Organisation for Economic Co-operation and Development

"Carbon management policies: Global practices in sustainability indicators and assessment", an OECD Workshop Proceedings

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This document constitutes the Proceedings and main findings of two webinars co-organised by the Norway delegation and the BNCT.

Webinar 1: General policy aspects, October 15
Webinar 2: Sustainability in value chains, October 22

The findings from these workshops as detailed in this report are intended to prepare and inform a more in-depth analysis of policy issues around the bioeconomy in the context of a carbon management policy paradigm.

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Proceedings from workshops on "Carbon management policies: Global practices in sustainability indicators and assessment"

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Introduction

1. Technology underpins economic growth and development of a more resource efficient and sustainable society. Moreover, technology is essential to analyse and monitor the progress towards these objectives. The Bio-, Nano- and Converging Technologies (BNCT) Working Party of the OECD organised two webinars to continue its longstanding work on technology-driven societal transitions such as the emerging bioeconomy.

2. The growing number of national bioeconomy strategies and related policy measures among OECD countries (Figure 1) shows an increasing commitment to the green transition, i.e. replacing fossil carbon with renewable resources. While the fundamental justification for public intervention in the bioeconomy is improved sustainability (Marvik and Philp, 2020), there is a need to agree on informative and practical measurement tools and indicators as a basis for policy development.

Figure 1. National bioeconomy strategies and related instruments.

Source: OECD updates of earlier work by the German Bioeconomy Council.

3. The bioeconomy is often described as a mechanism to address some of the grand challenges faced by global society. These challenges are presented in the United Nations Sustainable Development Goals (Figure 10), seventeen goals to address environmental, societal and economic issues and deliver a more sustainable future.

4. Even with the strongest intention to foster greater future sustainability and resilience, it is entirely foreseeable that the increasing use of biomass for food, materials, and chemicals, could lead to over-exploitation of natural resources. Limited resources could then lead to competition for land between bioenergy (climate action) and food crops (food security) or between such bio-based production and the preservation of biodiversity and natural ecosystems. This raises a series of critical questions. How much land can be

used for economic purposes without disrupting wider ecosystem services? If land is limited how should it be best used, for food? Feed? Energy? Or industrial products?

5. Like the wider economy the bioeconomy draws on finite resources. Land is limited, which places a constraint on biomass availability. Sustainability is multi-faceted; environmental, social and economic factors all contribute to sustainability. When considering environmental impact; energy consumption, GHG emissions and water use are just three indicators of sustainability.

6. With so many goals to work towards, it is inevitable that decisions on priorities and on where to find compromises will be required to ensure development is balanced across all parts of society and global regions. Hence, a particularly important topic for bioeconomy policy development is a systemic approach and a broad international discussion of the relative weight and priority given to different sustainability goals in situations where these goals may be in conflict.

7. With these considerations in mind, the two webinars that constituted the workshop comprised:

- Webinar 1: General policy aspects, October 15.
- Webinar 2: Sustainability in value chains, October 22, exemplified by the key value chains of aviation fuels, animal feed and plastics.

8. Taking the arguments one step further: should the bioeconomy be seen as one part of an over-reaching carbon management strategy under the umbrella of a renewable carbon economy ("Bioeconomy is not alone"), which also includes recycling and CO_2 utilisation (CCU and CCS)? Is there a need for common sustainability criteria for all carbon-based products? These overarching questions centre on understanding sustainability trade-offs and the relevance of a carbon management perspective.

9. A further purpose of these workshops was to prepare and inform a more in-depth analysis of policy issues around the bioeconomy during the next two-year Programme of Work and Budget of the BNCT.

Structure of the webinars

10. Both webinars followed the same format. Presentations were made by experts from the public sector, either government, international organisation or academic, followed by perspectives from industry. This balance is important: history has shown that sustainability assessment is exceedingly complex and it would be easy to make the mistake of constructing assessment and certification schemes that are so complex and expensive that industry would not be able to support them. At the same time, 'industry' is not monolithic. Sustainability affects multinationals as well as small-to-medium enterprises (SMEs). While multinationals would find it easier to accommodate sustainability financially, that would not apply to the many SMEs in the bio-based value chains. Thus the more voices that are heard from industry the more realistic can be the recommendations.

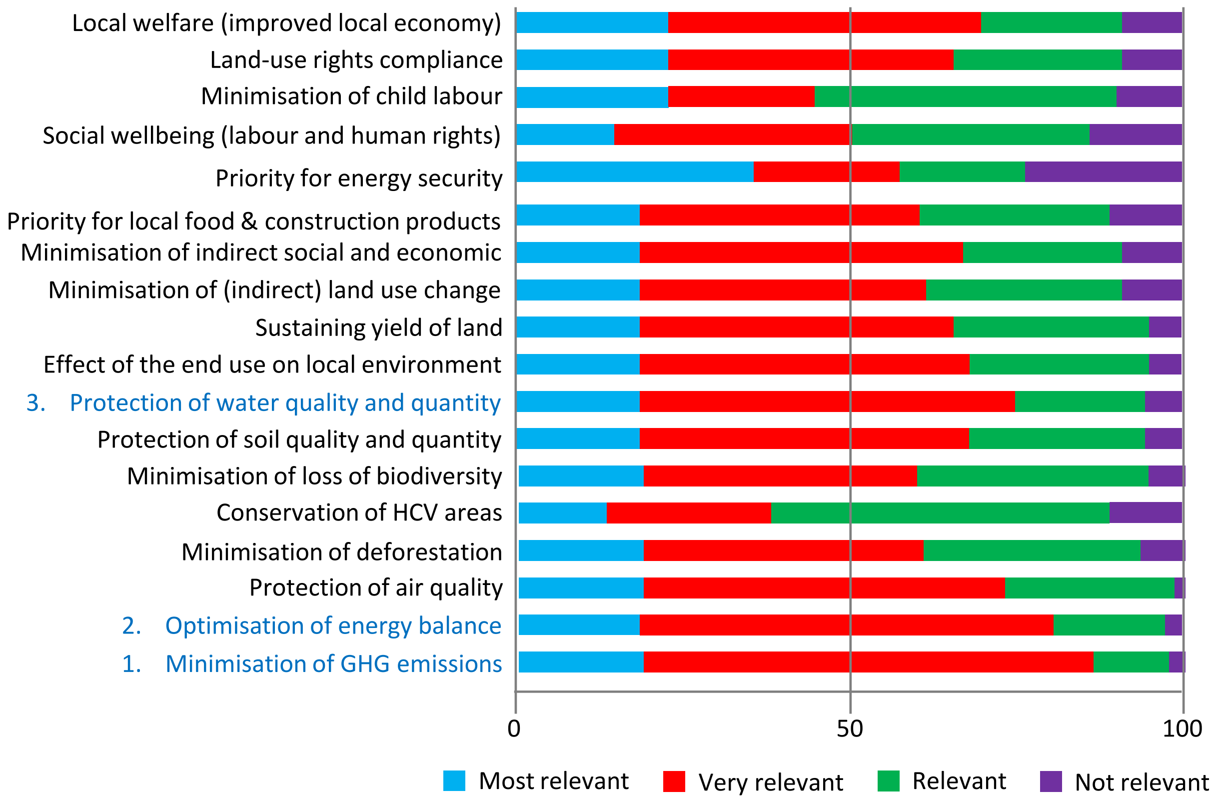
Origins of work on sustainability of bio-based products at the OECD

11. A stand-out publication in this area that highlighted the difficulties in harmonisation of indicators was that of van Dam and Junginger (2011) and the responses to a questionnaire (Figure 2). It received 473 responses collected from 25 EU member countries and 9 non-European countries; 285 could be used for further processing. Based on the sum of "*most relevant and very relevant*" the respondents rated the following three sustainability criteria with greatest relevance.

- Minimisation of GHG emissions (87%).
- Optimisation of energy balance (81%).
- Protection of water quality and quantity (76%).

12. The authors analysed responses in greater detail by making subsets of respondents. Generally, the criteria that are given the highest importance are focused on climate and energy issues, followed by water conservation. There is no clear preference amongst respondents for including biodiversity, environment or socio-economic criteria in a certification system. The overall message is that designing indicators is one thing; gaining consensus among stakeholders is a rather more difficult task.

Figure 2. Responses to a questionnaire on the importance of criteria or indicators for



Source: Adapted from van Dam and Junginger (2011)

13. An OECD workshop was run on June 10-11, 2014 on biomass sustainability. From that workshop, the many policy implications were observed, and summarised in OECD (2014). Since then, the debate on what to measure has continued (e.g. Martin et al., 2018) and remains unresolved. Clearly LCA only applies to environmental impacts.

14. Previous work at the OECD has focussed on biomass (feedstock) sustainability, but also on bio-based products. The two are part of the overall sustainability picture; the processes for production should be fit for purpose with sustainable feedstocks, and the end-of-life of products is also important.

Webinar 1: General policy aspects

1. Transnational policy

1.1. The OECD 2013 Council Recommendation on the Sustainability of Bio-based Products: an implementation review

15. The OECD Council adopted the Recommendation on the Sustainability of Bio-based Products to support the development of bio-based products in a manner that would guarantee their sustainability. It applies to commercial or industrial goods (other than food or feed) composed in whole or in significant part of biological products, forestry materials, or renewable domestic agricultural materials, including plant, animal, or marine materials.

16. The world has tilted more towards a green, circular and sustainable world since the publication of the Recommendation. In essence, bio-based products represent a gradual shift from oil to biomass as a feedstock for industrial production to reduce emissions. Thus the Recommendation also aligns with the shift towards carbon neutrality.

17. OECD Council Recommendations are not legally binding but practice accords them moral force as representing the political will of Adherents. There is an expectation that Adherents will do their utmost to fully implement a Recommendation. In 2013, the Council Recommendation on the Sustainability of Bio-based Products was published. Its provisions are listed in Box 1.

Box 1. Provisions of the OECD Council Recommendation on the Sustainability of Bio-based Products.

It contained 10 overall recommendations

1. Develop and implement national frameworks for assessing the sustainability of bio-based products.
2. Build consensus amongst relevant stakeholders in developing sustainability assessment frameworks.
3. Ensure the international consistency of approaches.
4. Facilitate the development and adoption of assessment methodologies for bio-based products that are science-based … to minimise the possibility of generating trade barriers.
5. Facilitate the development and adoption of international sustainability indicators for bio-based products.
6. Develop and implement effective and efficient third party peer review.
7. Collect and make public appropriate data relevant to the sustainability assessment of bio-based products … to facilitate the development of assessment methodologies for evidence-based decision-making.
8. Promote awareness of the sustainability aspects of bio-based products.

