impacts and bioeconomy responses. Thus, the analysis presented here is preliminary.

It needs substantiation from further analysis, considering future results from monitoring, and scientific knowledge expected to arise in the 2021-2022 timeframe.

2 Setting the scene: COVID-19 and the EU bioeconomy

The COVID-19 pandemic is causing an unprecedented global health crisis and socio-economic upheaval since first reported in Wuhan, China, on 31 Dec. 2019 (ECDC 2020a). On 9 Jan. 2020, the European Centre for Disease Prevention and Control published a Threat Assessment Brief on the cluster of pneumonia possibly associated with the novel coronavirus in Wuhan (ECDC 2020b).

On 24 Jan. 2020, the first European case was reported in France (ECDC 2020a). In Fall 2020, the so-called 2nd wave reached many European countries, causing further lockdown.

The pandemic led to severe consequences well beyond previous crises which mostly were related to financial (banking, stock market) issues. It represents a sudden economic, psychological, and partly physical shock to markets, societal sub-systems (e.g. food, health), and people.

This 'Black Swan' socio-economic event was impossible to predict due to its extreme rarity (Rowan & Galanakis 2020). Authorities and companies were neither prepared for it, nor have they planned to transition beyond it (Reid et al. 2020).

Today, food security and resilience are at stake. The effects on biobased products and bioenergy (in particular: transport fuels) are different, and their role in the recovery could differ as well due to possible changes in customer's behaviour.

The linkages of the bioeconomy and post-pandemic recovery is currently being discussed by many (BIC 2020, EC 2020d, GBS 2020, IACGB 2020), both with regard to impacts, but also possible responses[1].

Before addressing the latter in more detail in Section 3, the following sub-sections present a wrap-up of current understanding of COVID-19 impacts on the EU bioeconomy.

[1] Previous severe 'Black Swan' events, e.g., the Black Death that devastated the Byzantine Empire, the Cholera outbreak of the 1830s, the Spanish Flu of 1918-1920, and World War II all indicate that societies responded to these traumata by unleashing tremendous changes in creativity, culture, thinking, and ambition to prevail (Rowan & Galanakis 2020). A similar reaction to COVID-19 can be expected, fuelling the discovery of disruptive innovations beyond this pandemic and novel approaches for the EU bioeconomy.

2.1 Impacts on the food system

The COVID-19 pandemic hit the food system hard, putting food security at risk. The impact is systemic, affecting not only components of food value chains but also generating indirect and delayed effects and feedback[2]. Table 1 illustrates the significant impacts of COVID-19 on the food system and respective food security implications.

Table 1 Impact of COVID-19 on the food system

Section	Direct impact	Impact on food security
Supply	Reduced capacity of input provision to food chains	Reduced food availability
Production	• Production losses due to shortage of inputs and labour • Demand collapse due to lockdown of canteens and restaurants • Wastage of perishable product that could not be stored	Reduced food availability Prices increase and incomes reduction
Processing	• Production losses due to shortage of inputs and labour • Demand collapse due to lockdown of restaurants • Wastage of perishable product that could not be stored • Unemployment of workers • Lack of investments	Prices increase Income reduction Technologies are not renovated
Trade	Disruption of (international) trade flows	Reduced local availability
Logistics	• Disruption of transportation routes • Reduced operativity of wholesale markets	Reduced local availability
Retailing	• Panic buying, queuing due to distancing, congestion of home deliveries • Closure of small retailers, boost of e-commerce • Direct links farmers-consumers • Pressure on food assistance organisations	Physical access to food
Catering	• Forced inactivity • The collapse of demand related to tourism • Food home delivery • Unemployment	Workers' income reduction
Consumption	• Change of eating patterns • Change of dietary patterns • The collapse of demand related to tourism for restaurant and hospitality	Widening inequalities Food insecurity for the most vulnerable groups

Source: own compilation based on HLPE (2020) and CCRI (2020)

The systemic nature of the COVID-19 shock implies indirect effects (i.e., an activity B affected by the impact of COVID-19 on an activity A, as in the case of cascading effect of restaurants' lockdown), delayed effects (business bankruptcy for lack of liquidity), and feedback effects (scarcity generated by panic buying caused by the fear of absence).

The drastic rise of remote working, closure of cultural sites (concert halls, clubs, movie theatres, museums), education facilities (kindergartens, schools, universities) as well as cancellation of congresses, exhibitions, and fairgrounds reduced food provision through canteens, caterers, restaurants, and street food suppliers. Home cooking increased, shifting logistics and consumption patterns (e.g., for pre-processed food), and potentially rising food waste, though evidence in some countries points to reducing food wastes[3].

[2] COVID-19 impacts point to a modest reduction of direct greenhouse gas (GHG) emissions from agriculture of about 1% or 50 million t of CO_2 equivalents in 2020 and 2021 (Elleby et al. 2020).

[3] https://www.weforum.org/agenda/2020/11/covid19-coronavirus-lockdown-food-waste-sustainability/

COVID-19 has impacted unequally on individuals, social groups, enterprises, and territories and widened existing inequalities. Most vulnerable groups have suffered the most substantial losses, e.g., mini-jobbers, single-parent families, and homeless people.

The food system was also subject to COVID-19 hotspots, e.g., the centralised slaughterhouses employing temporary workers living in crowded places in Germany closed temporarily as a result of workers experiencing high illness rates and to halt transmission of COVID-19 in their communities (Marchant-Forde & Boyle 2020; HLPE 2020).

2.2 Impact on bio-based products and materials

COVID-19 so far had mixed impacts on forestry, non-food bio-based products and chemicals. These impacts have been both direct and indirect and there have also been variable effects across Europe.

The demand for single-use plastics for wrappings and packaging materials increased and this is expected to continue, implying the growth of future potential for bio-based plastic substitutes (Gyekye 2020). The increased interest in the use of bio-based materials for the improvement of living conditions could be further mobilised. Linking "nature-based solutions" to the production of bio-based products (see Sections 3.3 and 4.2) may be important for effective recovery, also ensuring the maintenance and improved resilience of forests.

In some areas, there has been significant disruption in forest management and forestry sector activities. Table 2 provides an overview of COVID-19 impacts on the forest and woody biomass processing sectors.

Table 2 Overview of impacts of COVID-19 on the forest and wood processing sectors

Activity	Impact
Total wood supply	In some areas it has almost been "business as usual", in others there have been some restrictions to "essential" activities including limitations to supply wood only to those industries categorised as "essential".
Construction wood supply	Variable impacts but generally, a reduction in construction wood supply, in some cases a complete collapse, related to suspension or decline in construction activities. The situation recovered quickly after lifting of lockdowns. Increased consumption of certain "niche" products, e.g., garden decking and furniture, as people sought to renovate gardens and homes during lockdowns.
Small roundwood supply	Some regions have noticed significant increases in small roundwood production for paper, card, and pallet wood, related to an upsurge in online shopping.
Waste and recycling	During lockdowns, home renovation and "stock cleaning" led to rising demand for new clothing and furniture which increased household waste, and the recycling of used textiles.
Forest management	Lockdown measures restricted workforce activities (e.g., reduced mobility of migrant workers, social distancing during tree planting) or slowed processing of e.g., harvesting permits. In some areas, activities are limited to "essentials", e.g., responding to forest fires or pest/disease outbreaks. Generally, it is taking longer to deliver outputs at pre-COVID levels. Some activities have been reduced or completely stopped, e.g., forest surveys, consultancy.
Recreation and tourism	Commercial activities in forest areas providing holiday and recreation facilities and services have been reduced or completely stopped.