9. Enhance collaboration with non-members and assist them in the development and implementation of principles for assessing the sustainability of bio-based products.
10. Provide …support to SMEs involved in bio-based production.

For recommendation number 5 there were several specific recommendations

Facilitate the development and adoption of international sustainability indicators for Bio-based Products that are science-based, unambiguous and validated. These should take into account factors such as:

i. Energy balance, including non-renewable and renewable energy use.
ii. All greenhouse gas reduction over product life cycles.
iii. Bio-based content as an indicator of renewability.
iv. Anticipated product life.
v. Water and solvent use during the different stages of production, and impacts on biodiversity during feedstock production and subsequent processing.
vi. Direct and indirect land used for feedstock production.
vii. All aspects of end of product life.
viii. Conventional as opposed to alternative bio-based production economics.
ix. Impact on human and environmental health.

Source: OECD (2013)

18. During the last decade many differing views on what constitutes a definition of a bioeconomy have arisen. A single, harmonised definition has the simplistic beauty that it can then be used to measure and compare the contributions of the bioeconomy to the economy overall. Convergence now seems unlikely, as definitions have often arisen in response to the priorities of an individual country (Frisvold et al., 2021). On the one hand, there are definitions such as those of the OECD, which are very narrow and focus on biotechnology. On the other hand, there are examples like France, which define the bio-economy very broadly. Thus there is a distinct divide in countries that promote biotechnology in their bioeconomy strategies, including some of the largest economies of the OECD Members, and those that do not.

19. OECD (2009): the bioeconomy is "*the set of economic activities in which biotechnology contributes centrally to primary production and industry, especially where the advanced life sciences are applied to the conversion of biomass into materials, chemicals and fuels*".

20. Ministry of Agriculture and Food, France (2018): "*Bioeconomy must help in the transition from an economy based on fossil resources, to a competitive and sustainable economy based on renewable carbon. With bioeconomy on the rise, sectors such as agriculture, forestry, aquaculture and fisheries, will position themselves as key players in the transition to a carbon free economy. The development of bioeconomy brings us the opportunity to remember that farmers, foresters and fishermen feed us, but that they can also heat us, dress us, and, finally, provide us with electricity and materials*".

1.2. The role of bio-based industry in the EU Green Deal

21. In the European Green Deal, the bioeconomy can play a role in biogenic waste streams conversion to bio-based products, although the European Commission is not convinced of the environmental superiority of bio-based versus fossil-based[1]. Several research works point to reduced emissions (e.g. Weiss et al., 2012), but there is a history of studies that show that bio-based is not always better in terms of other sustainability criteria, such as acidification and eutrophication potential (e.g. Brizga et al., 2020; Broeren et al., 2017; Harding et al., 2007; Pawelzik et al., 2013). Significantly, land use impacts, such as the potential loss of biodiversity, soil carbon depletion, soil erosion, deforestation, as well as GHG emissions from indirect land use change (iLUC) were not quantified by Weiss et al. Thus work needs to be done by life cycle analysis (LCA) and other tools on a case-by-case basis. Along with the Circular Economy Action Plan 2.0, the Farm to Fork Strategy, the Biodiversity Strategy and more, there will be also a specific new Bioeconomy Strategy & Action Plan.

22. Bio-based materials can meet 60% of European material demand and reduce the overall environmental footprint of material use. Special potential environmental benefits are: carbon sequestration, biological processes are more energy efficient and less polluting, and the replacement of non-renewable (fossil or mineral based) materials.

23. The support of the bio-based industry is focused on research and development and investment support (see Figure 3). The most important sustainability indicators are:

- Life cycle indicators.
- Based on EU Product Environmental Footprint methodology.
- Development of LCA database to facilitate access to life-cycle data.
- Complementary indicators on impact on land use and biodiversity.
- Certification schemes for biomass.
- Land use change indicators combined with ecosystem services mapping and biodiversity evaluation.

Figure 3. EU support to the bio-based industry.

⇒ **Direct support to industry focused on R&I via EU Research programmes**

- Horizon 2020 (2014-2020):
  - Bio-based Industry Joint Undertaking – EUR 800 million
  - R&I calls
  - Circular Bioeconomy Fund – EUR 250 million investment fund
  - ERC
- Horizon Europe (2021-2027)
  - Circular Bio-based Europe Partnership – EUR 1 billion
  - R&I calls
  - InvestEU - generic and thematic instruments
  - ERC and EIC

⇒ **Indirect support, e.g. policy development in MS, R&I capacity building**

Source: Maltagliati (2020)

1.3. Guiding countries in the development of sustainable and circular bioeconomy strategies and programmes

24. The importance of sustainability in the development of the bioeconomy is a primary focus. The most important environmental concerns are:

- A sustainable and circular bioeconomy is a systemic approach that has a key role in keeping the economy, including food systems, in a safe operating space, respecting all planetary boundaries.
- The planetary boundaries concept identifies nine global priorities relating to human-induced changes to the environment, five of which are directly related to food systems, such as biodiversity and climate change.

25. In addition to environmental aspects, the social dimension is also of central importance for the United Nations Food and Agriculture Organization (FAO), especially food security and nutrition in the context of human and ecosystem health. A sustainable bioeconomy should promote cooperation, collaboration and sharing between interested and concerned stakeholders in all relevant domains and at all relevant levels. It is crucial to establish bioeconomy strategies and programmes that enable the bioeconomy to be developed in a sustainable and circular way.

26. The FAO has different projects on sustainability indicators (e.g. 'food first' sustainable bioeconomy), by the German government ('Towards guidelines for sustainable bioeconomy development') and by the International Sustainable Bioeconomy Working Group (ISBWG). The FAO has a working paper entitled "Indicators to monitor and evaluate the sustainability of bioeconomy", that elaborates the aspirational principles and criteria of a sustainable bioeconomy (Figure 4). The FAO recommends a step-wise approach to sustainability assessment of bio-based products and the bioeconomy as a whole. As part of this approach, countries or bio-based product producers and manufacturers are provided with a long list of scientifically robust indicators, from which

to choose a limited number of indicators that suits their needs and circumstances. At the product/value chain level, the selected indicators can be adapted for each bio-based product based on the relevant value chain and its hotspots. At the territorial level, the selected indicators can be adapted to the bioeconomy priorities of the countries. This pragmatic approach reflects that 'one size fits all' is impractical, but at the same time would negate the relevance of harmonisation.

Figure 4. Indicators to monitor and evaluate the sustainability of bioeconomy (FAO)

PRINCIPLE 1. SUSTAINABLE BIOECONOMY DEVELOPMENT SHOULD SUPPORT FOOD SECURITY AND NUTRITION AT ALL LEVELS
Criterion 1.1. Food security and nutrition are supported
Criterion 1.2. Sustainable intensification of biomass production is promoted
Criterion 1.3. Adequate land rights and rights to other natural resources are guaranteed
Criterion 1.4. Food safety, disease prevention and human health are ensured
PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED
Criterion 2.1. Biodiversity conservation is ensured
Criterion 2.2. Climate change mitigation and adaptation are pursued
Criterion 2.3. Water quality and quantity are maintained, and, in as much as possible, enhanced
Criterion 2.4. The degradation of land, soil, forests and marine environments is prevented, stopped or reversed
PRINCIPLE 3. SUSTAINABLE BIOECONOMY SHOULD SUPPORT COMPETITIVE AND INCLUSIVE ECONOMIC GROWTH
Criterion 3.1. Economic development is fostered
Criterion 3.2. Inclusive economic growth is strengthened
Criterion 3.3. Resilience of the rural and urban economy is enhanced
PRINCIPLE 4. SUSTAINABLE BIOECONOMY SHOULD MAKE COMMUNITIES HEALTHIER, MORE SUSTAINABLE, AND HARNESS SOCIAL AND ECOSYSTEM RESILIENCE
Criterion 4.1. The sustainability of urban centres is enhanced
Criterion 4.2. Resilience of biomass producers, rural communities and ecosystems is developed and/or strengthened
PRINCIPLE 5. SUSTAINABLE BIOECONOMY SHOULD RELY ON IMPROVED EFFICIENCY IN THE USE OF RESOURCES AND BIOMASS
Criterion 5.1. Resource efficiency, waste prevention and waste re-use along the whole bioeconomy value chain is improved
Criterion 5.2. Food loss and waste is minimized and, when unavoidable, its biomass is reused or recycled
PRINCIPLE 6. RESPONSIBLE AND EFFECTIVE GOVERNANCE MECHANISMS SHOULD UNDERPIN SUSTAINABLE BIOECONOMY
Criterion 6.1. Policies, regulations and institutional set up relevant to bioeconomy sectors are adequately harmonized
Criterion 6.2. Inclusive consultation processes and engagement of all relevant sectors of society are adequate and based on transparent sharing of information
Criterion 6.3. Appropriate risk assessment and management, monitoring and accountability systems are put in place and implemented
PRINCIPLE 7. SUSTAINABLE BIOECONOMY SHOULD MAKE GOOD USE OF EXISTING RELEVANT KNOWLEDGE AND PROVEN SOUND TECHNOLOGIES AND GOOD PRACTICES, AND, WHERE APPROPRIATE, PROMOTE RESEARCH AND INNOVATION
Criterion 7.1. Existing knowledge is adequately valued and proven sound technologies are fostered
Criterion 7.2. Knowledge generation and innovation are promoted
PRINCIPLE 8. SUSTAINABLE BIOECONOMY SHOULD USE AND PROMOTE SUSTAINABLE TRADE AND MARKET PRACTICES
Criterion 8.1. Local economies are not hampered but rather harnessed by the trade of raw and processed biomass, and related technologies
PRINCIPLE 9. SUSTAINABLE BIOECONOMY SHOULD ADDRESS SOCIETAL NEEDS AND ENCOURAGE SUSTAINABLE CONSUMPTION
Criterion 9.1. Consumption patterns of bioeconomy goods match sustainable supply levels of biomass
Criterion 9.2. Demand and supply- side market mechanisms and policy coherence between supply and demand of food and non-food goods are enhanced
PRINCIPLE 10. SUSTAINABLE BIOECONOMY SHOULD PROMOTE COOPERATION, COLLABORATION AND SHARING BETWEEN INTERESTED AND CONCERNED STAKEHOLDERS IN ALL RELEVANT DOMAINS AND AT ALL RELEVANT LEVELS
Criterion 10.1. Cooperation, collaboration and sharing of resources, skills and technologies are enhanced when and where appropriate