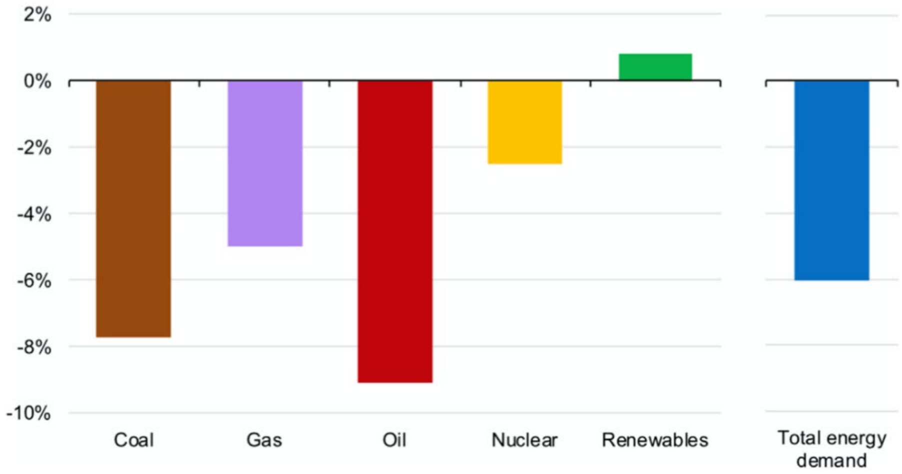
Source: own compilation

Activities enabling social engagement with nature and rural areas (recreation, tourism) have been hardly hit, suggesting recovery may be difficult; this could be particularly damaging for rural revitalisation and may have wider implications for health and wellbeing in the period after the pandemic.

2.3 Impacts on bioenergy

IEA analysed the impacts of COVID-19 on the energy sector, in particular to renewables, including biofuels (IEA 2020a). Electricity demand in the EU dropped significantly (Eurelectric 2020), and according to IEA (2020a), projected changes in 2020 compared to 2019 are highest for oil, followed by coal, gas, and nuclear, while renewables slightly increase (Figure 1).

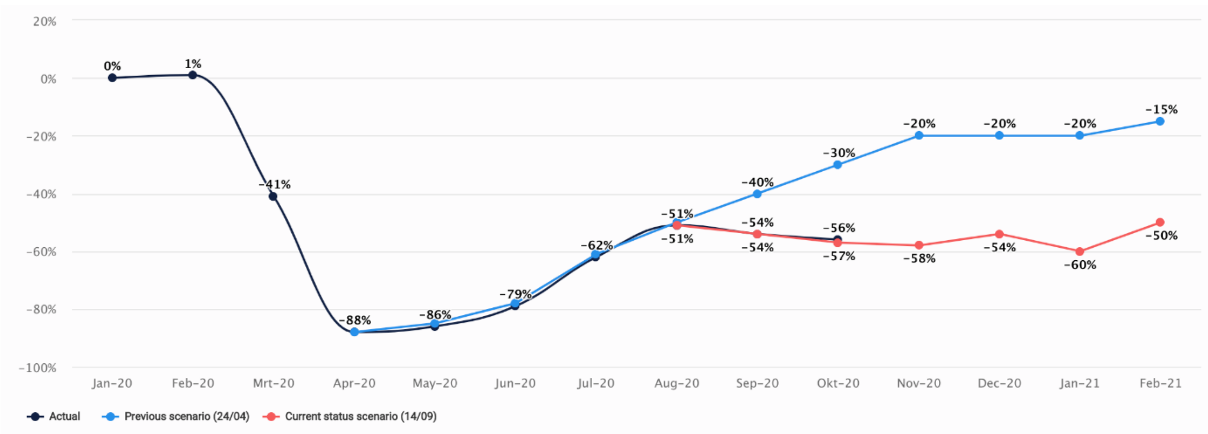
Figure 1 Projected changes in primary energy demand by fuel in 2020 relative to 2019



Source: IEA (2020a)

The drop in oil demand is predominantly caused by COVID-19 impacts on the transport sector, especially aviation, and scenarios indicate possible lasting reductions (Figure 2).

Figure 2 Draft aviation scenarios



Source: Eurocontrol (2020) Reference not found N.B the diagram available at: https://www.eurocontrol.int/traffic-scenario/eurocontrol-issues-new-draft-traffic-scenarios has a different curve

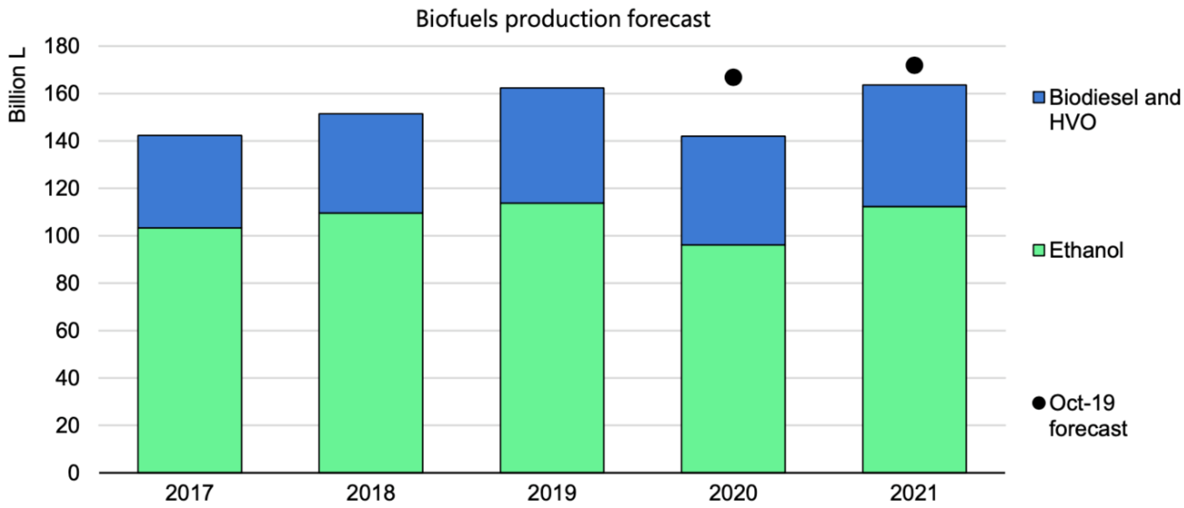
Bioenergy, the largest renewable energy source globally and in the EU, was also partly impacted by COVID-19 and the spring lockdowns put in place by many EU countries (WBA 2020), and lockdowns following in the fall 2020.

Notably, investments in the (bio)energy sectors are expected to decline in 2020 due to the unfavourable and challenging economics (lower profits and cash flows, higher debts, reduced demand, see Chiaramonti & Maniatis 2020).