Source: Bogdanski (2020)

2. National policy examples

2.1. The USDA BioPreferred Program

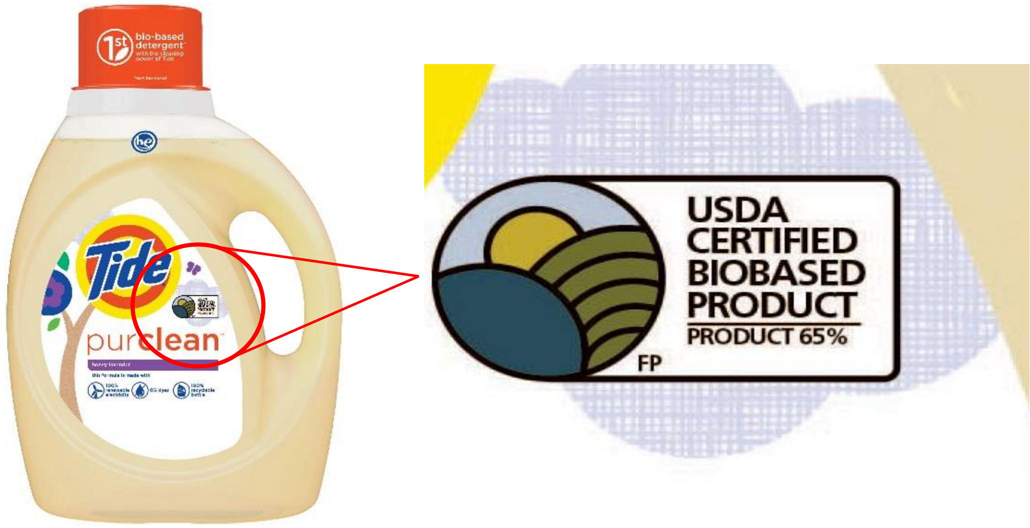
27. The BioPreferred Program is managed by the US Department of Agriculture (USDA). It was established in 2002 as part of the Farm Bill and then expanded in 2008, 2014 and 2018 and it identifies and seeks new markets for bio-based products. The mission is:

- Spur economic development.
- Create new US jobs.
- Provide new markets for farm commodities.
- Reduce reliance on petroleum.
- Increase the use of renewable agricultural resources.

- Reduce adverse environmental and health impacts.

28. Two major programme elements are mandatory federal purchasing and the voluntary labelling programme (Figure 5); the latter helps consumers quickly and easily identify bio-based products. It is a response to the growing desire for products that are good for consumers, good for communities and good for the planet. Research suggests that 66% of consumers are willing to pay more for sustainable brands.

Figure 5. Voluntary bio-based content label of the USDA.



Note: FP means the product qualifies for Federal Procurement.
Source: Jermolowicz (2020)

29. The BioPreferred catalogue contains about 16 000 products in 139 different categories (at the time of writing), including cleaning products, bioplastics, lubricants, and adhesives. Federal agencies and federal contractors are required to buy bio-based products in categories designated by USDA. The catalogue is a unique resource. In no other country is there a comparable database for public purchasing or labelling of bio-based products. In Europe, after more than 10 years of discussion, there is no relevant catalogue.

30. One reason for this success is the simple system that focuses exclusively on the bio-based share. USDA identifies bio-based product categories that make sense for federal purchasing. As part of this process, USDA identifies a minimum bio-based content percentage for a product within a category to qualify for federal purchasing. Some of the categories of products are in the food service arena. Dishwashing products, for example, must be 58% bio-based to qualify for the federal procurement preference. USDA uses ASTM 6866 "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis" to verify qualification.

31. According to the USDA, the use of bio-based products instead of petroleum counterparts would displace about 9.4 million barrels of oil per year. Potential GHG emissions reductions resulting from the bio-based products industry are estimated at 12.7 million metric tons of CO_2 equivalents per year.

2.2. The Importance of the bioeconomy from the energy perspective in Japan

32. The Japanese government has committed to reduce GHG emissions by 80% by 2050. In the energy sector, this is to be achieved by expanding renewable energies,

including bioenergy. Japan has also begun to explore the possibility of decarbonising hydrocarbons, gas, oil and even coal. It may be necessary to develop new technologies:

- Bio-based production.
- Fossil fuels + CCS to Hydrogen/ammonia.
- Carbon recycling.
- Direct air capture (DAC).

33. The circular carbon economy (CCE) is a holistic approach to manage carbon emissions as a closed circular system with '4R' technologies:

1. Reduce: reducing the amount of carbon entering the system.
2. Reuse: reusing carbon without chemical conversion.
3. Recycle: recycling carbon with chemical conversion.
4. Remove: removing carbon from the system.

34. Table 1 shows more details on the strategy and the 4R technologies. In addition to bio-based and recycling, the utilisation of CO_2 (CCU) and the storage of CO_2 (CCS) are important components of the overall strategy.

Table 1. 4R technologies to manage carbon.

Reduce	Reuse	Recycle	Remove
• Reduce the amount of carbon entering the system	• Reuse carbon without chemical conversion	• Recycle carbon with chemical conversion	• Remove carbon from the system
• Energy and materials efficiency • Renewable energy, including hybrid use with fossil fuel • Nuclear energy including use with fossil fuel • Advanced ultra-super-critical technologies for coal power plants • Hydrogen (blue/green) fuel cells for long distance heavy-duty vehicles • Ammonia produced from zero-carbon hydrogen (blue/green) • Direct reduction in steel making by using CO_2-free hydrogen (blue/green)	• Carbon capture and utilisation (CCU) • Use CO_2 at carbon utilisation facilities such as at greenhouses for enhancing crops • Bio-jet fuels with reed beds • Algal synthesis	• CCU • Artificial photosynthesis • Bioenergy recycle in the pulp and paper industry • Bioenergy with CCS • Carbamide (urea production using CO_2 as feedstock) • Coal ash concrete curing with absorbing CO_2 • Electrochemical reduction of CO_2 • Fine chemicals with innovative manufacturing processes and carbon recycling • Fischer-Tropsch with hydrogen syngas • Hydrogenation to formic acid • Oil sludge pyrolysis • Sabatier synthesis (CO_2 methanation; exothermic of CO_2 with blue/green hydrogen • Thermal pyrolysis	• CCS • Direct air capture (DAC) • CO_2 removal • Fossil fuels-based blue hydrogen

Source: Mansouri et al. (2020)

35. To date it is not known to what extent the bioeconomy can replace fossil carbon. However, the complete replacement of fossil carbon seems infeasible. Rather, both forms of carbon could be complementary and essential elements of the global sustainable economy.

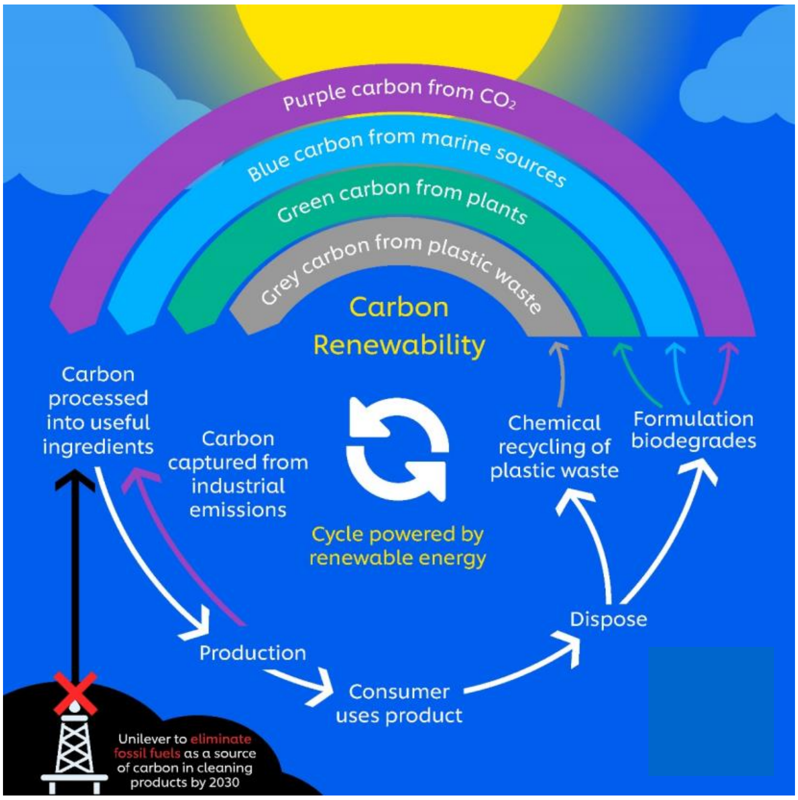
3. Comments from industry

3.1. Unilever, United Kingdom: the Clean Future Strategy

36. Unilever's Clean Future Strategy includes the aspects Zero Waste; Climate Smart; Water Smart; Eco-Design; Non-Virgin Petrochemical, and; Non-Persistent. Regarding the sustainable bioeconomy, Non-Virgin Petrochemical and Non-Persistent are particularly important.

37. Non-Virgin Petrochemical is the strategy to replace fossil carbon with non-fossil carbon in all products of organic chemistry, such as plastics or detergents (carbon renewability), i.e. 'purple' carbon from CO_2, 'blue' carbon from marine biomass, 'green' carbon from agriculture and forestry and 'grey' carbon from plastic waste (Figure 6).

Figure 6. The Unilever carbon rainbow.



Source: Parry (2020)

38. The Carbon Circular Economy is driven by renewable energy. Unilever is consequently a founding member of the Renewable Carbon Initiative (RCI), which has precisely this focus. It is interesting to note that the bioeconomy, as a replacement for the petrochemical industry, does not stand alone here, but is complemented by the feedstocks CO_2 and plastic waste – and all three are on an equal footing and together the aim is to replace fossil carbon. Unilever is also focusing on biotechnological processes and biodegradability where recycling is not possible – as with detergents.

39. The strategy is based on two main pillars: "efficiency" (weight efficiency, concentration, waste and water) and "renewable and sustainable feedstocks". An example

from the company is the new dishwash detergent Quix, a new formulation plant-based, 100% biodegradable, renewable cleaning agent.

3.2. Mitsubishi Chemical, Japan: Activity on bioplastics

40. For Mitsubishi Chemical, the main problems of the current plastics industry are:

- The main resource is fossil and generates GHG emissions, and;
- 90% of used plastics are treated as waste.

41. The future can be different with increased utilisation of renewable resources and the minimisation of waste and emissions. An example is the production of BioPBS in Thailand based on bio-based succinic acid. Based on BioPBS, more environmentally friendly packaging materials, including optimised, biodegradable multilayer barriers are possible. Combinations of paper and PBS are also possible.