IEA forecasts carried out during the first pandemic wave estimated a significant recovery of oil demand by December 2020 in the different regions of the world. However, the second wave of COVID-19 affecting many EU countries changed this expectation.

Concerning biofuels, production is expected falling by 13% in 2020 due to transport fuels' reduction demand, while in 2021, the 2019 level may be reached again (Figure 3). However, the effects of the second pandemic wave, and a possible third one, could further delay the return to consumption patterns comparable to pre-pandemic.

Figure 3 IEA biofuel production forecast



Source: IEA (2020g)

Table 3 Summary of main impacts of COVID-19 on the (bio)energy system

Activity	Impact
Electricity and CHP generation	Reduced demand for electricity, with limited impact on bioenergy, because heating is the main market and feed-in priority given to renewables. The biomass-based cogeneration sector showed good resistance to COVID-19 impacts, given the role of bioenergy in the renewable energy system, delivering heat and electricity to end-users, and the type of contracts in place. Feedstock supply was however partly affected by the pandemic, and this in turn impacted on bioenergy generation. Delay (or even halting) of energy investments was also a critical element for the sector.
Heat generation	The heating sector was rather resilient to the pandemic, in particular the pellet sector, which benefits from long-term contracts. Moreover, heating is viewed as an "essential" service.
Transport fuels	Transport was the most impacted area by COVID-19: fuel demand in some sectors almost collapsed, in particular in aviation. Reduction in diesel and gasoline demands directly translate into reductions of biofuels, as quota are expressed in percentages. Oil price fell, lack of storage capacity emerged, and thus opportunities for renewable fuels also diminished, given the very low oil prices. Investments and financing of new initiatives on transport fuel halted: this heavily impacted also on investments in the renewable fuel area. Some companies redirected their business to sanitisation and disinfectants (in particular, the ethanol sector).

Source: own compilation

3 Recovery: Build back better with the bioeconomy

The COVID-19 pandemic occurred in a time when the EU policy agenda was taking a powerfully transformative shape: the European Green Deal, committed to achieving the SDGs and the targets of the Paris climate agreement, has specified respective goals, tools, and timelines (EC 2019). Rather than deviating from this pathway, the COVID-19 crisis has shown that a system change is needed. However, it has shown also that this transformation may encounter several obstacles, and that their removal requires a combination of regulatory effort, multi-level coordination, and massive financial resources (Fritsche et al. 2020).

As the EU and the Member States begin to emerge from the lockdowns and plan their recovery, respective strategies, and contingency plans to manage further waves of the pandemic, attention must return to addressing the climate crisis and building resilience (IAP 2020) – and in that, the bioeconomy has a role to play (IEA 2020b-f).

In parallel to the pandemic, the ambition to meet the Paris climate agreement increased in the EU and elsewhere (e.g., China, Japan, Korea), in parallel to the need of financing new initiatives aligned with the European Green Deal goals. Climate action will be mainstreamed in all EU programs funded under the Multiannual Financial Framework[4] and Next Generation EU programs, with buffers for distributive effects (Just Transition Fund[5]). The enormous funds (both public and private) mobilised and significant economic stimulus packages developed to address the crisis offer opportunities to invest in the future, including in a sustainable circular bioeconomy which can put nature and restoration of natural capital at the centre of the entire process[6].

Burger et al. (2020) evaluated 130 studies and programs on design and effectiveness of 'green' economic recovery. They found a broad consensus on criteria to be applied and suitable areas of support: climate adaptation measures and nature-based solutions (e. g., reforestation[7]) are frequently recommended. However, only a fraction of the stimulus measures adopted worldwide have so far been 'green', and explicit notion of sustainable bioeconomy options in the recovery is scarce. 'Green' stimulus includes a long list of possible COVID-19 recovery interventions that support low-carbon development and build climate and disaster resilience (ADB 2020a+b; Hepburn 2020; NCI, PBL & IIASA 2020; OECD 2020b; TWI 2020):

- Improvements in climate-smart agricultural value chains enhancing biodiversity and sustainable food supply systems
- Deploying industry green transition, incorporating more sustainable production modes and ICT/AI in the value chain
- Upgrade of health facilities to disaster and climate resilience standards
- Health projects promoting disaster preparedness (e.g., long-term disease surveillance)
- Energy efficiency schemes, including support for retrofits (e.g., low-interest loans), construction of low-energy buildings, and skill development
- Rural green infrastructure projects, such as grid expansion and off-grid rural electrification, and rural low-carbon household programs, such as clean cooking programs (biogas, efficient wood-burning stoves) and solar lighting
- Labour market programs to protect natural assets and green infrastructures
- Investment in education and training, natural capital investment, and clean R&D.

In the following, opportunities for a circular sustainable bioeconomy to contribute to a post-pandemic recovery are presented, focusing on the EU.

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[4] https://ec.europa.eu/info/multiannual-financial-framework_en

[5] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/just-transition-mechanism/just-transition-platform_en

[6] https://www.sustainable-markets.org/

[7] Which should follow the Pan-European Guidelines for Afforestation and Reforestation: https://foresteurope.org/pan-europeanafforestationreforestationguidelines

3.1 Options in the food system

The pandemic has revealed that our food systems are not resilient enough to adapt to severe stress, such as economic crises and climate change (OECD 2020a). Although being different in nature, the pandemic crisis and climate risks have common characteristics as both of them represent physical shocks, systemic, non-stationary, and regressive changes.

The current pandemic could be a preview of future shocks from climate change to supply and demand, disruption of food supply chains, and global pathogen transmission. Moreover, measures taken against each could result to improve the other, e.g., steps taken in climate-resilient infrastructure could increase economic and environmental resiliency.

Improving food systems to become more sustainable and resilient should be more than ever an urgent priority, including contingency plans and mitigation strategies that allow adapting fast to extreme events, as well as ensuring that inevitable crises will minimally affect food chains and vulnerable people (SCAR 2020).

Key to these plans is the strengthened position of farmers in the value chains (EC 2020f). Both the Green Deal and the CAP emphasise cooperation of producers within producer organisations and respective associations, which will allow producers to strengthen their position in supply chains as well as their resilience to economic and environmental challenges and contribute to climate action.

The EU Farm to Fork Strategy (EC 2020a) and the Biodiversity Strategy (EC 2020b) indicate the need for transforming in the food system: carbon neutrality, radical reduction of pesticides and fertilisers, a significant increase of organic farming and protected areas. As some of the root causes of the pandemic crisis are in the food system, the commitment to change is even stronger (HLPE 2020).

A key priority will be related to the reorganisation of agricultural supply systems, based on the principles of agroecology (Tittonell 2020), circularity (van Zanten et al. 2019), and One Health (Zinsstag et al. 2011; WHO 2017), to radically reduce GHG emissions, pollution and the risks related to human/animal interfaces.

As known, the most relevant critical point of the supply system is livestock, using about 40% of agricultural land (Mottet et al. 2017). Animals can play an important role in circular agricultural systems, as they can use biomass (e.g., grasses) that cannot be used in other ways, and can contribute to soil fertility through their excreta. Incentives and compensation should be addressed to the conversion of intensive livestock systems into integrated crop-livestock systems, bringing to a Livestock Unit/ha rate of 1 by 2030.