42. Another example is the starch/glucose/sorbitol-based Durabio™, which is used in mobile devices and in the automotive sector. Mitsubishi is also working on international standards for marine biodegradable plastics.

43. The “Japanese Resource Circulation Strategy for Plastics” dates to May 2019. The basic principle is “3Rs + Renewable” and the three “Rs” are:

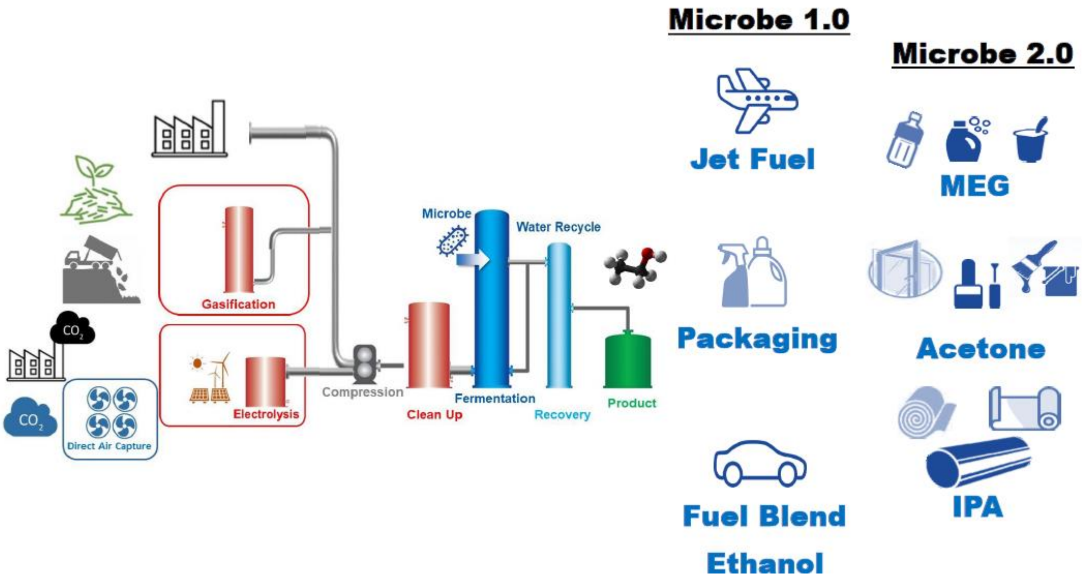
1. Reduce: cumulative suppression of 25% of single-use plastics by 2030.
2. Reuse / Recycle: effective use of 100% of used plastics by reuse and recycling etc. by 2035.
3. Recycling and Bio-based Plastics: double the use of recycled content by 2030, introduce about 2 million tonnes of bio-based plastics by 2030.

44. Recycling and bio-based are seen as equal solutions for the future of plastics.

3.3. LanzaTech, United States: Recycles carbon today for a cleaner tomorrow

45. LanzaTech has focused on producing a wide range of chemicals and fuels from CO_2/CO-rich waste gas streams from power plants and industry (e.g. the steelmaking industry) as well as direct air capture (DAC) using bacterial fermentation (Figure 7). The first commercial plant is already in operation in China, which has already produced more than 60 million litres of ethanol from the exhaust gases of steel plants. This ethanol can be used to make everyday products such as polyethylene and aviation fuel.

Figure 7. Gas fermentation to fuels and chemicals.



Source: Holmgren (2020)

46. The use of renewable carbon presents a variety of challenges for both the private sector and policymakers. For policymakers, technology neutrality is important and it necessary to support all solutions and get recycled carbon, including energy, fuels and chemicals to market. Policies, definitions and funding can either drive or block the build out of disruptive technologies. This is an enduring message from the private sector to policymakers.

47. It is also important not to set expectations too high with new technologies at the outset: perfection is not possible at the start, and iteration is an essential part of the process for disruptive technologies. The direction has to be right and optimisations take time. At the same time, it is clear that there is no way around the use of renewable carbon. Thus the company is a founding member of the Renewable Carbon Initiative (RCI), which has precisely this focus.

4. Summary and outlook

48. The biggest problems in building a strong bioeconomy are direct and indirect land use changes with significant impacts on biodiversity and climate change. The solution could be in developing a comprehensive indicator systems. It has proved very difficult to develop consistent and harmonised systems that are also applicable, especially since there are so-called ‘green-green conflicts’ when certain indicators are in opposition. At the same time, the requirements of the Renewable Energy Directive have led to the development and establishment of various biomass certifications on the market. This begs the question if there is there any further need here.

49. On the other hand, there is the possibility, and this was made clear in several presentations, of expanding the reference system. The bioeconomy has never been an end in itself, never been propagated for its own sake. Rather, the bioeconomy should help reduce GHG emissions in the areas of fuels, chemicals and materials by replacing the fossil economy. The carbon needed for these sectors should then no longer be taken from fossil sources, but from plants from the atmosphere. Over the past decade, it has become clear

that the bio-economy cannot achieve this without seriously compromising food security and biodiversity. For this reason, bioeconomy policy should be developed with caution, should be restrained with strong measures, and be focused primarily on biogenic waste streams.

50. Fortunately, new technologies have been developed in the last 10 years that also represent an alternative to fossil carbon: electric mobility and hydrogen fuel cells for transport; direct CO_2 utilisation (CCU) and chemical recycling of plastic waste represent significant alternative carbon streams that substitute additional fossil carbon. The bioeconomy is not alone. All three renewable carbon sources together – bio, CO_2 and recycling – may be able to replace the entire fossil system.

51. What is the significance of the bioeconomy in a comprehensive renewable carbon economy? A new, comprehensive strategy for sustainable chemicals and materials must include what carbon demand exist in the long term – following the extensive decarbonisation of the energy sector. And how this carbon demand can be met in the most sustainable way possible – and what role the bioeconomy can play in this, in different regions, for different applications and technologies.

Webinar 2: Specific value chains

5. Webinar Purpose

52. Overly concentrating on individual bio-based products can lose sight of the importance of the value chain. If policy is diverted to only part of the value chain, it can collapse due to weaknesses elsewhere in the value chain. This has been overlooked in many studies and policy discussions. Thus the second webinar started to address this omission for policy makers by looking at three different value chains of high importance for the future.

6. Sustainability assessment and indicators

6.1. Sustainable biofuels and bioproducts in a de-fossilised economy

53. To control warming, CO_2 emissions need to decline by about 25% by 2030 and reach net zero around 2070. Bioenergy use needs to undergo a large shift by 2050; from its current predominately residential application to a large-scale adoption by industry and transport. It was argued that due to the limited bioenergy potential from biomass residues, large-scale decarbonisation requires the cultivation of dedicated energy crops.

54. The potential to produce renewable jet fuel from forest residues in Norway was highlighted. Opportunities exist through a thermochemical Fisher-Tropsch process or could be based on lignocellulosic sugar fermentation to ethanol and subsequent conversion to jet fuel. Analysis of the carbon footprint of renewable jet fuel in the immediate, medium and long term demonstrates the significant potential for reducing GHG emissions. Analysis of the impacts of renewable jet fuel production has been studied in relation to the UN SDGs

(Cavalett and Cherubini, 2018). The study showed where trade-offs currently exist, but also that these trade-offs (versus the use of fossil based jet fuel) could be eliminated with technical development.

55. Achieving the UN SDGs is complicated by the potential trade-offs required to achieve different goals e.g. environmental protection versus human well-being. The potential to use ecosystem services as a basis for a balanced approach to achieving the SDGs needs greater scrutiny. The relative importance of different UN SDGs was examined through surveying recognised experts. The study showed large variation in how experts viewed the relative priority of different SDGs based on regional location. Sustainability indicators usage and trade-offs in bio-based value chains

56. The use and benefits of modelling and integrated assessment tools for multifactorial sustainability assessment were discussed. The ecological-environmental IMAGE model has been used to quantify synergies and trade-offs between bioenergy use and the UN sustainable development goals. The modelling used Shared Socio-economic Pathways (SSPs) (e.g. van Vuuren et. al., 2017; Riahi et, al., 2017) as scenarios for economic development with varying emphasis on mitigation and adaptation actions. Each scenario was run once with bioenergy and once without bioenergy to isolate the effect of bioenergy use.

57. Modelling demonstrated that synergies and trade-offs were largely dependent on how bioenergy was implemented and wider socio-economic development. In a scenario based on sustainable global development mostly synergies are seen; however under a scenario of regional economic rivalry, mostly trade-offs are observed. A middle of the road scenario showed predominately positive impacts on SDGs, but they were less pronounced than in the sustainable development scenario. The study provides evidence of the need to consider bioenergy in the context of, and not in isolation from, other economic and social developments.

58. The sustainability of biomass supply chains depends on the design of the supply chain, its management, and the biophysical and socio-economic conditions of the region(s) across which it operates. The sustainability of the supply chain is context-specific, and as context varies over space and time the sustainability of biomass supply chains should be assessed in a spatially explicit and temporal way.

59. An integrated assessment approach has been developed to assess the impacts of an expanding Brazilian ethanol industry. Several scenarios have been modelled and their impacts on GHG emissions, biodiversity, water, employment and GDP considered. The assessment indicated that the expansion of sugar cane ethanol production would result in both positive and negative impacts on GHG emissions, biodiversity and hydrology; however negative impacts prevailed. The largest biodiversity and carbon impacts occurred because of indirect land use changes. Importantly measures could be taken to reduce these impacts.

60. Integrated assessment enables the identification of likely patterns of land use change and the quantification of environmental and socio-economic impacts. It also allows the evaluation of the effect of land use change mitigation measures. Assessments can provide important insights for governments on how to integrate biomass production into agriculture and land use planning, and ensure sustainable biomass production.

6.2. Sustainable supply chain: low-carbon-intensity “drop-in” fuels in Canada

61. Western Canada is well placed to exploit new bioeconomy opportunities. It has an established and innovative forestry industry, a large forest resource, a strong pellet sector

and over 160 million hectares of certified sustainable forest. However, large areas of Canada's forest have been killed by Pine Beetle infestations: in British Columbia, 15-17 million hectares have been affected, equivalent to the combined area of Denmark and Portugal.

62. Wood pellet production primarily for bioenergy production has grown considerably in recent years in Canada. The last 20 years has seen a significant expansion in North American pellet production and export, up from a thousand tonnes in 2000 to 11.5 million tonnes currently. Most North American pellets are exported and used to generate power or heat.