In parallel, tighter regulation of antibiotic use and support to antibiotic-free labelling as well as significant incentives to organic farming are required to achieve the goal of 25% of the area under organic farming by 2030. All of that will be subject to the next medium-term CAP reform (Maréchal et al. 2020; Matthews 2020).

A further point of attention will be 'blue bioeconomy' resources (EC 2020c). As fish capture cannot be expanded (FAO 2020), investments should be made in sustainable aquaculture – especially in multitrophic systems – and in cultivating algae (Fritsche et al. 2020).

Urban agriculture in all its forms, from community gardening to rooftop agriculture to vertical farming, will contribute to the green transition, making urban areas less dependent on long-distance trade for fresh vegetables, improving quality of urban life and contributing to consumers' education (Fritsche et al. 2020). For that, increased policy intervention is needed on dietary choices (Reisch et al. 2021), with investments in food retail, initiatives to make fresh and nutritious food more affordable, and regulation of junk food.

Food industries should innovate fast enough within the imminent economic crisis caused by the COVID-19 pandemic, offering affordable and competitive products, e.g., by developing functional foods fortified with bioactive compounds and antioxidants that promote health and support consumers' immune system (Galanakis et al. 2020). These products may emerge from food processing by-products, grasses, fungi, microalgae, seaweeds, and yeast that reduce inflammatory responses typically associated with cytokine storm in severe COVID-19 patients (Rowan & Galanakis 2020). There is also significant interest from existing businesses and various start-ups in animal protein alternatives, bio-based fibres, and respective marketing[8].

Viewed in the context of a global food syndemic, the interplay of food insecurity, malnutrition, and obesity based on dietary behaviours amid the COVID-19 pandemic indicate opportunities for addressing social and structural determinants of healthy eating as a strategy to improve the health of people and the planet (Abubakar 2020; Fears et al. 2020).

As part of the farm to fork chains, more safety measures are needed since more people (and subsequently more potential infection) are involved in the process. Thus, there is a need to develop respective bioanalytical protocols for food and environmental safety applications to adapt in the post-lockdown period highlighted (Rizou et al. 2020).

Advances in bioinformatics and next-generation sequencing will also help with improvements in microalgae applications and the determination of microbial populations in the system, including the emergence of pathogens or problematic microorganisms (Rowan & Galanakis 2020).

3.2 Innovation: Technologies and processes

Innovations in production such as climate-smart forestry, multitrophic aquaculture, carbon farming, and process innovations (e.g., robotics, automation of food production) as well as innovative products (e.g., biobased packaging, plant-based meat alternatives, composite wood materials) are under development and expected to disrupt the food and manufacturing industries (Fritsche et al. 2020; Galanakis 2020; Nakicenovic et al. 2020).

The pandemic presents an opportunity to accelerate green innovation, such as using bio-based materials for packaging or other uses in disposable objects (e.g., in 3D printers; biobased facemasks, see Das et al. 2020) and 3D-printed food (Portanguen 2019). Yet, circularity requires at least degradability of bio-based disposables.

The potential of digitisation in the food system (Aragonés et al. 2020) and beyond, as well as its contribution to sustainability is linked to strategies that address the issues of infrastructures, data availability and access, and system integration. These strategies identify application scenarios able to reorganise businesses and re-design production, logistics, distribution, consumption, and administrative and policy interfaces.

An appropriate option is to improve the interconnection of the different supply chains and ensure higher involvement of all stakeholders. Local and regional food systems with shorter supply chains are part of this preparedness (Petetin 2020), as is multi-scalar integration and governance that facilitates coordination and cooperation (Blay-Palmer et al. 2020). A shift to a more decentralised food system and biorefineries (e.g., using smart specialisation actions to enable the development of local/cities' bioeconomy) can provide security that farmers, small businesses, workers, and customers need.

To prevent displacing environmental and social degradation to third countries through imports, bi- and multilateral trade rules will need to be subject to stringent sustainability standards (Fritsche et al. 2020).

As fishery captures need to be maintained at current levels or below, and controls on illegal fishing will be tightened, room for a moderate expansion of fish and seafood supply will come from multitrophic aquaculture as a 'sustainable intensification' pathway.

Increased availability and a variety of alternative proteins will be needed. Agrobiodiversity may reveal itself as a strategic asset to provide a diversified supply fit to consumer tastes.

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[8] As addressed in presentations during EFIB in October 2020, see https://efibforum.com/programme-overview

3.3 Bio-based materials, bioenergy, and biofuels

Currently, the industrial system is too linear, resource-intense and based on non-renewable resources[9]. There are scalable innovations and viable technologies to produce sustainably sourced bio-based alternatives, though (Palahì et al. 2020), such as bioplastics, nanocellulose, and wood-based textiles with could significantly reduce both amounts of materials used and GHG emissions while creating durable carbon pools (Churkina et al. 2020, EFI 2017, IPCC 2019, Roe et al. 2019). Bio-based materials are also critical for more resilient cities (Wurm 2020), and bio-based products can help reducing GHG emissions in hard-to-abate industrial sectors in Europe (Chiappinelli et al. 2020).

Both in bio-based products and in bioenergy, possibilities to integrate biochemical and thermochemical processes gain attention, as well as the ability to valorise residues and co-products of upstream routes to improve on circularity. Also, the extraction of critical raw materials, as identified and listed in EC (2020h), should be developed in combination with biorefining processes.

Good examples, to indicate only some, are the integration of anaerobic digestion and slow pyrolysis to produce biomethane and organic carbon/nutrients (Casini et al. 2019), and lignocellulosic biomass refining into ethanol and biocrudes through hydrothermal or chemical processing of co-produced lignin-rich streams (Miliotti et al. 2019).

The same approaches can be applied to the valorisation of organic fractions from various sources, including municipal solid wastes, beyond the traditional waste recovery methods. Circular, zero waste value chains can ameliorate many challenges economies face struggling to deal with their carbon budgets and at the same time create value for the economy and the society.

As for biotechnologies, gene editing, and phenotyping have already opened a new era. In the fields of microbiology, synthetic biology and precision fermentation may grow fast, as they will be able to produce food in laboratories. In the area of plant and animal breeds and varieties, biotechnologies will impact, especially on the reduction of time to introduce genetic improvements to markets.

3.4 Environment and ecosystem services

Sustainable circular bioeconomy can offer diversity and embed activities within ecosystem services through a portfolio of natural based solutions, increase the planet's resilience to shocks and reducing risks from unexpected pandemics. The bioeconomy offers a unique contribution to addressing desertification effects due to climate change significantly in the Mediterranean, bringing organic carbon and nutrients back to the soil, and re-establishing microbiota in the soil and land fertility.

Agroecological farming can be an important component of that without compromising yields (Tamburini et al. 2020, Tittonell 2020). Another example is re-developing peatland (paludiculture).

Furthermore, the deployment of composted organic matter and biochar in Mediterranean lands should be pursued, given the ongoing desertification process affecting this area, with more than 8.5 Mha under risk of marginalisation (Chiaramonti & Panoutsou 2019), together with sustainable agricultural models able to increase soil organic carbon. This is an important option also globally (Yang et al. 2020).

This will, in turn, stimulate higher biodiversity and develop natural capital, matching with renewed interest and value placed today on nature, ecosystem services, and recreation. The options to permanently remove carbon from the atmosphere are excellent opportunities to contribute to climate mitigation (Jeffery et al. 2020).

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[9] Only 12% of the materials globally come from recycling (Palahì et al. 2020), non-metallic minerals such as sand or gravel account for about 50% of all resources extracted (IRP 2019).

3.5 BioCities, rural bioeconomies, and tourism

The role of cities in a sustainable circular bioeconomy is vital (Acuto et al. 2020): cities are the place where most consumers live, purchase, and consume. The choices related to commerce, infrastructures, health, mobility, and education significantly affect urban livelihoods and the environment, both through demand and supply.

Urban agriculture will have a more decisive role, especially about the provision of fresh vegetables (see Section 3.1), and urban forestry could become an essential nature-based component of rebuilding cities to provide healthy spaces during lockdowns while providing local feedstocks for the bioeconomy, and biodiversity gains[10].

Communities should be supported through training and education, both on the technical aspects as well as business models and management, so to create new employment opportunities during the transition to a low carbon economy, especially in rural areas fostering regional development (Chateau & Mavroeidi 2020). The significant development and implementation of regional bioeconomy models will be critical for the transition's success (BBI-JU & SCAR-BSW 2019).

Thus, boosting the green jobs market will help to drive economic recovery following the COVID-19 pandemic, bring socio-economic benefits to communities while stimulating the green transition in a win-win virtual loop. Examples include promoting labour-intensive retrofitting of sustainable biomass supply chains or biomaterials for energy-efficiency measures in existing buildings and green infrastructure (Wurm 2020) and should become an important component of the European renovation wave (EC 2020e).

For the tourism industry, it is vital to transform from the current model that favours a high resource consumption to a model that supports the circular bioeconomy (Prideaux et al. 2020). Framing the decarbonisation of transport systems as a means to keep walking and cycling and protect green spaces rather than directly promoting them as climate policy measures may increase public support (Rousseau & Deschacht 2020).

3.6 Financing the sustainable, circular bioeconomy as part of the recovery

Examples from Ireland indicate that providing liquidity to vulnerable businesses is important (IBEC 2020). This includes liquidity and financing support for farmers, fishers, and agri-food businesses and for banks to offer early flexibility to their customers regarding emerging cash flow issues (Rowan & Galanakis 2020).

Beyond that, the enormous EU funds (both public and private) for the economic recovery as stimulus packages to address the crisis offer opportunities to invest in the future, including in a sustainable circular bioeconomy which requires investments into 'sustainable' bio-based activities, enabled by the EU Taxonomy[11].

In order to support the EU industry in its transformation towards a sustainable and circular bioeconomy, sufficient EU funds need to be leveraged to de-risk innovative projects and stimulate private investments, far beyond the €250 million, which is the current target size of the European Circular Bioeconomy Fund. Furthermore, closely monitoring the effectiveness of these financial programs is essential.

More near-term, the EU should back crowdfunding for local bioeconomy investments as part of the NextGenerationEU Recovery Plan and add a sustainable fair-trade component with a focus on sub-Saharan Africa to foster solidarity.

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10 For more details see e.g., Alexandra & Norman (2020); Cabanek, Zingoni de Baro & Newman (2020); Daniels et al. (2020); WBGU (2020); Wurm (2020).

11 https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en

3.7 Enhancing the social infrastructure: including culture and arts

It has been argued that a circular sustainable bioeconomy should extend its scope to include the social dimension better, especially culture and arts with their close linkages to food, materials consumption, and mobility as a means to drive the transformation (Fritsche et al. 2020; Hanspach et al. 2020).

In the political discussions around providing financial support to compensate for COVID-19-related economic losses, the role of culture and art is yet a fringe issue, though: the cultural dimension of closing museums, performing art centres, and restaurants is mostly neglected.

A key reaction to the COVID-19 pandemic is to 'go virtual', i.e., remote working and teaching (home office, digital schooling). This surely helps to reduce or at least slow the further spread of the Coronavirus but implies a massive lack of social interaction. The change also concerns leisure time (gaming, social media) – and being more online may result in losing much of the 'dampening' of individualistic behaviours through real-world social interaction and opens for tampering public opinions (fake news and 'bubbles', populism). These trade-offs and risks to social cohesion must be acknowledged.

Thus, it is crucial to bring recovery support also to culture & art as an investment in the social infrastructure and to recognise this as a part of the bioeconomy transformation.

3.8 Towards a BioWEconomy

Civil society activities and engagement will be a key game-changer for behaviour, contributing to changing social norms related to food, material consumption, and mobility. The involvement of civil society in the bioeconomy will expose companies and public administrations to new values and goals and allow new governance arrangements (Fritsche et al. 2020). In that regard, social marketing is needed to understand attitudes, perceptions, and barriers that influence the behavioural change of consumers and businesses. Subsequently, this change will adapt to new norms enforced by the COVID-19 pandemic (Galanakis et al. 2021).

First successful experiences showed that involving stakeholders with different behaviours, values, and backgrounds is a crucial enabler of the process. It is a precondition for increasing the social acceptability of bioeconomy facilities (production and conversion sites, logistic areas etc.) by informing citizens and civil society organisations and, at the same time, it improves the feedstock availability by increasing coordination between actors dealing with waste management (Morone & Imbert 2020).

To be socially accepted widely, the bioeconomy needs to rely increasingly on 'circular' feedstocks from bio-based residues and wastes to reduce dependency on crops that compete with agriculture/food markets. Food waste represents a valuable option (Sanchez Lopez et al. 2020) as it allows for producing a broad group of biobased products ranging from biofuels to bioplastics (Aldaco et al. 2020; Morone & Imbert 2020).

It is also essential to financially support SMEs, innovative industries, farmers, fishers, and agri-food businesses that fit in local bioeconomy models. The development of the BioWEconomy concept to actively include smallholder farmers, indigenous people, women, and the youth by using upstream engagement and bottom-up approaches in the decision-making process can be a buffer against unemployment in times of economic crisis and open up the bioeconomy to socio-cultural and economic innovations.

Value story-telling and sharing to capture acceptable practices and lessons learned could be relevant approaches to build solidarity to amplify the communities' voices that have needed solutions (GAFF 2020). Beyond food, the re-design of cities to improve living and health conditions through bioeconomy and nature-based options (see Section 3.5), the transformation of mobility and tourism, and improving the circularity of material consumption all require not 'just' technologies and respective investments, but cultural innovation and societal engagement.

4 How the EU bioeconomy can enhance resilience

The intensification of severe events such as the COVID-19 pandemic and extreme weather (extended drought periods, heavy rainfalls) as foreboding indications of climate change underline trespassing biophysical and societal boundaries makes human-built systems more vulnerable. For instance, the impact of climate change on the day-by-day business is already a reality for many EU farmers, particularly in Southern EU, which heavily affect their economic operations and returns.