63. The production of renewable aviation fuel is considered an important target for the Canadian forest sector. The aviation industry has a growing interest in biofuels as a mechanism to address fuel security, price volatility and the industry's climate change impact. Current renewable aviation fuels are derived from fatty acids, but they suffer from sustainability concerns and limited feedstock availability. The potential for development lies in the use of 'biocrudes' produced using pyrolysis or hydrothermal liquefaction.

64. The IEA Task39 ATM project has assessed the likely technology pathways used to produce biojet from forest residues. The project looked at: the upgrading of biocrude from three different technology providers to biojet; feedstock supply chain logistics and feasibility; assessment of biocrude production process performance, techno-economics and environmental life cycle; demonstration plant concept and design, and; the policy environment. The project found that biojet fuel could be successfully produced via upgrading of biocrudes meeting most of the general ASTM specifications. GHG emissions reductions of up to 71% were possible and that techno-economics were reasonable compared with other biojet fuels. British Columbia is pursuing the opportunity to produce renewable aviation fuels through its decarbonisation strategy for long distance transport (BC-SMART).

7. Sustainability of aviation fuel supply chains

7.1. Creating a sustainable aviation fuel research and development ecosystem to accelerate commercialisation: supply/value chains in the United States

65. Developing and introducing sustainable aviation fuels (SAFs) is a complex task. Three requirements are:

1. The need for interagency cooperation on strategy.
2. The requirement to build a R&D ecosystem.
3. The need for public private partnerships.

66. Interagency collaboration was established through the 'The Farm to Fly 2.0 (F2F2) Agreement –2013-2018' which resolved to "*enable commercially viable, sustainable bio-Jet fuel supply chains in the US*". Collaboration was strengthened with the 'Federal Alternative Jet Fuels R&D Strategy -2016'[2]. The aim of the strategy was to enable the development, production, and use of environmentally sustainable, cost-competitive and socially responsible alternative jet fuel with stable supply to significantly meet the needs of US jet aviation.

67. The development of value chains and the use of various biomass feedstocks is being investigated through the USDA's Agriculture and Food Research Initiative Coordinated

Agricultural Projects (CAPs). The projects link regional biomass supply chains to bioeconomic value propositions including biofuels and biobased chemicals and products.

68. Northwest Advanced Renewables Alliance (NARA) represents a large number of industrial and academic stakeholders covering the full SAF value chain. NARA's goal was the sustainable conversion of woody biomass to lignin and SAF, demonstrating the conversion of 1 ton of biomass to 600 US pounds of lignin and 46 US gallons of SAF. The NARA programmes outcomes included the world's first cellulosic based SAF flight, a collaborative infrastructure study between Alaska Airlines, Boeing and the Port of Seattle and an ongoing SAF assessment between Delta Air Lines and Pacific Northwest.

69. Ongoing collaborative SAF strategy projects include the ASCENT Alternative Jet Fuel Supply Chain Project. This project is examining barriers to alternative jet fuel production across the range of pathways being considered for ASTM approval.

70. SAF development is being coordinated by the Biomass Research and Development Board Advanced Aviation Fuel Interagency Working Group. The Group provides a platform for strategy, collaboration, communication and industry engagement. It also coordinates DOE SAF research funding programs, FAA's ASCENT project and USDA's SAF CAPs.

7.2. The US Federal Aviation Administration's role in the development of SAF

71. The international aviation industry has committed to address international aviation CO_2 emissions through a three-goal approach. It has an immediate goal of a 1.5% annual average fuel efficiency improvement from 2009 to 2020, a goal to stabilise net aviation CO_2 emissions at 2020 levels with carbon neutral growth, and a long-term goal to reduce aviation's net CO_2 emissions to 50% of 2005 levels by 2050. Delivering on these commitments is focussed on four pillars - technology, operations, infrastructure, and market-based measures. The long-term goal of reducing emissions can only be achieved through the introduction of radical new technologies and SAFs.

72. The commercial use of SAFs in the US has shown sustained growth over the last four years (up from around 1 million gallons in 2016 to over 4 million gallons in 2020). Worldwide there are significant plans for the expansion of SAF production.

73. The FAA SAF Program focuses on testing to accelerate SAF availability, analysis of supply potential and impacts, and the coordination of public/private and international developments through CAAFI and ICAO respectively. Founded in 2006, the Commercial Aviation Alternative Fuels Initiative (CAAFI) is a public/private partnership to facilitate and promote the introduction of SAF.

74. The UN International Civil Aviation Organization (ICAO) sets standards and recommended practices for civil aircraft to allow a safe, efficient, secure, economic and environmentally friendly global aviation system. ICAO has a standing Committee on Aviation Environmental Protection (CAEP) which conducts environmental technical work. This work includes the "Carbon Offsetting & Reduction Scheme for International Aviation" (CORSIA). Which is designed to help international aviation meet its goal of carbon neutral growth (relative to 2020 baseline). CORSIA Eligible Fuels (CEF) can be used by an airline to reduce their offsetting requirements. CAEP technical groups include the CAEP Fuels Task Group (FTG) responsible for LCA and GHG emission assessments and a Sustainability Certification Schemes Evaluation Group (SCSEG). ICAO are considering expanding the sustainability criteria under CORSIA to include additional environmental criteria and introduce social and economic criteria, such as human and labour rights, land use rights and food security.

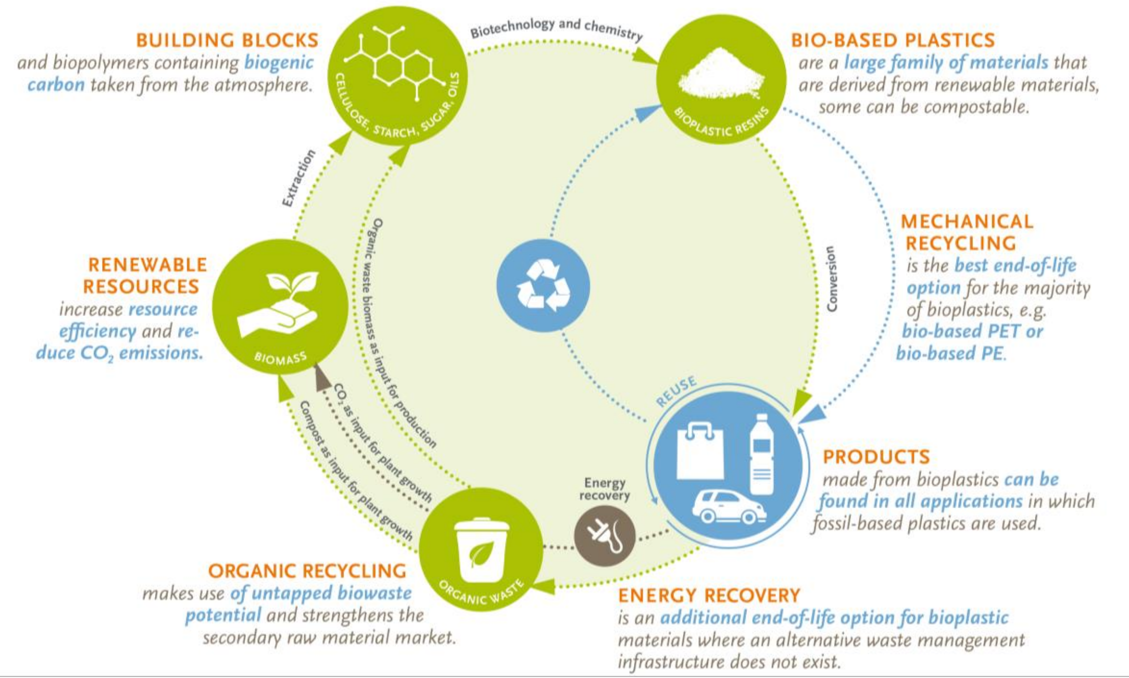
8. Sustainability of (bio)plastics supply chains

75. Bioplastics represents a group of plastic materials either produced from biomass (bio-based) or being biodegradable. The sustainable sourcing of feedstock is a prerequisite for more sustainable products, including bioplastics. Focus should be given to the efficient use of resources including the use of material cascades, the implementation of good agricultural practices for feedstock cultivation, and the responsible choice of feedstock considering local availability. Sustainable sourcing and production should be demonstrated through third-party certification.

76. Sustainability assessment schemes should take economic, social, and environmental aspects into account and use indicators backed up by commonly agreed methodologies. Suitable environmental indicators for bio-based plastics are described in a range of published standards, including for bio-based content (EN 16640, EN 16785-1, ASTM 6866) and GHG emissions (ISO 14067, PAS 2050:2011), and standardised sustainability criteria of bio-based products (EN 16751). Many sustainability certification schemes are available, e.g. FSC and PEFC for wood/paper, ISCC PLUS for industrial and feed use and the Roundtable Sustainable Biomaterials (RSB).

77. LCA methodologies are increasingly used to compare materials from different feedstock, e.g. bio-based and fossil-based plastics. To avoid unfair or inappropriate comparisons, consideration should be given to the transparency of data, the potential for carbon sequestration in the use of the product, how direct and indirect effects are modelled and end-of-life scenarios (Figure 8).

Figure 8. Bioplastics life cycle model – closing the loop.



Source: Ißbrücker (2020)

9. Sustainability of fish feed supply chains: The growing demand for fish feed and how the market is responding to address sustainability concerns

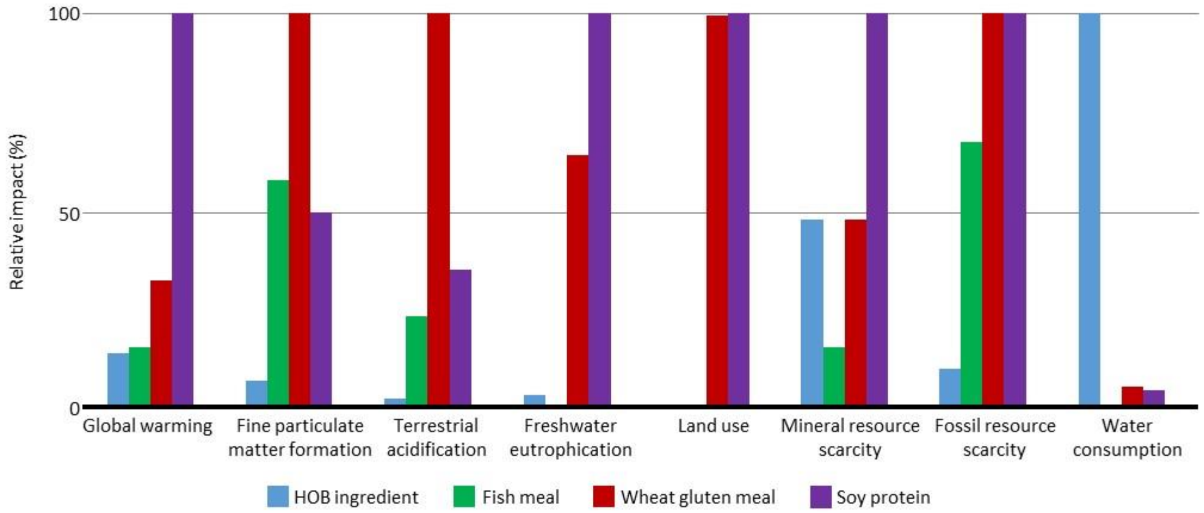
78. Increasing salmon production means increasing feed demand and an increasing cost of fish meal and oil. The use of fish meal is placing sustainability pressure on marine resources and therefore alternative feed sources are required. The fish feed industry has seen a move from the use of fish oil and meal to the use of plant dry matter and plant oils. The feed industry is now focusing on the use of marine cultivated feed (e.g. seaweed), single cell protein and mesopelagic raw materials.

79. Traditional sustainability concerns centred on the depletion of fish stocks have been joined by concerns over large land use requirements for soy protein production. In addition to resource consumption (fish and land) other important sustainability indicators include GHG emissions, energy consumption and water use. The production pathways for the different feed products differ considerably and therefore the environmental impacts of the different feed are significantly different.

80. Important considerations when reviewing fish feed LCA results include understanding whether logistics are considered (local versus international use), whether the impact of refrigeration and packaging is included, and whether land use change impacts are considered (Figure 9). Other important criteria which need to be considered when comparing feed types include the effect of consumption changes on other food streams, differences in protein quality, technology maturity, and uncertainty in results due to gaps in knowledge e.g. production processes for single cell proteins.

Figure 9. Life cycle impact assessment for key feed ingredients (1 tonne of protein).

Relative impact category results for the four main feed ingredients



Source: Halseth (2020)

10. Comments from industry

10.1. Neste, Finland: Aviation fuel sustainability assessment and SDG trade-offs in alternative supply chains

81. Neste MY Sustainable Aviation Fuel (SAF) is made 100% from waste and residue oils and fats. Neste fuel has quality and performance comparable to fossil jet. The fuel burns cleanly and produces less particle emissions than traditional jet fuels. It provides a drop-in fuel solution as its use does not require investments in aircraft or fuel supply infrastructure. These attributes have enabled its commercial use. Based on this growing market Neste's SAF capacity is anticipated to reach 1.5 million tons by 2023. Neste have plans to become carbon neutral by 2035 based on the use of renewable electricity and hydrogen.

10.2. Novamont, Italy: Bioplastic in the circular bioeconomy.

82. There is a clear need to build a sustainable bioeconomy based on the requirement for healthy productive soil supporting food production and industrial uses. A proposal for an EU Mission on Soil Health and Food has been developed. Soil performs multiple basic functions required for life on earth including the supply of healthy food and clean water, the maintenance of biodiversity and nutrient cycles, and a means to adapt and mitigate climate change.

83. Despite these recognised services, 65-75% of agricultural soils in EU have nutrient inputs at levels risking eutrophication of soils and water, thus affecting biodiversity. Cropland soils are losing carbon at a rate of 0.5% per year. About 50% of peatlands have been drained and are losing carbon, increasing climate change. In Europe, the land area with a high or very high sensitivity to desertification has increased by 177 000 km^2 in less than 10 years and the costs associated with soil degradation exceed EUR 50 billion per year. The EU Mission on Soil Health and Food would have the objective to ensure 75% of soils are healthy by 2030.

84. Bio-based plastics and food share the same type of feedstock and bio-based plastics should be used as key instruments in changing unsustainable production practices, addressing the over-exploitation of resources, issues of pollution, and the need to close the carbon cycle. To achieve this, four key priorities are proposed:

1. Stop thinking about unlimited economic growth.
2. Be regenerative and transformative, using bioplastics to trigger a cultural change making more with less.
3. Choose priorities based on a sound systemic impact assessment.
4. The use of biodegradable bio-based products in applications where there is a high risk of accumulation of non-degradable products in the environment.

85. Biodegradation in soil is needed in products used in agriculture creating accumulation problems (i.e. herbicides, plastic mulch, slow release systems, coatings of seeds/ fertilizers etc.). Biodegradation in water is needed for products with problems of accumulation in water and in sewage sludges, e.g. non-biodegradable additives in cosmetics and detergents. Biodegradation in waste treatment facilities (e.g. compost) is needed in applications highly likely to be polluted by food residues or which would pollute organic wastes (e.g. fruit and vegetable bags, waste bags, coffee capsules, foodservice products).

10.3. Nutreco, The Netherlands/Norway: Protein sustainability assessment and SDG trade-offs in alternative supply chains.

86. There is an opportunity to address issues in fish feed sustainability through the production of bacterial protein using CO_2 as a carbon source. Bacterial-based protein production offers a route to reduce the land pressure from soy protein production. The land requirement for bacterial protein produced from CO_2 is negligible and the production of 100 000 tons of bacteria protein would remove the need for 650 km^2 of arable land. For comparison, based on current fish feed protein supply (25% soy protein concentrate), the supply of soy protein would require 7 200 km^2 of arable farmland.

87. Nutreco employ over 12 000 people worldwide and operate over 100 production plants in 37 countries. Kiverdi is developing a process to produce protein from CO_2 using hydrogen-oxidising bacteria.

88. Norwegian salmon producers use 1.9 million tons of fish feed per year, 600 000 tons of which is protein. More than 90% of all raw materials are imported. The Norwegian salmon industry is expanding and by 2050 could represent 5 million tons of salmon production. This scale of production would require 6 million tons of fish feed, including a 2 million ton demand for protein.

89. A comparative Life Cycle Assessment of salmon feed protein shows the varying environmental impacts of different feed production pathways. Feed produced with hydrogen-oxidising bacteria has relatively low impacts in most impact categories assessed although water consumption was high compared to conventional salmon feeds.

90. When considering sustainable development goals, differing goals may be in conflict and progress in one goal may come at the expense of another e.g. climate change mitigation versus zero hunger. Thus sustainability needs to be view as a journey of sustainability rather than sustainable versus non-sustainable. There is a need to measure more than just carbon footprint; fish meal has a much lower carbon footprint than soy but is not an option on which to base sustainable fisheries.

11. Messages and discussion

11.1. Sustainability perspectives

91. The drive for a more sustainable way of living, embracing the need for economic, social, and environmental sustainability, is best reflected in the United Nations Sustainable Development Goals (SDGs) (Figure 10). SDGs were used by several workshop participants to demonstrate the varying impacts of bioeconomic activity.

Figure 10. The United Nations Sustainable Development Goals.

Source: https://www.un.org/sustainabledevelopment/blog/2015/12/sustainable-development-goals-kick-off-with-start-of-new-year/

92. The UNs Global Agenda for Sustainable Development by 2030 has 17 SDGs and 169 associated targets. This large number of targets demonstrates the complexity in the analysing and determining what could or should be considered sustainable development.

93. All economic activity has impacts. Understanding how positive impacts can be maximised and how negative ones can be minimised and mitigated is at the heart of sustainable economic development. The influence and impact that a transition to an economy increasingly based on the use of renewable resources has on these goals requires careful consideration and detailed analysis. How each goal is impacted by a specific bio-based supply chain will be determined by the choice of feedstock, the geography of cultivation and processing, the manufacturing technologies, the level of consumption and how products are ultimately disposed of.

94. However, the breadth and depth of the analysis that any supply chain can realistically undertake is limited. Therefore, an agreed understanding on what are the key/significant impacts of bio-based supply chains is required, which can then be translated into clear and consistent guidance on pragmatic and practical sustainability assessment.

95. While all the SDGs are relevant to the bioeconomy, in the development of sustainability guidance for the Bio-based Industries Consortium (BIC), the Institute for European Environmental Policy (IEEP) identified seven SDGs of particular importance to bio-based industries. The seven key SDGs were considered to be zero hunger (SDG2), clean water and sanitation (SDG6), industry, innovation and infrastructure (SDG9), responsible consumption and production (SDG12), climate action (SDG13), life below water (SDG14), life on land (SDG15) (Allen et al., 2020).

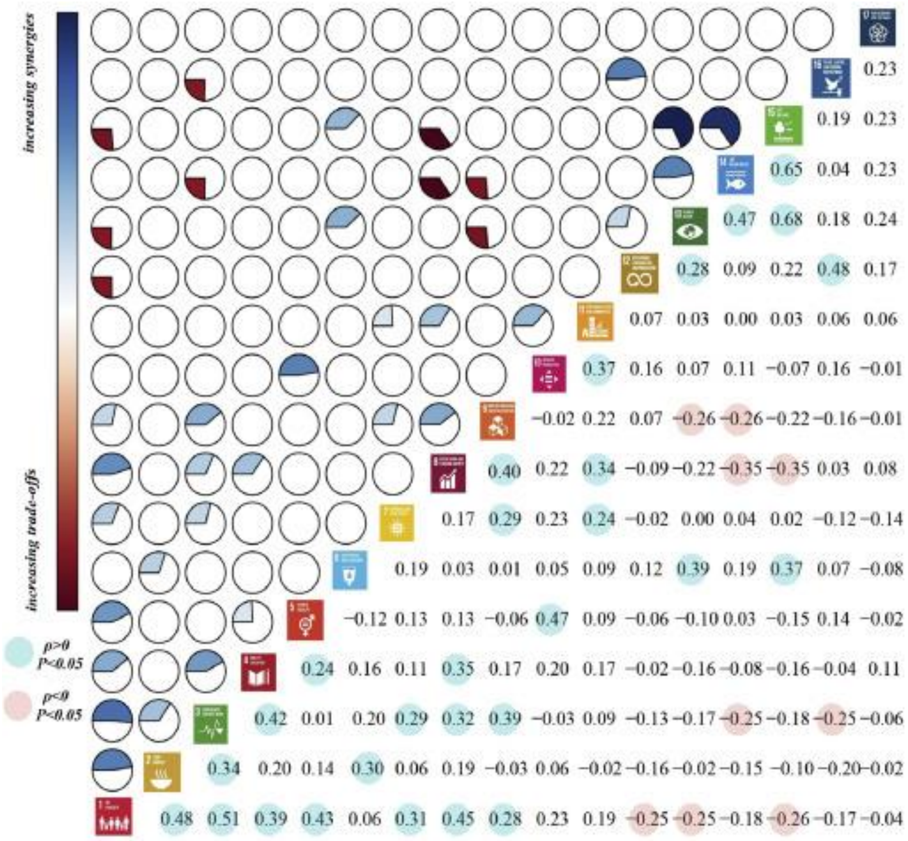
96. Other researchers choose an expanded list of sustainable development goals as their scope for assessment. Additional goals considered include, no poverty (SDG1), good health and well-being (SDG3), affordable and clean energy (SDG7), decent work and economic growth (SDG8), sustainable cities and communities (SDG11) (Cavalett and Cherubini, 2018).