Given this, there is an urgent need to re-design socio-ecological systems to bring vulnerability down to acceptable levels. On the other hand, it must be acknowledged that risk is inherent to the complexity of human societies, and action to both prevent risks and to prepare for them is required, as well as respective foresight to explore resilient options (EC 2020g).

As risk is inherent to complex systems, societies need to prepare actively for crises. Food is an essential component of managing risk (SCAR 2020). A food security policy implies establishing organisations and networks to assess system vulnerabilities, foresee shocks, foster redundancy and modularity, design recovery plans, and ultimately cope with crises.

Early warning systems, capable of detecting weak signals, would allow us to act more rapidly and mitigate the impact. Foresight exercises should be regularly carried out, as starting now in the European Commission (EC 2020g), at all administrative levels. To reduce the risk of under-or over-compensation of losses, accurate monitoring tools should be put in place, and fiscal policies based on redistribution should be considered.

4.1 The food system

Food system resilience is more likely to be fostered through a combination of local, informal, regional, and then global supply chains (Blay-Palmer et al. 2020). Once the COVID-19 pandemic has passed, matching short food supply lines with local demand and consumer needs will be a great challenge to reduce uncertainties from global systemic risks and urban population growth (Pulighe & Lupia 2020).

First examples of successful experiences suggest that cooperation and coordination between key stakeholders, such as public authorities, practitioners from industry and industry associations, local administrations and waste management organisations as well as consumers and civil society are essential to ensuring that the industry can take advantage of wastes generated locally, minimising any form of resistance associated with 'not in my back yard' and 'locally unwanted land use' behaviours (Morone & Imbert 2020). There is a need to reconstruct globalised systems in a way that puts people and the planet's wellbeing at its heart (Benton 2020).

In terms of food supply, a priority of transforming the bioeconomy towards circularity and sustainability is the intensive livestock farming systems, given their contribution to GHG emissions and the risks related to zoonoses and antibiotic resistance (SCAR 2020).

Specific resources should be dedicated to the conversion of some of these farms upon organic and carbon farming, with a reduction of the livestock/land rate, integration of livestock with crops, agroecology approaches, and advanced technologies for the production of biogas and digestate. Furthermore, the blue bioeconomy offers interesting alternatives to land-based feed for animals (Kinley et al. 2020).

Although innovative farming deployment will not solve food security and dietary issues, it might shape a more resilient urban food system (Pulighe & Lupia 2020).

Moreover, the implementation of legislation, policies, and research programmes in which different sectors and stakeholders communicate and work together to achieve better public health outcomes within the 'One Health' approach could contribute further to the resilience of the food system (WHO 2017). This approach is particularly relevant in food safety, the control of zoonoses (diseases that can spread between animals and humans, such as flu and COVID-19) and combatting antibiotic resistance.

The application of the principle of diversity will imply a degree of re-territorialisation of food systems, with an increase of the capacity of local production systems to satisfy basic needs and giving local communities a greater degree of control over the governance of the distribution system.

This may imply support to logistic infrastructures, diversification of distribution systems, and support to farm investments to improve their capacity to keep added value on-farm.

The increase of organic farming will require a clear policy commitment, based not only on financial support to farms but also on the development of reformed Agricultural, Knowledge and Innovation Systems (AKIS) to allow farmers to benefit from state-of-the-art knowledge and advanced technologies and give them support to the conversion.

4.2 Bio-based materials and nature-based solutions

One possible approach to supporting resilience and a green recovery, whilst moving towards a target of net zero emissions, is aligning the utilisation of woody biomass to produce a wider range of bio-based materials, in conjunction with adapting 'nature-based solutions' in the forest sector. This could contribute towards urban greening (Section 3.5) and rural regeneration.

Woody biomass can be utilised for a range of products. Fritsche et al. (2020) emphasise that, beside traditional use of biomass for construction, fibre, furniture and textiles, modern biomaterials, especially bio-based chemicals, lubricants, and plastics need consideration. Many of these wood-based products represent a reservoir of sequestered carbon. All of the products and can be used in place of (i.e., to 'substitute' for) generally GHG-intensive non-biomass materials and energy sources.

The potential role of bio-based materials for supporting regional and rural regeneration, particularly through regional deployment at small scales has already been highlighted in Section 3.3. In particular, regionally based small-scale biorefineries offer promising alternative routes to large-scale biorefining, and seem more compatible with rural development, resilience, and system efficiency.

Woody biomass can be an important low-emission contribution to a circular bioeconomy, with positive employment effects (Jonsson et al. 2021), which means in the context of the pandemic recovery:

"A sustainable forest sector lies at the heart of COVID-19 recovery plans that seek to Build Back Better." ACSFI (2020)

However, Fritsche et al. (2020) point out that forests have a finite capacity to supply wood renewably, whilst a quite large increase in harvesting in EU forests will lead to negative impacts on forest carbon stocks and the forest carbon sink. The role for woody biomass in the bioeconomy thus appears to be a highly constrained optimisation problem, in terms of using woody biomass and the associated forest management practices, if wider climate change and sustainability goals are to be met.

Climate-Smart Forestry (Verkerk et al. 2020) has been proposed as an approach to managing forests, which involves variously conservation of forest carbon stocks or harvesting for timber and biomass supply, or some combination of both activities, recognising local circumstances and the objective of climate change mitigation.

Fritsche et al. (2020) note the importance the effective use of available wood resources, possibly by matching the supply of woody biomass types to the best applications, biomass cascading: this involves prioritising the use of wood for the manufacture of longer-lived and structural products, preferring the use of wood industry residues (e.g. chips and sawdust) for material products (including innovative new wood-based products), ensuring effective re-use, repurposing and recycling of wood at end of use and eventual energy generation on disposal or as a by-product of materials production.

Such an approach involves considering "*the whole [woody biomass] value chain*" (Jones et al. 2019), from forest management, through wood processing, decisions about the use of wood products in service, the treatment of wood at end of life, second/third-life uses and ultimately combustion with energy recovery.

Forest management strategies are also linked to efforts towards forest protection, restoration, and diversification, so as to support the adaptation and resilience of forests to climate change and the maintenance of other ecosystem services alongside support to bioeconomy development and climate change mitigation through potential substitution of biomass for other materials and fuels.

Crucially, forest management in the context of mitigating climate change must also be able to adapt or be resilient to environmental change. There are a number of possible relevant approaches, sometimes collectively referred to as nature-based solutions.

The International Union for Conservation of Nature (IUCN) has defined nature-based solutions as "*actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*"[12]. The importance placed on benefits to both human well-being and biodiversity should be noted. Specific actions within the scope of nature-based solutions include[13]:

- Protecting forests with existing high carbon stocks and biodiversity value
- Restoring forests in which carbon stocks and biodiversity are at risk
- Managing forests to provide biomass resources, whilst conserving or increasing carbon stocks and biodiversity
- Creating new forest areas, to provide additional biomass resources, whilst enhancing terrestrial carbon stocks and biodiversity.

Relevant measures have been presented in Fritsche et al. (2020). Overall, the development of the use of bio-based materials, in conjunction with nature-based solutions can be seen to support the objectives of developing a circular bioeconomy development, climate change mitigation and increased resilience, provided measures are matched to local circumstances.

It may be noted that such measures are already being identified as particularly relevant to supporting a green recovery and the development and revitalisation of rural areas (Hirst & Lazarus 2020).

However, some measures also appear relevant to urban regeneration and greening, if deployed at an appropriate scale, notably including urban forest creation and restoration, again possibly linked to utilisation of locally produced biomass resources and effective wood use and reuse and the development of biomass cascading facilities (WBGU 2020).

The challenge is to support a coherent portfolio of activities involving expansion of nature-based solutions, supporting the greater use of bio-based materials, wood reuse, recycling, and disposal. This is an area where practical guidance and decision support tools still need to be worked on.

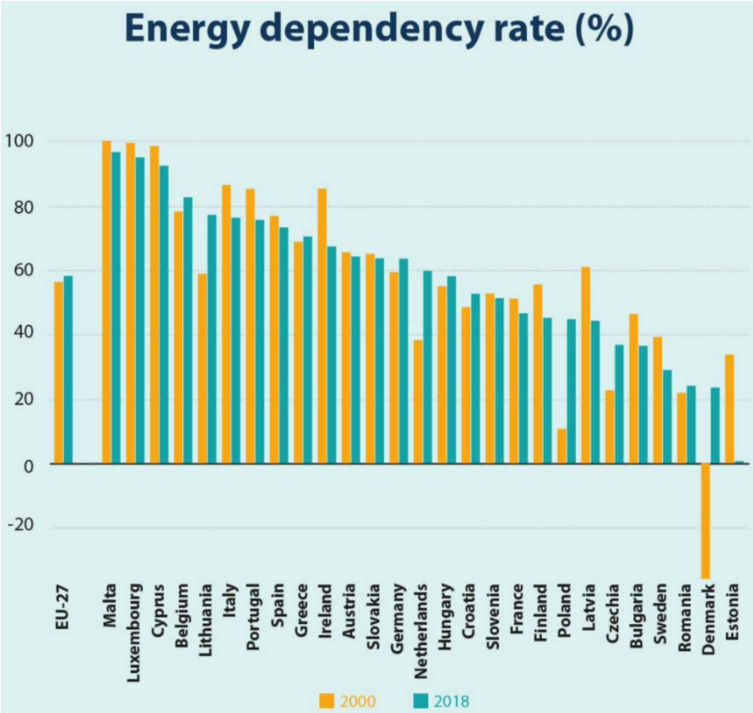
[12] https://www.iucn.org/theme/ecosystem-management/our-work/iucn-global-standard-nature-based-solutions

[13] Classification suggested by Prof. Pete Smith, University of Aberdeen, UK (personal communication)

4.3 The energy system

The EU energy markets are significantly dependent on imports, as shown in the following figure.

Figure 4 EU-27 and Member States energy dependence rate



Source: EUROSTAT (2020)

Up to 58% of EU-28 energy was imported in 2018, which is a significant increase compared to 47% in 2000. Oil products dominate imports, followed by natural gas and coal. This high dependency represents a strategic risk for the EU (Buffet 2016).

The need for energy security combined with local resilience during pandemic crises, as the one now, is prominent. It can be facilitated through prioritisation of bio-based value chains within their geographic settings and focus on resource-efficient options that use domestic biomass, contribute to rural and wider economic development, and meet overarching climate change and circularity targets (Panoutsou & Singh 2020).

A circular bioeconomy with short supply chains offers the opportunity to improve resilience by mobilising domestic biomass resources, improving resource efficiency through cascading, and valorising wastes which otherwise would have to be disposed of and leveraging specific strengths within EU regions (Feindt, Proestou & Daedlow 2020).

This approach will achieve higher market uptake of sustainable, domestic biomass, mitigate raw material competition, and facilitate rural, industrial, and economic development, and simultaneously deliver higher biomass shares within sector targets (Panoutsou & Singh 2020). Fossil energy imports will be subsequently reduced.

During the first COVID-19 related lockdowns, renewable energies from biomass, hydro, solar, and wind continued to produce as normal.

With increases in variable renewable energy from PV and wind, bioenergy as a form of energy storage is a perfect candidate to offer balancing in electricity and district heat systems (Arasto et al. 2017; Lehtveer & Fridahl 2020).

While the above considerations apply to electricity grid balancing, the role of biofuels in the future transport markets can be more relevant than ever, and essential to achieve decarbonisation even if a high penetration of electricity in transports is assumed (Bacovsky et al. 2020a+b).

As noted above, the energy system is almost completely dependent on import of fossil oil and gas, which fact has a quite large impact not only on the environment but also on the economic balance of Europe and Member States.

COVID-19 surge keeps oil below $40, which is considered by many as a minimum equilibrium price. During the second trimester of 2020 almost €50 billion write-downs were recorded.

Also, US and EU oil majors seems adopting diverging strategies, with US more focused on conventional business, while EU companies on cutting fossil (for instance, BP announced 40% oil cut by 2030). This business framework limits investments in the energy sector, and thus also on renewables, including bioenergy, unless strong policies are in place.

Bioenergy within the broader bioeconomy can in fact bring value back to the EU economy, especially if supply comes from within the EU. Furthermore, investments in biofuel production will mostly address systems, processes and technologies designed and built by EU stakeholders.

Thus, the entire chain would increase resilience of EU companies throughout the entire chain, and favour sustainable economic and social development in the post-COVID-19 era, beyond environmental benefits. This would fall perfectly within the European Green Deal priorities.

5 Synopsis and preliminary conclusions of EU bioeconomy options in the post-COVID-19 recovery

The previous considerations for potential EU bioeconomy contributions to the post-COVID-19 recovery are summarised in the following.

Table 4 Synopsis of potential EU bioeconomy contributions to post-COVID-19 recovery

Sector	Options
Agriculture	• Foster agroecology, carbon farming practices (e.g., crop rotation, cover crops) and from rehabilitation of degraded land • Support more sustainable agricultural modes through organic nutrients/fertilizers, and urban farming. • Accelerate the transition of livestock systems to sustainable levels and practices • Strengthen farmers in the circular bioeconomy transformation
Forestry	• Support use of nature-based solutions for increased production of woody biomass for bio-based materials and bioenergy, including extension into 'urban forestry'
Fishery	• Support transformation of smaller-scale fisheries to multitrophic aquaculture, macro-and microalgae production
Food	• Set sustainable trade standards coherent with the Green Deal goals. • Support innovative food (e.g. plant-based proteins), local food systems (urban-rural collaboration), and food education. • Encourage sustainable food environments
Energy	• Support advanced biofuel production from domestic resources as residues and wastes, from intercropping and cover crops and from rehabilitation of degraded land • Support green infrastructure projects (e.g., small-scale biobased combined heat & power production for local and industrial heat, and for grid balancing high-efficient solid-oxide fuel cells using biomethane for CHP, smart grid solution allowing for higher amounts of Variable Renewable Energy, etc)
Materials	• Stimulate bio-based products for households and companies purchasing low-carbon bio-based products. • Quota systems for bio-based construction materials, and incentives for better use of wood and cascading
Transport	• Support infrastructure for bio-based (and electric) local public transport and respective car-sharing • Invest in extending high-speed train routes • Favour multi-modal means for transportations of goods
Finance	• Valorisation of the EU Taxonomy for 'sustainable' bio-based activities • Leveraging of EU funds, and mobilise private investment into the bioeconomy, including 'crowd funding' • Stimulating innovative solutions for industrial symbiosis, and connecting different sectors through new business models
Tourism	• Support regional bioeconomy clusters, integrating conservation forestry, nature protection areas, food systems, and agroecology
Cross-cutting	• Support decentralised biorefineries, innovative bioprocessing, and stimulate a BioWEconomy through society engagement at all levels

Source: own compilation

This synoptical list needs to be substantiated and concretised.

The following examples provide a first collection of respective suggestions which should be refined and extended based on further analysis:

Agriculture

- Improve crisis management and forecasting capacities: develop crisis and disaster management plans that anticipate potential threats, forecast impacts on agriculture, and create mechanisms to manage these threats (Lioutas & Charatsari 2021). These tools should include prevention, emergency response, and resumption plans, and include innovative value chains (Altieri & Nicholls 2020).
- Bring digitisation to agriculture: support creation of open big data platforms (Jones et al. 2017), new Agricultural and Rural Knowledge and Innovation Systems (ARKIS) focused on agroecology and on data-driven farming (Ingram & Maye 2020), digitise agriculture-related administration (Ehlers, Huber & Finger 2021), and create a European-wide program to combat rural digital exclusion (Park & Humphry 2019)
- Provide support to reconversion of farms that should be phased out because of their environmental impact (Poux & Aubert 2018)
- Learn from others: e.g., Canada increased the budget for enhancing lending capacity of farmers by offering in parallel a grace period of loan payment (Ker 2020). The US launched a $19 billion fund (Coronavirus Food Assistance Program) to ensure that farmers and supply chain actors continue to produce and distribute food (USDA 2020).

Forestry

- Develop guidance to support the forest sector in translating the concept of climate smart forestry into practical measures with tangible outcomes. Build on existing efforts, develop tools to support forest practitioners in making plans and decisions to implement the approaches of climate smart forestry.
- Engage with Member States to explore how policies could support a cooperative framework to mobilise wood resources, whilst maintaining forest carbon stocks and carbon sequestration and achieving GHG benefits, recognising how the burden of effort would fall to very contrasting extents in different Member States.
- Engage with Member States to explore how national plans could adopt the principles of climate smart forestry by e.g., supporting the establishment of demonstration forest areas to guide the forest sector in implementing relevant practices.

Food Systems

- Create community marketing schemes (Thakur 2015) for local goods (Richards & Rickard 2020) and public services from agriculture (Verhaegen & van Huylenbroeck 2001) to ensure an income floor, even when they are used as secondary distribution channels. This can play a significant role in food assistance programs, making easier the access of needy families to food (Sharma et al. 2020).
- Intensify and support efforts on reducing and valorising food waste in biorefineries
- Support establishing urban food councils (Gupta et al. 2018) - learn from others: The Toronto Food Policy Council is an example of successful food planning and policy. It advises the City of Toronto on food policy, and is a forum for action across the food system

Energy Systems

- Stimulate local supply chains and decentralised schemes in bioenergy and biofuels, to support local economy recovery through securing investments in renewable fuels by new specific financial instruments and stable policies

- Improve energy resilience through circular bioeconomy (Jiang, van Fan & Klemeš 2021), considering balancing the grid, and enhancing digital capacities to recalculate potential bioenergy role in the post-COVID-19 era (Schwarz et al. 2020)
- Account for changes in urban environments, e.g., teleworking, consumer behaviour, etc. (Sisson 2020) to re-adjust planning and market uptake of bioenergy carriers within the circular bioeconomy (Lim 2020).

Cross-cutting

- Sustainability criteria for production and use of all biomass to support optimal utilisation and ensure that negative impacts on carbon stocks and sequestration in agricultural and forest systems (Camia et al. 2021) are avoided, minimised, or ameliorated.

At present, it remains unclear how the COVID-19 pandemic will manifest itself in the long run: this applies to the 1st and 2nd waves of the pandemic and even more to potential subsequent wave(s).

Governments are under intense pressure to embark on the recovery while fighting the spread of the virus: they must learn from the lessons COVID-19 has already delivered and avoided favouring business-as-usual approaches, or worse, rolling back existing environmental standards.

Indeed, it is currently not possible to deliver a complete and forward-thinking analysis, as too many uncertainties still exist in both the sanitary and economic dimensions.

However, a sustainable, circular, and transformative bioeconomy fostering innovation and people's inclusion represents great opportunities with at least partly solutions in the post-COVID-19 era and during the EU economic recovery.

These opportunities cover all sectors of the bioeconomy and beyond – from agriculture, fishery and forestry to food, energy, materials, transport, and tourism as well as financing and cross-cutting options such as decentralised biorefineries, innovative bioprocessing, and stimulation of an inclusive BioWEconomy.

Concerning the recommended actions, considering the need to ensure a transition leaving no one out, both short- and long-term strategies should be immediately elaborated with dedicated measures.

In that, supporting economic operators, communities, and stakeholders to overcome the crisis and preserve jobs and economic activities need to be combined with decarbonisation and sustainable production and use models.

EU financial programmes should thus stimulate private investments and monitor effectiveness. A significant increase of the European Circular Bioeconomy Fund is needed to support the European industry in its transformation towards a circular and sustainable bioeconomy – the current funding of €250 million is far too small for that.

It should also be investigated more deeply how the circular bioeconomy can encounter the sustainability implications of COVID-19 in urban and rural areas, and what impacts this will have on ecosystem services and on achieving the SDGs.

Last but not least, the recovery must acknowledge that sustainable investments not only concern 'hardware' but also the socio-cultural practices: culture and arts are essential components and drivers of societal change, and this role must be amplified.

Given that the global pandemic is ongoing also in the EU and its Member States, and relatively little evidence exists yet on COVID-19 impacts and bioeconomy responses, the analysis presented here is preliminary and needs substantiation from further work, considering future results from monitoring, and scientific knowledge expected to arise in the 2021-2022 timeframe.

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List of abbreviations and definitions

ADB	Asian Development Bank
AFOLU	Agriculture, Food, and Land Use sector
AI	Artificial intelligence
BAU	business-as-usual
BIC	Bio-based Industry Consortium
CAP	Common Agricultural Policy
CHP	Combined Heat and Power (cogeneration)
EC	European Commission
ECDC	European Centre for Disease Prevention and Control
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas(es)
ICT	Information and communication technologies
IEA	International Energy Agency
IINAS	International Institute for Sustainability Analysis and Strategy
IPCC	Intergovernmental Panel on Climate Change
IRP	International Resource Panel of the United Nations Environment Programme
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre of the European Commission
LDC	Less Developed Countries
LSU	Livestock Units
LULUCF	Land Use, Land Use Change and Forestry
NoE	Network of Experts
OECD	Organisation for Economic Co-operation Development
SCAR	Standing Committee on Agricultural Research
SDG	Sustainable Development Goals
SME	small and medium-sized enterprises
US	United States of America
WB	World Bank
WBA	World Bioenergy Association
WHO	World Health Organization

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