97. The relative importance of individual SDGs is based on value judgements made at a personal and societal level. These judgements are informed by the economic, geographic,

and social context in which the judgement is made. As noted by Unilever (United Kingdom), to identify the most sustainable feedstock for manufacturing, regional specificities need to be taken into consideration. Certain regions may have highly sustainably managed forest stocks making wood an attractive feedstock whereas other regions are more suited to agricultural production and therefore crops or crop residues are an attractive feedstock. Cultivation practices, particularly around water demand and artificial irrigation, are important regional factors for determining feedstock sustainability.

98. The results of a survey of bioeconomy experts showing how the perceived importance of different sustainability measures differs based on economic needs (Figure 11). However, the study did highlight that the SDGs associated with basic human needs such as poverty, hunger and clean water are universally considered priorities (Yang et al., 2020).

Figure 11. Trade-offs and synergies among SDGs.



Source: Yang et al. (2020)

99. A clear theme running through the workshop was the recognition that the bioeconomy is rooted in the use of land and that sustainable development requires the creation of new supply chains which grow without negatively affecting existing ecosystems and ideally produce products which support the restoration of ecosystems.

100. Novamont (Italy) placed an emphasis on sustainability in the context of preserving and restoring soil health and fertility. The use of biodegradable materials in applications with high probabilities of material leakage into the environment was discussed, this need is particularly clear in the case of plastic pollution.

101. There was a recognition of the linkages between food, feed and biomass for products and a need for sustainability assessment to consider agricultural systems. For instance, there is a need for all land uses, including food production, to be measured and assessed equally.

102. The FAO presented several projects on sustainability indicators and presented a holistic approach: A sustainable and circular bioeconomy should develop in "a safe operating space, respecting all planetary boundaries" i.e. the ambitions of the bioeconomy must not exceed planetary constraints on raw materials (biomass, phosphorus, nitrogen, etc) or to an extent that activities negatively impact planetary systems such as climate, oceans or atmosphere. In addition to the environmental aspects, the social dimension needs to be considered: food security and nutrition in the context of human health and access to land and other natural resources to combat poverty.

103. SINTEF (Norway) and Nutreco (Netherlands/Norway) discussed the sustainability implications of different protein sources for aquaculture and how each source and supply chain could have very different impact and relevance for individual sustainability criteria. The alternatives may for example include agricultural feedstocks such as soy, new marine biomass from low trophical levels and microbial fermentation of CO_2 and hydrogen (CCU) to single-cell proteins for feed production.

11.2. Sustainability analysis

104. The workshop participants highlighted the wide range of approaches, tools, and techniques to consider and measure the environmental and social impacts of bio-based supply chains. Life cycle analysis (LCA) is a widely used tool for measuring the environmental impacts of manufacturing and supply chains. The tool is well established with defined international standards for its implementation. Although LCA approaches to social impacts are less well adopted, guidance for their use has been developed.

105. FFA (United States) pointed to the role and activities of the International Civil Aviation Organization as a coordinating body to manage efforts towards sustainable aviation. CORSIA (Carbon Offsetting & Reduction Scheme for International Aviation) has developed and established guidance processes, and certifications for aviation fuels, providing credibility and validation for sustainable fuel providers. Neste (Finland) showed how, alongside policy support, these sustainability tools and processes have created a market for Neste's sustainable aviation fuel.

106. LCA provides a measure of a given impact e.g., GHG emissions, and provides an excellent method to monitor and improve the sustainability of a given supply chain. If handled carefully and using equivalent data and approaches, LCA can also be used to compare the relative impacts of different supply chains, i.e. with different feedstocks or manufacturing technologies, leading to the same or equivalent product (due to ISO every comparison should only be published after a critical review).

107. European Bioplastics (based in Germany) discussed the importance of sustainable sourcing of feedstock as a prerequisite for the sustainable production of bio-based plastics. Recognised standards are in place defining sustainability criteria for bio-based products and how to calculate bio-based content and GHG emissions. It was noted that many sustainability certification schemes are available, e.g. Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) for wood/paper, International Sustainability and Carbon Certification (ISCC) and ISCC PLUS and the Roundtable Sustainable Biomaterials (RSB) for all kind of biomass (and CO_2 or recycling) in a wide range of applications for food, feed, chemicals and materials as well as bioenergy and biofuels.

108. Complex models are available and they allow the assessment of how changes in economic activity, such as a transition to a bio-based economy can impact on environmental and social criteria. Martin Junginger of Utrecht University explained how the use of models allows the examination of scenarios to investigate how transition pathways for new supply chains affect SDGs in positive or negative ways. The use of complex models can be used to identify where synergies and conflicts lie between SDGs.

11.3. Synergies and conflicts and adoption issues

109. The path taken in recent decades to overcome these green dilemmas has been to define sustainability indicators which can be measured using LCA and compliance with which would guarantee a certain sustainability of the biomass and thereby reduces sustainability trade-offs.

110. However, this strategy has brought with it several problems: on the one hand, it is difficult to agree globally on "international sustainability indicators for bio-based products". The OECD has worked in this field, which has been ongoing for over ten years. A set of indicators was published in 2013, but has not yet been comprehensively implemented.

111. Another problem is the enforceability of sustainability requirements: so far, this has only been achieved for the use of biofuels and partly for bioenergy in Europe, where strong financial support via quotas is linked to compliance with sustainability standards (Renewable Energy Directive).

112. In this context, several commercial sustainability systems for biofuels have been able to establish themselves, which are accepted by the European Commission, and some of which can also be used for other applications such as bio-based products. In this case, however, it is purely voluntary, because there are no subsidies for market access for bio-based products worldwide.

113. The European Commission announced the upcoming Green Finance Taxonomy, which supports investments in sustainable economic activities, including sustainable bio-based products, if they perform better in the life cycle assessment than their fossil counterparts. This is the first time that there are financial incentives (here in the form of investment aid) for bio-based products if certain sustainability criteria are met. It is important that the LCA criteria are carefully defined, which is much more difficult for the material sector than for e.g. biofuels because the comparability of the products is less clear.

114. Another problem is the barriers and hurdles created by overly comprehensive sustainability systems, for example the exclusion of food crops, and prioritising wood and biogenic waste streams, rather than dedicated crops. Similarly, regulations demanding very time-consuming and expensive proofs of the different sustainability requirements could make the use of many biomass streams very difficult or even impossible and thus deprive the bioeconomy of its potential to replace the fossil raw material base.

115. And finally, the question arises why bio-based products, of all things, have to fulfil all these criteria, but not fossil products. And for which bio-based products, which already account for 10 to 30% of total production today (large differences between the various countries), should these rules apply?

116. The US Department of Agriculture is taking a completely different approach with its globally unique success story of the BioPreferred Program. A single sustainability criterion, a minimum bio-based content in the product that varies according to the application, has had a broad effect on the market launch of 16 000 bio-based products from

139 categories. Comparable projects in Europe failed due to the definition of a multitude of sustainability criteria, the fulfilment of which was more costly than the expected benefit.

117. LanzaTech added another important point about setting the bar too high and looking for permission with new technologies. The direction has to be right and optimisation takes time, but there is no way around the use of renewable carbon. Sustainability is a journey not a destination – seeking perfection can easily get in the way of progress.

12. The case for carbon management

118. Much of the work of the Working Party on Biotechnology and then BNCT has been centred on the sustainability of the bioeconomy. However, the work is being broadened to carbon management to reflect the fact that carbon neutrality will require many different technologies, some generic and applicable over very large territories (e.g. wind and solar renewable energy) while others may be more territorially specific. Thus any technology should be considered for the production of sustainable products – bio-, nano-, chemical and others. In particular, BNCT has a particular focus on convergence and it is highly likely that a specific problem will be addressed via a convergence of different technologies, and perhaps all held together and coordinated via digital technologies.

119. Various speakers broadened the view by considering the bioeconomy as only one of several components comprising the solution to the climate problem. The Institute of Energy Economics (Japan) gave an insight into the strategy in Japan: fossil raw materials should become largely neutral in their climate impact through carbon capture and use (CCU) or storage (CCS), the production of bio-based products should be expanded, as should recycling strategies. In addition, CO_2 could be extracted from the atmosphere (direct air capture, DAC) to be used in the chemical and plastics industries or to be stored.

120. The overarching question here is how the industry can be supplied with carbon in the future. It was argued that carbon management may capture the different facets of the answer: reduce the demand for carbon, reuse and recycle the carbon in the bio- and technosphere and remove carbon from the atmosphere.

121. This was illustrated by Mitsubishi Chemical. The main problems of today's plastics industry are 1) the main feedstock is fossil, generating GHG and 2) 90% of used plastics are treated as waste, that is incinerated or ending up in landfill. The future should look different with an increased use of renewable feedstock alongside high recycling rates. Recycling and bio-based are seen as equal solutions for the future of plastics.

122. As a further example of carbon management Unilever discussed how big brand manufacturers are striving to replace their current fossil feedstock consumption. Unilever has set ambitions targets for how quickly fossil carbon should disappear from their products, using a combination of renewable and recycled carbon. In their carbon rainbow they include plant materials (green), marine resources (blue), recycled plastics (grey) and industrial flue cases (purple).

123. LanzaTech showed how a wide range of chemicals and fuels can be produced by bacterial fermentation (biotechnology) utilising CO_2/CO-rich waste gas streams from power plants and industry (e.g. steel industry) as well as direct air capture. The examples show that solutions previously only possible via bioeconomy can also be realised on the basis of CO_2 utilisation (and are already being operated commercially in some cases). It therefore makes sense to strategically consider both biomass and CO_2, (including alternative conversion technologies), to develop an overarching renewable carbon strategy.

13. Summary and outlook

124. The bioeconomy has never been an end in itself and has never been propagated for its own sake. Rather, the bioeconomy should help reduce GHG emissions in the areas of fuels, chemicals and materials by replacing the fossil economy. The carbon needed for these sectors would no longer be taken from fossil sources but extracted by plants from the atmosphere. However, capturing atmospheric carbon through plant photosynthesis is very resource intensive, demanding large land areas, water and fertilizers. Therefore, replacing the volume of fossil carbon consumed by the whole of global economy across energy, chemicals and materials applications with biomass has never been considered a realistic proposition.

125. Over the past decade, debate has raged on how much of the fossil economy could be replaced by biomass without seriously compromising food security and biodiversity. For this reason, European bioeconomy policy acts very cautiously, is restrained with strong measures, and focuses primarily on biogenic waste streams.

126. It has always been recognised, that with regards to energy provision, bioenergy would be only one component of the energy mix alongside wind, wave, solar and other renewable energies. As the cost of non-carbon sources of energy decreases and their deployment expands, the need for carbon fuel is reduced. However, some sectors will remain dependent on carbon for the foreseeable future (e.g., heavy goods vehicles and aviation) and to produce many chemicals and materials, carbon is a fundamental requirement.

127. Carbon management strategies which consider all available non-geological sources of carbon provide a holistic mechanism to plan for the efficient supply and use of carbon, putting the carbon in its various forms to best use. Carbon management strategies would bring together new tools to boost bioproduction (e.g. biotechnology), measures for resource efficiency (e.g. precision farming and cascading use of materials) and the circular economy.

128. In the near to medium term the most practical form of virgin non-fossil carbon will continue to be biomass. The volume of biomass which can be sustainably sourced remains an area of debate and efforts should be made to minimise the need for biomass, which in turn reduces the need for land and subsequently many SDG trade-off such zero hunger and life on land. However, a reduced demand for biomass does not negate the need to ensure that biomass for traditional or new applications alike is sourced sustainably.

129. Arguably the biggest problem in building a strong bioeconomy is the related direct and indirect land use changes which can have significant negative impacts on biodiversity, climate change and food security. Despite attempts to develop comprehensive sustainability indicator systems, it has proven very difficult to develop and apply consistent and harmonised systems. This is especially so since there are green dilemmas when certain indicators are in opposition.

130. The requirements of the Renewable Energy Directive (RED) in Europe have led to the development and establishment of various organisations offering biomass (sustainability) certification. These certification schemes are equally applicable to all carbon dependent products and bodies such as the RSB and ISCC offer bio-based product specific schemes. While these well established and widely accepted schemes may be refined, there is little need to reinvent the wheel. One possibility for governments, then, is to adopt such schemes as government standards.

131. The impacts of sourcing and using biomass can be assessed through LCA. LCA provides a standardised and accepted method of assessing the environmental and to some

extent social impacts of economic activity. LCA allows the effective comparison of different processes on the basis of impact criteria e.g. comparison of carbon footprints or eutrophication impact. To provide a comprehensive assessment of a product's sustainability, LCAs practitioners must consider multiple impact criteria. This approach raises issues when, in comparison to the counterfactual process, the LCA shows both positive and negative impacts across the chosen criteria. LCA is unable, however, to provide a guide as to the relative importance of different impacts.

132. Destruction of ecosystems will often represent irreversible loss of biodiversity and natural value. From an anthropocentric perspective, ecosystems provide many services. These include for instance the harvesting of wood or foodstuff, crop pollination, fresh water, and genetic resources. Additionally, ecosystems provide regulating (climate, flood, disease etc) and cultural (recreational and therapeutic) services. The term Natural Capital describes the value of the ecosystem services provided by an area of land.

133. Natural capital may be used to reflect regional and temporal differences in environments and the importance ecosystem services e.g., the impact of industrial water demand in areas of differing water availability. The concept of natural capital offers a means to ensure long term sustainable development by focussing on projects which increase natural capital i.e., restorative projects.

134. In the context of carbon management more work is required to understand the constraints on land use and identify methods of assessment which guide the sustainable use of land. Ecosystem management and the measurement of natural capital may provide a mechanism to compare the relative significance of different impacts assessed during LCA.

135. So, the question of how to deal with sustainable trade-offs may have found a surprising answer: Expand the reference system to all alternative carbon sources as bioeconomy is no longer alone to replace the fossil feedstock. From this perspective, the bioeconomy is a significant but fully integrated part of a comprehensive renewable carbon economy.

136. Also, the question of the relevance of a carbon management perspective has a clear answer: Carbon management is the new overarching challenge and could serve as an excellent framework for constructive discussions between all stakeholders in carbon-dependent value chains.

137. What is the long-term carbon demand of chemicals and materials after the energy sector has been largely decarbonised? And how can this demand be met as sustainably as possible, including all alternative carbon sources? What is needed here is an overarching carbon management strategy that takes specific regional and application-related features into account. This sets the same sustainability requirements for all renewable carbon streams. Such a carbon management strategy does not yet exist, but it is indispensable to transition from bioenergy to renewable chemicals and materials, to renewable products. In this way is there a realistic option to completely substitute fossil carbon and thus tackle the climate problem at its root.

14. Critical policy lessons: from the bioeconomy towards an integrated carbon management strategy

138. The lessons learned from the webinars and subsequent desk research indicate that the sustainability measurement field has moved on in the last decade in both the academic sector and as a private sector practice. The work of the Working Party on Biotechnology

and subsequently BNCT is evolving. The major shift is from a total focus on the bioeconomy and biomass as a feedstock to overall carbon management. Some old policy issues remain and new ones arise with the arrival of this shift. The critical policy lessons are given in Box 2.

Box 2. Critical policy lessons arising from the workshop

1. Carbon management includes strategies and policies to ensure that our limited carbon resources are used for the optimal application.
2. In principle, all carbon feedstocks, whether fossil or renewable, should be judged by the same sustainability criteria.
3. The relative weight given to these criteria will determine the feedstock's attractiveness of use and for what purpose.
4. There is not enough biomass available to substitute the entire fossil carbon system, without damaging consequences for biodiversity and food security.
5. Biomass is not alone however, and can be complemented by recycling of carbon waste and industrial fixation of atmospheric CO_2.
6. Moreover, future carbon demand will be significantly reduced by decarbonisation of the energy sector.
7. Both the decarbonisation of the energy sector and energy requirements for carbon recycling calls for integration of carbon management and renewable energy policies.
8. New carbon supply chains depend on novel technologies; hence implementation of carbon management is strongly connected to innovation policies.

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Annex: Agendas for the two webinars

Agenda, Webinar 1: Thursday 15 October 2020

Registration in Zoom

14h30-15h00 (Paris time)

Webinar 1: General policy aspects

15h00 – 15h05

David Winickoff, BNCT Working Party, OECD: ***Welcome and introduction by OECD secretariat***

15h05– 15h15

Michael Carus, CEO, Nova Institute, Germany: ***Introduction by the moderator***

Transnational policy work

15h15 – 15h30

Jim Philp, Policy Analyst, BNCT Working Party, OECD:

OECD's work in sustainability assessment policies and reporting on the 2013 recommendations survey.

15h30 – 15h45

Pavel Misiga, Head of Eco-innovation Unit, Directorate General for Research and Innovation of the European Commission.

The role of bio-based industry in the EU Green Deal

15h45 – 16h00

Anne Bogdanski, Natural Resources Officer and Project Coordinator Bioeconomy, UNFAO, Office for Climate, Biodiversity and Environment (OCB)

Guiding countries in the development of sustainable and circular bioeconomy strategies and programmes.

National policy examples

16h00 – 16h15

Andrew Jermolowicz, Assistant Deputy Administrator, US Department of Agriculture (USDA), United States

The USDA BioPreferred Program

16h15 – 16h30

Masakazu Toyoda, CEO, The Institute of Energy Economics, Japan

Bioeconomy and a balanced energy mix in Japan.

Break: 16h30 – 16h45

Comments from industry

16h45 – 17h00

Neil Parry, R&D Programme Director Biotechnology and Biosourcing, Unilever, United Kingdom

17h00-17h15

Yoshihiro Fujimori, Division General Manager, Sustainable Resource Division, Advanced Polymers Business Domain, Mitsubishi Chemical, Japan

17h15-17h30

Jennifer Holmgren, CEO, Lanzatech, United States

Moderated panel discussion

17h30-18:30

All speakers and questions from audience

Agenda, Webinar 2: Thursday 22 October 2020

Registration in Zoom

14h30-15h00 (Paris time)

Webinar 2: Sustainability in value chains

15h00-15h05

David Winickoff: BNCT Working Party, OECD: Welcome and introduction by OECD secretariat

15h05-15h10

Adrian Higson, Company Director, NNFCC Ltd, UK: Introduction by the moderator

Sustainability assessment and indicators

15h10-15h25

Francesco Cherubini, Professor, NTNU, Norway

Sustainable biofuels and bioproducts in a defossilized economy.

15h25-15h40

Martin Junginger, Professor, Univ. Utrecht, The Netherlands

Sustainability indicators usage and trade-offs in bio-based value chains.

15h40-15h55

Jack Saddler, Professor, University of British Columbia, Canada

Value chains for sustainable aviation fuel

Introduction to value chain cases

15h55-16h25

Bill Goldner, Senior Advisor Renewable Energy, Natural Resources, and Environment at USDA Office of the Chief Scientist, USA

Nate Brown, Alternative Jet Fuel Project Manager, Office of Environment & Energy, Federal Aviation Administration, USA

Topic: Sustainability of aviation fuel supply chains.

16h25-16h40

Constance Ißbrücker, Head of Environmental Affairs, European Bioplastics, Germany.

Topic: Sustainability of plastics supply chains.

16h40-16h55

Sepideh Jafarzadeh, Research Scientist, SINTEF Ocean, Norway

Topic: Sustainability of fish feed supply chains.

Break: 16h55-17h10

Comments from industry

17h10-17h25

Sami Jauhiainen, VP Business Development, Sustainable Aviation Fuel, Neste, Finland

Aviation fuel; sustainability assessment and SDG trade-offs in alternative supply chains.

17h25-17h40

Catia Bastioli, CEO, Novamont, Italy

Bioplastic in the circular bioeconomy perspective.

17h40-17h55

Viggo Halseth, Chief Innovation Officer, Nutreco, The Netherlands/Norway

Protein; sustainability assessment and SDG trade-offs in alternative supply chains.

Moderated panel discussion

17h55-19h00

All speakers and questions from audience

Endnotes

[1] https://cordis.europa.eu/article/id/125396-factormyth-biobased-organic-biodegradable

[2] Federal Alternative Jet Fuels Research and Development Strategy. http://www.caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf