Leading the way to a European circular bioeconomy strategy

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The report has been written by authors with a scientific background, and the approach has been to try to base the arguments on scientific knowledge, when possible. However, given the strategic nature of the report, and the lack of scientific evidence on some of the issues, we also based the analysis on expert knowledge and our own understanding and views. To support the policy relevance of the report, and to guide its focus, we had the honour to have highly experienced former politicians as 'godfathers and godmother' to our report, and they have also contributed by writing the *Foreword*. We take the opportunity to express warm thanks to Esko Aho (former Prime Minister, Finland), Cristina Narbona (former Minister of Environment, Spain), Göran Persson (former Prime Minister, Sweden) and Janez Potočnik (former European Commissioner and Minister for European Affairs, Slovenia) for their experienced and insightful advice and support.

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Foreword: Why circular bioeconomy now?

Esko Aho, Cristina Narbona Ruiz, Göran Persson and Janez Potočnik

For the first time in human history, we face the emergence of a single, tightly coupled human socio-ecological system of planetary scope. The world and Europe are facing unprecedented interconnected challenges which will even strengthen in the coming decades: increasing demand for food, water, materials and energy while mitigating and adapting to climate change and reversing environmental degradation, including biodiversity loss, nutrient emissions and land degradation. Addressing such grand challenges, while supporting social and economic prosperity for a growing population, requires **a system change in our economic model**.

For 200 years we have had an industrial era built on a **fossil-based, linear economy.** We have seen the transformation of global societies as never before in human history. The industrial era has delivered economic and demographic growth as well as social and technological progress. Over the last 50 years the global economy has experienced a great acceleration, which has triggered significant global economic convergence and a significant reduction of both poverty and inequality between rich and poor countries. However, poverty and inequality are still an issue, even for developed countries.

The industrial era and its economic acceleration has also resulted in an unprecedented rate of environmental degradation related to economic growth. This is clearly seen when comparing GDP growth with other indicators adjusted for natural capital destruction. **The world has grown out of the planet.** According to the *Global Footprint Network,* in 2015, we already used a full 1.6-times the sustainable level of resources in our planet. In two decades it will require two planets to sustain our current economic system.

The context of global and European societies has changed. Now we need a new concept for the new context, a new economic paradigm that puts the basis for human prosperity within the planetary boundaries. The year 2016 was a turning point: the 2030 Agenda for Sustainable Development and its Sustainable development Goals (SDGs) were adopted, and the Paris Agreement on climate change came into effect. These sent out a global political message on the way forward to transform our economic system to end poverty**,** protect the planet**,** and ensure prosperity for all.

This requires new concepts to realize these international agreements, and bring them to action. **The circular biobased economic paradigm can be this –** it builds on the synergies of the circular economy and bioeconomy concepts**.** These two concepts have so far been developed in parallel, but now need to be connected to reinforce each other.

On 13 February 2012, the European Commission adopted a strategy for "Innovating for Sustainable Growth: A Bioeconomy for Europe". Many European and world countries have developed their own bioeconomy strategies in recent years. In 2017, the EU started to review the existing Bioeconomy Strategy to reflect on its future development. We believe **the circular bioeconomy has great potential to catalyse an inclusive European economic, political and societal project that is urgently needed.** A project in which economic prosperity is more equally distributed among citizens and placed sustainably within the renewable boundaries of the planet.

The shift to a circular biobased economic paradigm should be a long-term strategy for decoupling economic growth from environmental degradation. It needs to be socially, economically and environmentally sustainable. The story of the first-generation biofuels in the beginning of this century is a lesson from which we should all learn. Science and technology are laying the foundations for the bioeconomy age. Biobased products have emerged that can substitute fossil-based materials like plastics, chemicals, synthetic textiles, cement and many other materials. Now the big question is how do we take this scientific and technological success to a scale of economic paradigm shift. How can we ensure that longstanding industries such as the textile, petrochemical, construction and plastic sectors join and even lead this paradigm shift in a sustainable way?

We welcome this report coordinated by the European Forest Institute (EFI). It reflects on the main needs to update existing bioeconomy strategies, connecting to the UN SDGs, the Paris Agreement and other recent developments including the circular economy. It provides strategic recommendations which should be considered when developing a new bioeconomy strategy for Europe, based on sustainability principles. It also provides science-based insights on the potential of forest resources, our main biological infrastructure, and on how forest-based solutions can help to develop the bioeconomy from niche to norm.

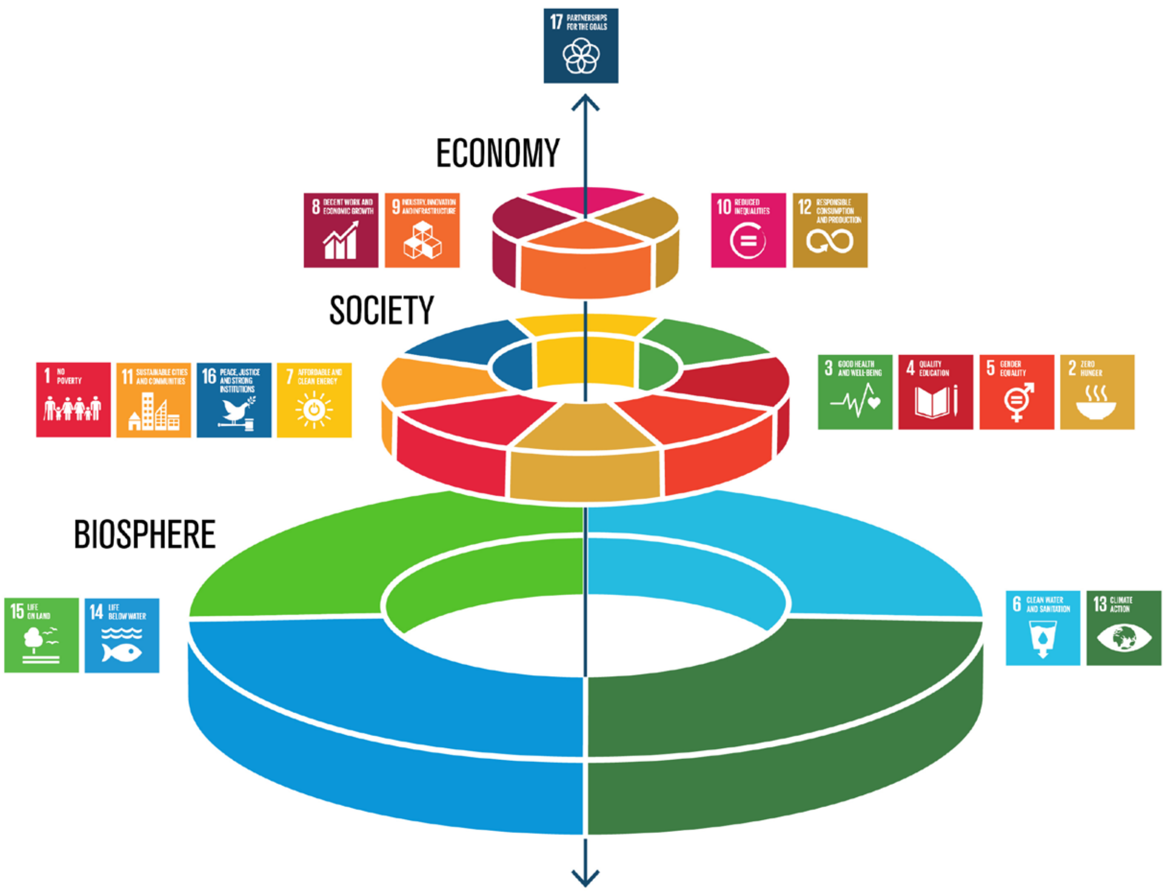
Executive summary

In 2016, the Sustainable Development Goals and the Paris Climate Agreement gave global, overarching societal objectives for future decades. The critical question now is how to reach the targets they set. We argue that a necessary part of the answer will be **the move to a circular bioeconomy.**

It is widely agreed that in order to reach these ambitious global targets, a *business-as-usual* model will not work. Policies and production and consumption habits will need to change. These global agreements give a mandate to change our existing economic model to one which includes natural capital in the way we advance societal wellbeing. One necessary element in this change is the move to a circular bioeconomy, which increases the use of renewable non-fossil raw materials and products in sustainable, resource-efficient and circular way.

This report analyses what a circular bioeconomy strategy would require, particularly in a European context. Existing bioeconomy strategies have been helpful in demonstrating the need to advance the use of renewable biomass to substitute for fossil-based raw materials and products to create a more sustainable society. A bioeconomy contributes to sustainable economy in general, and engages many industries and services, such as clothing, housing, health, food and transportation. In addition, it is becoming a central element of developing cities worldwide, as a basis of sustainable living and consumption, and providing many services, from food and fresh water supply to recreation and urban cooling.

However, many strategies, for example the EU Bioeconomy Strategy and Action Plan from 2012, have gaps in scope or focus, and need updating due to major recent changes and new initiatives. Developing a circular bioeconomy strategy for the long-term requires it to be connected across key sectors and policies in a coherent policy framework. There is a need



Graphics by Jerker Lokrantz/Azote

Figure 1. The layers of Sustainable Development Goals that form the basis for a circular bioeconomy strategy. Source: Azote Images for Stockholm Resilience Centre.

to mainstream bioeconomy within the rest of the economy, not just advance it as a separate sector of interest to mainly rural communities.

In particular, it is crucial to connect bioeconomy to the circular economy concept. Together they are stronger and make more sense in terms of reaching societal goals, than advancing them separately. We should address the following priority elements to transform the circular bioeconomy from niche to norm.

Key recommendations for a circular bioeconomy strategy

Create a science-based circular bioeconomy narrative

A socio-economic strategy needs a narrative explaining why it is important. Show how it helps to integrate natural capital in an economic model to decouple economic growth from environmental degradation and achieve the SDGs. The circular bioeconomy narrative should be especially appealing to highly urbanised areas, where the bulk of EU citizens live. The bioeconomy is increasingly relevant and necessary for cities, not only for rural communities, as traditionally emphasized. A narrative is necessary to gain long-term societal engagement (voters) to support circular bioeconomy policies and actions. *"No policy – no matter how ingenious – has any chance of success if it is born in the minds of a few and carried in the hearts of none."*[1]

Do not assume a bioeconomy is sustainable

Design policies to support all dimensions of sustainability. This also means giving more attention to social and environmental dimensions than has been the case in current bioeconomy strategies. Connect the circular bioeconomy more directly to climate and environmental policies (e.g., increasing plastic waste in oceans), and the challenges and opportunities they generate for circular bioeconomy development. *Maximize synergies and minimize trade-offs between biomass production and ecosystem services* (food, biodiversity, recreation, water, etc.). Understand that you cannot have bioeconomy without biodiversity, because biodiversity is a key feature of our natural capital and a basic condition for any biobased product or service. In a modern society, bioeconomy is often needed to support biodiversity.

Define priority strategic pathways and the key enabling environment

This should include measures to increase the carbon price (tax, effective ETS) and extend it more widely to direct economies to a low carbon path, in which a bioeconomy will play a crucial role. The need to abolish consumer and producer subsidies supporting the use of fossil fuels is also very urgent, and the possibilities of a tax shift from labour to resource and energy consumption should also be analysed. Additional policies are also needed at a sectoral level, (e.g., construction, chemicals, plastics, textiles, fertilisers, etc.). Provide long-term policies that help to guide major investments to these sectors and make them more sustainable.

Invest in R&D, innovations and developing new skills

The circular bioeconomy will be based increasingly on new, innovative, more resource-efficient and circular processes, products and services. R&D is necessary for the disruptive developments that this requires, e.g., merging digital and biological technologies. Support for basic and applied science and research is essential, but needs to be supplemented with support for business innovation. Skills are crucial for the circular bioeconomy to become mainstream. Improving linkages between researchers, trainers, educators, industry and public administration will be the key. The curricula in universities and applied educational institutes need to be updated, and there is a need for cross-cutting research - including economic, political, environmental and foresight research, not just biotechnology, engineering and chemistry.

Provide the right regulatory framework

This is a key catalyst for the transition from a fossil-based economy to a circular bioeconomy. It requires coordination of all significant policy instruments, including public procurement and infrastructure development and planning, to meet the needs of the strategy and create an *enabling architecture*. To take one example, public procurement has great potential as a policy instrument, as it represents 14% of GDP in the EU. Directing public procurement to products and services that are circular,

1 A quote from Henry Kissinger, former US Secretary of State and political scientist. In the original quote Kissinger referred explicitly to *foreign* policy, here we use it to apply to *all* policies.

biobased and contribute to closing resource loops, can play a significant role. The key target is to have clear, defined roles for both the government providing the regulatory operating environment, and the business sector implementing the investments and business operations. The more complex the operating environment, the more need there is for cooperation between the EU, Member State governments and business.

Enhance risk-taking capacity

New innovations usually have high risks. A circular bioeconomy will need policies to reduce or share the risks, and high-risk financial mechanisms such as venture-capital funding. For example, in 2016 the EU launched a pan-European Venture Capital Fund(s)-of-Funds programme that could be used to support circular bioeconomy investments. Green bonds are likely to be increasingly important for financing circular bioeconomy investments. The public sector could support high-risk investments, especially when they are thought to have more extensive positive spill-over impacts. This could be e.g. R&D spending to reduce knowledge-related risks, or investment support for pioneering pilots, demonstration projects, start-ups and mills. Finally, policy actions should demonstrate a *long-term, stable regulatory commitment and environment* to support circular bioeconomy alternatives to fossil-based products targeting the entire products sector and value chains.

Develop EU-level common standards and regulations

This is important for the development of new circular bioeconomy products and services. A well-known past example is the success of the Global System for Mobile Communications (GSM) -standard that was adopted in Europe in 1987. New circular bioeconomy products and services would benefit from this type of standard. One example is wood construction, in which the lack of common standards and regulations (e.g. fire regulations) hinders its large-scale deployment in high-rise buildings. Biosourced materials and secondary raw materials are often not 'identical' to virgin raw materials, and may require different safety criteria.

Emphasise biobased services

The services related to biobased products, such as immaterial rights, servicing, design, R&D, consulting, marketing, sales and administration will become increasingly important with the development of digital technology and big data. What will this mean for business opportunities, the geographical location of the different value chain parts, skills needs, etc.? In addition, natural resources provide key ecosystem services to society: cultural services (recreation, ecotourism, hunting), regulating services (clean air, erosion control, climate mitigation), and provisioning services (drinking water, non-wood forest products like mushrooms and berries). The opportunities these create, and the policies and actions their development requires, should receive more attention in a new circular bioeconomy strategy.

Make use of the opportunities that forests provide

The current EU bioeconomy strategy has not sufficiently understood what the forest sector can contribute. Forests are the biggest land-based renewable resource, with the potential to contribute in a far wider way than previously thought. Often the role of forests and the forest sector is seen in a very traditional way – it is about timber, pulp and paper and perhaps bioenergy. This century has shown that the sector is going through major development and diversification, which extends its opportunities and importance. For example, the sector is increasingly entering areas such as textiles, construction, bioplastics, chemicals, and intelligent packaging. In many regions, the services related to forests e.g. in tourism are also developing from niche to significant businesses. All these provide diverse and increasing opportunities to contribute to circular bioeconomy development.

1. Introduction: The need for a circular bioeconomy

1.1 Background

There have always been politcians, scientists, pundits and activists who have argued for fundamental changes in societal systems; some have even experimented with them. History has included communist societies, utopian communities and different kind of dictatorships. But history also shows that they have more or less failed. With good reason, we tend to have a reserved attitude towards those arguing for drastic changes in our societal systems. Yet it now seems that we have a globally agreed license to do exactly that. The world states agreed in 2015 on Agenda 2030 (the Sustainable Development Goals, SDGs) and the Paris Climate Agreement. It is also widely agreed that business-as-usual model – the policies, production and consuming habits we have followed so far - will not help us to reach these goals. These agreements and goals can therefore be interpreted to give a mandate to change the existing economic model, or how we advance societal well-being. We do not expect this to be an easy or rapid process. Even with strong commitment and actions, it will take decades to achieve the SDGs and Paris Agreement targets. It will also require all economic sectors and institutions to contribute. In this report, *we argue that a circular bioeconomy is a necessary strategy to catalyse this transformation*.

Given the extensiveness of a circular bioeconomy, and the many actions needed to mainstream it in our societies, we have restricted our focus in a number of ways, to be able to address the issue within the scope of one report. First, the report's focus is mainly at the strategic level:

- What are the gaps in existing bioeconomy strategies that limit the possibilities to support the global agreements and goals?
- Why it is important to link the bioeconomy and circular economy strategies, instead of advancing them separately?
- What are the key strategic elements that a successful circular bioeconomy strategy would need to have?

Second, we illustrate the potential of the circular bioeconomy with three concrete examples related to the construction, textiles and plastics sectors. We highlight the importance of services, often forgotten in bioeconomy discussions. Due to the often limited understanding of the potential role of the forest sector in bioeconomy strategies, and due to our expertise, the focus in these concrete examples is the forest sector. However, the strategic implications are relevant to the circular bioeconomy in general, not only to the forest sector.

1.2 Context

The *linear fossil-based economic paradigm* on which we have relied since the Industrial Revolution has delivered substantial global socio-economic and technological development, but at the price of escalating resource use, global environmental degradation and unprecedented human-induced climate impact. The industrial era has provided global economic convergence, but at the risk of sacrificing the safe operating space of our planet.

Research defining nine *planetary boundaries* for a safe operating space for humanity concluded in 2015 that four of them have been crossed: climate change, loss of biosphere integrity, land-system change, and altered biogeochemical cycles (phosphorus and nitrogen) (Steffen et al. 2015, see Figure 2). Two of these, climate change and biosphere integrity, are 'core boundaries', meaning that their alteration would drive the earth system into a new state which cannot any longer sustain our current economic system.

Planetary boundaries become even more relevant when considering population development. Today, the global population is growing by an additional 83 million people annually (the population of Germany), with world population projected to reach 8.5 billion in 2030 (United Nations 2015). Alongside this, the key socio-economic driver will be the unprecedented expansion of the *global middle class* (Kharas 2017, see Figure 3). Today 3 billion people belong to the global middle class, and about 140-170 million people are expected to join in it annually in future. This means that by 2030 there could be two billion people more belonging to the global middle class. This offers major business opportunities, but also great environmental and social challenges. It has been estimated that by 2030 the world will need to produce 50% more food, 50% more energy, and 30% more fresh water to meet the needs of the growing population and middle-class than in 2010 (United Nations 2012).

There will also be a significant increase in demand e.g., of consumer goods, housing, transport

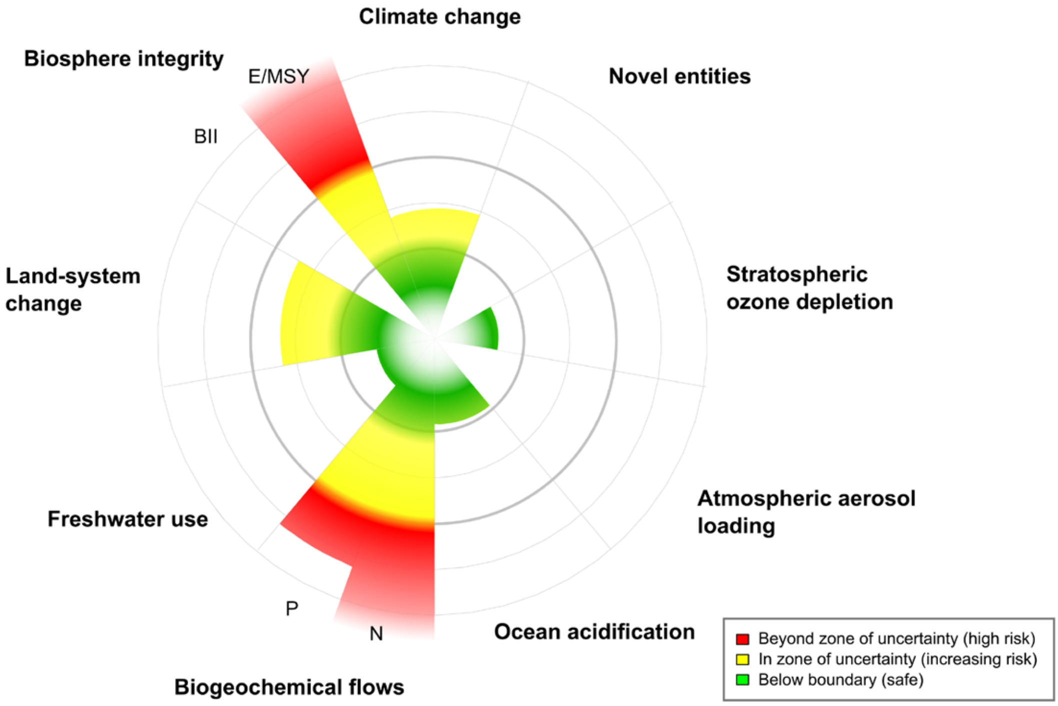


Figure 2. The current status of the nine planetary boundaries. The green zone is the safe operating space, yellow represents the zone of increasing risk, and red is the high-risk zone. The planetary boundary itself lies at the inner heavy grey circle. From: Steffen et al. (2015). Reprinted with permission from AAAS.

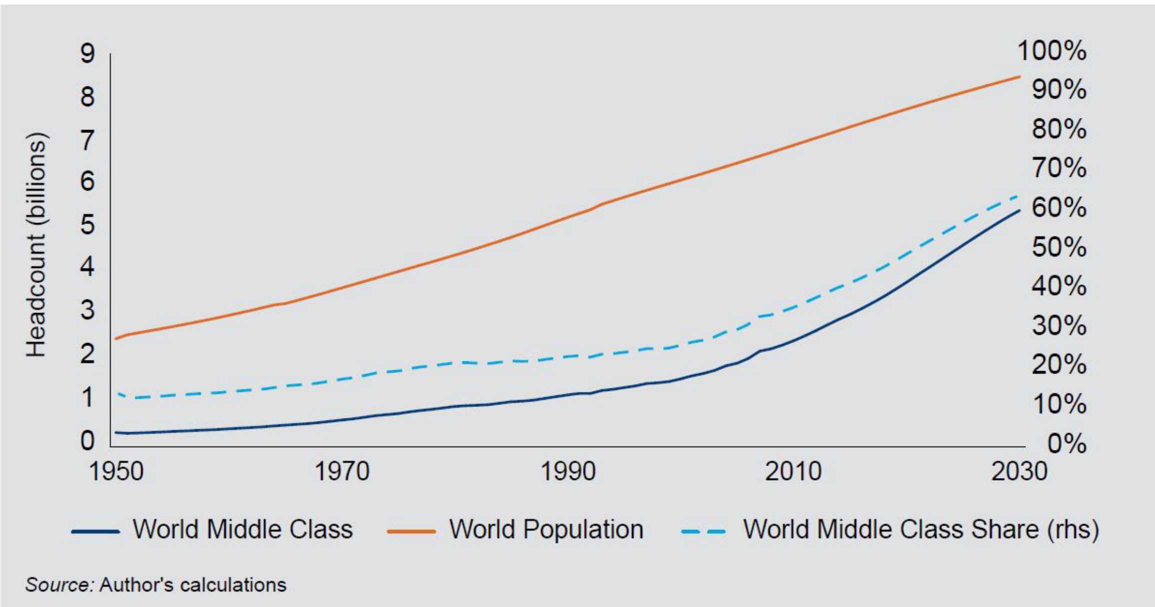


Figure 3. Development and outlook for global middle class. Source: Kharas (2017).

and packaging, which in turn will increase demand for raw materials. The middle classes will also be decisive in shaping the *qualitative demand* for healthier food, clothes, more convenient living conditions, mobility, and housing. To reduce the environmental footprint of their expansion, economies and societies will need to be designed in a new way. There is also a need to craft political support from the middle-class by reframing and transforming globalization into a win-win for the middle class in each country. Politicians need to advance 'inclusive growth' in order to distribute and preserve the benefits afforded by globalization, technological change and innovation to the whole of society.

These are only some of the key global drivers. Others, such as migration (increasing with climate change), digitalization and urbanization will also shape global society and markets.

In this setting, the current economic model has a systemic failure by assuming unlimited resources and sinks. It undervalues the environmental costs resulting from its functioning, and the importance of *natural capital* for its long-term viability (e.g. Rockström et al. 2017; Helm 2015). It fails to create the right incentives for the market to move towards an economy that prospers within the natural renewable boundaries of our planet. There is a need to improve economic prosperity and social wellbeing, while at the same time advancing towards a *double decoupling process*. This implies the proportional reduction of both resource use (resource decoupling) and negative environmental impacts (impact decoupling).

In the transition from a fossil to a low carbon economy, the policy and media focus tends to be on the energy sector. However, it has been estimated that 60–65% of the environmental damage costs are related to the production of materials, and only 35–40% are energy related (UNEP 2017). This fact emphasizes the need for circular bioeconomy development. The energy sector may be almost fully decarbonized in the long-run, but the construction, textiles, chemical and plastics sectors depend on carbon, and therefore on renewable and circular carbon to reduce their negative environmental impacts (UNEP 2017).

1.3 What is the bioeconomy?

There are many definitions of the bioeconomy, as well as usage of similar terms, such as biobased economy and green economy. In practice, the bioeconomy has turned out to be a changing concept and adjustable for many purposes. In this report, we use the definition from the Global Bioeconomy Summit 2015: *'bioeconomy as the knowledge-based production and utilization of biological resources, innovative biological processes and principles to sustainably provide goods and services across all economic sectors'*. However, our emphasis is on two key aspects:

- the transformational role of the bioeconomy in replacing fossil-based products (e.g., oil-based plastics or textiles), non-renewable materials (e.g., steel, concrete), or non-sustainable biological products (e.g., cotton in certain regions);
- the enhancement of the *natural capital approach* to economy, i.e., better integration of the value of natural resources and life sustaining regulatory systems (e.g., biodiversity, fresh water supply) to economic development (Helm 2016).

The first part is generally already well understood in bioeconomy strategies, the latter less so. The long-term sustainable production of *natural capital* relies on the key role of forests as the most important land-based biological infrastructure on the European continent. Forests provide the largest source of renewable biological resource not competing with food production. Finally, although not specifically addressed in this report, we are aware that combining digital technology with biology can offer significant advances for the bioeconomy in the future.

The bioeconomy covers a wide variety of products and industrial sectors (and services), such as construction, bioplastics, packaging materials, food ingredients, textiles, chemicals, pharmaceuticals, and bioenergy. It also includes the *services* related to biobased products, such as intellectual property rights, consulting, R&D, marketing, sales, servicing of machinery, administration, etc. Ecosystem services such as recreation, tourism and water supply are also part of bioeconomy. Despite its sectoral importance, the bioeconomy should be seen in a holistic way, given its full potential to deliver broad social, economic and environmental benefits at the societal level. These include:

1. Inclusive economic growth and job creation

The use of biological resources provides better opportunities for sustainable, inclusive growth than fossil-based resources. Typically the oil assets and incomes generated by these are owned by relatively few. On the other hand, the EU has 16 million private forest owners and the Member States (citizens) own one-third of the forest area. The distribution, ownership and characteristics of forest biological resources offer high potential for inclusive economic development and jobs, also in rural areas. In cases where biological resources are owned by few, or there is a lack of well-functioning markets, there is a need to develop the institutional setting to allow inclusive growth.

2. The emergence of climate-friendly cities and industrial sectors

Urban areas are home to half the world's population, and almost three-quarters of the EU28 population lived in an urban area in 2014 (EUROSTAT 2016). Cities account for more than 80% of global economic output, consume close to two-thirds of the world's energy, and account for more than 70% of global greenhouse gas emissions (World Bank).

BOX 1: Natural capital: a key concept for the bioeconomy

Natural capital can be defined as the world's stocks of natural assets which include geology, soil, air, water, forests and all living things (sometimes also labelled as *green capital*). What makes it *natural* is that nature provides it free to humankind. It is *capital*, since it is an input into production, which in turn produces a flow of goods and services for the benefit of humans. For example, a sustainably managed forest can provide an indefinite flow of new trees and wood, whereas over-use of this resource would lead to a permanent decline or even extinction. From natural capital humans also derive a wide range of services, often called *ecosystem services*, which make human life possible. The most obvious include the food we eat, the water we drink, and the biomass we use for fuel, building materials, chemicals, clothing, etc. This also includes the many less visible ecosystem services, such as climate regulation, flood defences provided by forests, or the pollination of crops by insects. Even less tangible are cultural ecosystem services such as the recreation available in nature, or the inspiration we take from wildlife and the natural environment.

The advantage of viewing nature as a set of assets is that it can then be valued in economic calculations, and therefore it is also worth taking care of. The scarcer it becomes, the more it should be valued. However, these services are often not exchanged in markets, and therefore do not have monetary value. As a result, their importance may also be neglected, even though they are necessary to support life on earth. The *natural capital accounting approach* seeks to put a monetary value on these. Although some may object in principle to putting a monetary value on nature, not doing so can easily lead to ignoring natural capital in societal decisions, and therefore may result in their depletion. Indeed, the global initiative Economics of Ecosystems and Biodiversity (TEEB 2017) is focused on "making nature's values visible". TEEB's principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels. "It aims to achieve this goal by following a structured approach to valuation that helps decision-makers recognize the wide range of benefits provided by ecosystems and biodiversity, demonstrate their values in economic terms and, where appropriate, capture those values in decision-making." (TEEB 2017). Thus, an essential part of the bioeconomy should be to account for natural capital, measure it, and put a value on it. (Costanza et al. 1997a, 1997b; Helm 2015; De Perthuis & Jouvet 2015).

The SDGs have a specific goal (no. 11) for sustainable cities and communities – "to make cities inclusive, safe, resilient and sustainable". A circular bioeconomy can be an important contributor to this. The biomass building blocks of cellulose, hemicellulose, lignin and extractives are already available today, and can increasingly in future be the basis for materials in many sectors and products. This development combined with the use of trees and forests in urban areas can provide important nature-based solutions for developing climate-resilient cities.

3. Europe's biological capital and environmental sustainability

Bioeconomy and biodiversity should be seen as the two sides of the same coin. Biodiversity should be recognised as a crucial part of the natural capital, and valued and managed as a priority. Biodiversity increases the productivity and resilience of ecosystems (Liang et al. 2016). Second, long-term investments in a bioeconomy can enhance biodiversity and adaptation to climate change (Nabuurs et al. 2015). The existing linear fossil-based economy threatens biodiversity through its impacts on climate change, toxic wastes and other environmental aspects. Investing in biodiversity conservation should be a priority in a sustainable bioeconomy, with the aim of a positive coupling between economy and ecology.

4. Synergies with the energy and food nexus

The bioeconomy should ensure synergies with sustainable renewable energy production based on forest, non-food agro and waste biomass. It should advance closed circular nutrient cycles - nutrients (mainly phosphorus and nitrogen) need to be recovered and nutrient leakages prevented. The negative impacts of biological production, such as the expansion of the agricultural frontier (deforestation, loss of valuable habitats) and emissions of nutrients and agrochemicals to soil, water bodies and the atmosphere must be avoided. A bioeconomy must ensure sustainable nutrient use, through more efficient fertiliser use and nutrient recycling. It can also help soil carbon restoration e.g. by putting CO_2 back in the soil. Regenerative agricultural practices can reduce atmospheric CO_2, while also boosting soil productivity and increasing resilience to floods and drought. Techniques include planting fields year-round in crops or other cover, and agroforestry that combines crops, trees, and animal husbandry. It is vital in Europe not only to stock CO_2 in soil, but also to improve soil fertility, reduce the impacts of drought and increase erosion resistance.

1.4 Towards a new paradigm: a circular bioeconomy

The SDGs and the Paris Climate Agreement gave global, overarching societal objectives for future decades. The critical question is how to reach these objectives. We argue that a necessary part of this answer will be *the move to a circular bioeconomy*. It is a strategy and tool enabling us to reach the SDGs and climate change mitigation and adaptation.

A *circular economy* as defined by the Ellen MacArthur Foundation is "one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles". A circular economy aims to design products for a cycle of disassembly and reuse, and abolish waste. A bioeconomy offers the possibility to substitute fossil-based, non-renewable and non-biogradable materials with renewable and biogradable solutions. It can also offer new functions for biobased materials, such as a longer lifespan, higher endurance, less or no toxicity, etc., that circularity cannot alone offer. It makes sense and creates synergies to combine the two concepts: circular economy and bioeconomy (Antikainen et al. 2017).

The bioeconomy and the circular economy do not per se imply sustainability; they have to be made sustainable. For this, it is crucial that the production of biobased products does not compete with food production and does not have negative impacts on other ecosystem services (biodiversity, climate change mitigation, protection against natural hazards, etc.). At the same time, the circular economy needs to reduce its dependence on fossil-based and non-renewable materials with high environmental footprints. An integral part of creating synergies is to assess how biomass and biodegradable materials behave in circular economy, for instance, how easy the reuse in production is and when the recycling possibilities are exhausted. This implies that when new bioproducts are being planned, they should take into account in the design stage reusability and recycling needs.

Biobased solutions can mitigate climate change and increase resource security compared to fossil-based options, and are more regenerative and restorative by nature, and therefore better adapted to circular designs. This includes the high potential of biowastes (e.g., animal manure, sewage or other biobased by-products) for producing fertilisers, chemicals and energy. In addition, biobased products such as nanopulp can be used to increase the circularity of current waste-streams (through better and less environmentally problematic wastewater treatment), and reduce environmental damage, such as oil spills in seas and lakes (Suopajärvi et al. 2017). Consequently, a bioeconomy can help to establish an economy that is less dependent on non-renewable resources, more easily circular, recyclable and less polluting. On the other hand, the circular economy can help to make the bioeconomy more resource efficient and restorative in nature. The concepts of bioeconomy and circular economy clearly reinforce each other. However, so far, they have been developed mostly in parallel and they need to be strategically combined.

Key messages

- The current linear fossil-based economic model has resulted in our society already crossing some of the planetary boundaries for a safe operating space for humanity.
- Circular bioeconomy is necessary to be able to live within the planetary boundaries and to achieve the SDGs and the Paris Climate Agreement.
- Merge the bioeconomy and circular economy strategies. Circular bioeconomy is more than bioeconomy or circular economy alone.
- An evidence-based circular bioeconomy narrative is essential to engage society, especially the urban population, to support policies needed for circular bioeconomy strategy and policy implementation.
- Natural capital accounting is a key approach for circular bioeconomy.

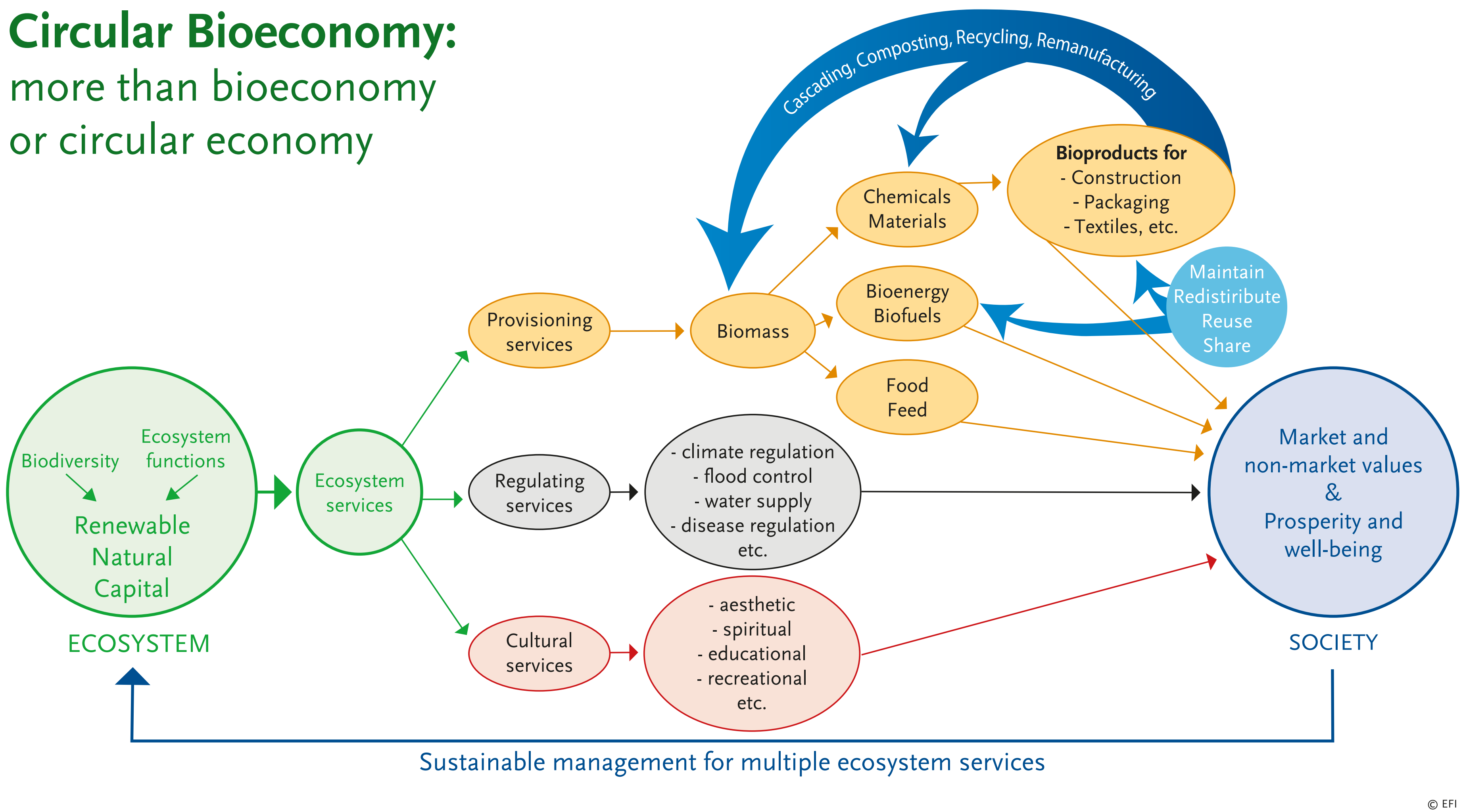


Figure 4. Illustration of circular bioeconomy flows. Source: EFI[2]

2 The concept of ecosystem services was defined in the Millennium Ecosystem Assessment (MEA 2005) as 'the benefits people obtain from ecosystems', both natural and managed. These services may be categorized as provisional, regulative, cultural or supporting services, also referred to as supporting processes. Ecosystem services are essential for human life and the well-being of humans (Costanza et al. 1997a, 1997b; MEA 2005).

BOX 2: Do we need yet another new concept?

Given the already confusing supply of similar types of sustainability-related concepts like *bioeconomy*, *circular economy* and *green economy*, what value added could yet another new *circular bioeconomy* concept bring?

D'Amato et al. (2017) used a machine learning-based analysis and reviewed close to 2,000 scientific articles dealing with circular economy, green economy and bioeconomy. Without going into details, the results show that there is significant variance between the concepts in the scientific literature, for example, in terms of issues emphasized, regional variation in how important a specific concept is seen as being (e.g., in China, Europe and North America), and the narratives used to justify the concepts. From the scientific and future research perspective, the exact definitions, objectives and differences between the concepts are clear and important. The possible value added of a new circular bioeconomy concept in this context is that it could help to merge two already important concepts and research lines (bioeconomy, circular economy), therefore streamlining the research agenda and finding synergies between the concepts.

From a policy and practical perspective, having several different but rather closely related concepts addressing sustainable development is of course unwelcome - it is likely to create confusion. The fewer, the better. Even though in the short-term the introduction of yet another new concept may create confusion, in the long-term it can reduce it by merging two already popular ones. There would also be additional substantial advantages.

As shown by D'Amato et al. (2017), in the literature circular economy tends to focus on industrial *urban processes* and decoupling resource use and economic output, whereas bioeconomy focuses on biological resource-based innovation and land use practices in the context of *rural development*. The circular bioeconomy concept merges these two trends and *links urban and rural communities*, something which is currently lacking.

If the bioeconomy focuses mainly on developing biobased materials and energy, and does not consider circularity aspects, it will be at risk of becoming too much a 'business as usual' scenario. Circularity means addressing recycling, reusability and resource-efficiency already at the product or service design stage. This also enhances life cycle and value chain thinking. One implication of this is that bioeconomy businesses need to expand their thinking outside their traditional focus, and find more broad and diverse cooperation with different actors. You cannot satisfy circularity by operating only in business-to-business networks. You also need to consider consumers and how to establish recycling and reuse of the products at the end of their first stage use. How could the life cycle of a new bioproduct be optimally designed, and how is the recycling and reuse institutionally operationalized to satisfy circularity requirements? Similarly, when designing policies, policymakers cannot just advance all possible bioeconomy developments, but rather those that also satisfy the circularity requirements.

In an EU context, the merging of bioeconomy and circular economy concepts could create administrative and resourcing synergies and help to decrease 'silo' thinking and operation. Currently bioeconomy is the responsibility of the Directorate-General for Research and Innovation, and circular economy the responsibility of the Directorate-General for Environment. Circular bioeconomy could be advanced with more synergies between the Directorates, and its implementation and resourcing could be the responsibility of several Directorate-Generals.

The fact is that the use of similar type of concepts, such as bioeconomy, circular economy, circular bioeconomy and green economy will most likely continue. But at a policy level, this confusion can be decreased by *interpreting all these concepts as tools that seek to achieve the SDGs and Paris Agreement targets*. In this sense, they are all integrated, despite their somewhat different emphasis in terms of actions.

2. Bioeconomy strategies

The notion of bioeconomy received attention early this century in the EU (e.g., European Commission, 2002), and more global interest was created with the OECD policy paper on bioeconomy 'The Bioeconomy to 2030 – Designing a policy agenda' (OECD 2009). Many countries have produced their own strategies and many more countries have tackled bioeconomy in other policy papers. The EU launched its bioeconomy strategy in 2012 and several of its Member States currently have their own bioeconomy strategies. This chapter provides a brief account of the strategies, their main messages and assesses their strengths and weaknesses.

2.1 Existing strategies

The German Bioeconomy Council provides an overview and synthesis of bioeconomy strategies (Bioökonomierat 2015a and 2015b). From Europe's perspective the analysis focusing on the EU and G7 (Canada, France, Germany, Italy, Japan, the UK and the United States) is most relevant. Priefer et al. (2017) provide a selective but chronological list of bioeconomy strategies in the world (see Table 1). Currently, almost 20 countries have or are producing specifically designed bioeconomy strategies, and the number is expected to increase. The importance and special role of bioeconomy is widely recognized.

In addition, it is important to note the Communiqué of the Global Bioeconomy Summit (2015, see also El-Chichakli et al. 2015) and the European Bioeconomy Stakeholders Manifesto (so-called Utrecht Manifesto 2016). In 2015, more than 700 experts from around 80 countries met in the first Global Bioeconomy Summit in Berlin. The members of the International Advisory Committee on the Bioeconomy (37 experts from around the globe who shaped the summit) outlined the principles that were agreed and the steps needed to advance them, as well as illustrating how these can be applied to individual SDGs.

Interestingly, all strategies provide their own definitions of bioeconomy and differ in the sectors and other aspects they find worth promoting (Bioökonomierat 2015; Priefer et al. 2017, Staffas et

Table 1. Selected bioeconomy strategies in chronological order.

Country	Strategy	Year
OECD-countries	The Bioeconomy to 2030 – Designing a policy agenda	2009
EU	Innovating for Sustainable Growth – A Bioeconomy for Europe	2012
The Netherlands	Framework Memorandum on the Bio-Based Economy	2012
Sweden	Swedish Research and Innovation – Strategy for a Bio-Based Economy	2012
USA	National Bioeconomy Blueprint	2012
Malaysia	Bioeconomy Transformation Program – Enriching the Nation, Securing the Future	2013
South Africa	The Bio-economy Strategy	2013
Germany	National Policy Strategy on Bioeconomy	2014
Finland	Sustainable Growth from Bioeconomy – The Finnish Bioeconomy Strategy	2014
West Nordic countries*	Future Opportunities for Bioeconomy in the West Nordic Countries	2014
France	A Bioeconomy Strategy for France	2016
Italy	BIT – Bioeconomy in Italy	2016
Spain	Spanish Strategy on Bioeconomy Horizon 2030	2016
Norway	Familiar Resources – Undreamt of Possibilities	2016

* West Nordic countries comprise Greenland, Faroe Islands and Iceland. Source: Priefer et al. 2017. The strategies of Italy, Spain and Norway have been added by the authors to the table provided by Priefer.

al. 2013). To take two extremes, the OECD provides a narrow, and German policy strategy a broad definition. The OECD strategy states: “bioeconomy can be understood as a world in which biotechnology contributes to a considerable extent to the economic output” (OECD 2009, p. 8). This definition is reiterated in OECD (2016), which stresses especially the role of advanced life sciences in biotechnology. The German policy strategy understands bioeconomy as a comprehensive societal transition that involves a variety of industries, such as agriculture, forestry, horticulture, fisheries, plant and animal breeding, wood, paper, textile, chemical and pharmaceutical industries as well as energy production (Priefer et al. 2017).

All strategies are linked to broad social goals, most importantly to the need to replace fossil resources in industrial and energy production with renewable biomass (Priefer 2017). Large-scale replacement is said to provide a transition to sustainable economy, which solves the challenges provided by food security, natural resource scarcity, climate change and environmental pressures. At the same time, the bioeconomy can provide new growth and jobs. Biomass is a unique source of carbon in the sense that it can substitute for almost all possible products from fossil fuel resources (European Commission 2012; Priefer 2017). Apart from these general and shared ideas, the strategies point to different opportunities and set their key aims differently depending on their prevailing industrial and economic profiles and countries’ natural resource potential (Bioökonomierat 2015a, 2015b).

Sustainability was initially given as a motivation for bioeconomy strategies, but they have mostly taken the sustainability of the bioeconomy as given. Discussion about the sustainability requirements of the bioeconomy has been brought up at a larger scale only more recently (Priefer 2017; Pfau et al. 2014). The concerns include, especially, the risk that bioeconomy leads to using EU forests at the cost of biodiversity, and the fact that bioenergy production leads to increased CO_2 emissions in the short-term (EASAC 2017; Fern et al. 2017; Open Letter 2017). How serious the problems turn out to be depends on how bioeconomy development will be advanced and monitored (Nabuurs et al. 2015; Berndes et al. 2016; Wolfslehner et al. 2016).

Given the ongoing discussion, it is important to ask what makes or ensures a sustainable bioeconomy, and if unsustainable, how can it be made sustainable? OECD (2016) suggests that the focus should be especially on the trade-off relating to agriculture and industry in bioeconomy production, with an emphasis on sustainable biomass production. In general, we should produce ‘more from less’ to avoid competition with food production. OECD also stresses that we should be specific as regards to various sources for bioenergy and biofuels, as they may differ in terms of sustainability. OECD concludes that sustainability requirements stress the role of innovation. A recent EC Joint Research Institute Bioeconomy Report 2016 (Ronzon et al. 2017) also draws attention to the environmental aspects of the bioeconomy, stating that “A sustainable bioeconomy cannot be conceived without the sound management of biological resources, respecting the regeneration levels of all renewable resources and healthy ecosystems on land and in the sea.” (See also section 2.3 and 2.4).

2.2 The main messages from the strategies

The general background to all the strategies is that the replacement of fossil resources by biogenic materials would mitigate climate change. An effective implementation of strategies is said to achieve a deep change in the structure of economies and improve competitiveness, provide growth and jobs together with an improved quality of the environment. But to achieve these goals, the bioeconomy must differentiate itself from traditional primary production in agriculture, forestry and fisheries. The bioeconomy uses new scientific knowledge and emerging technologies in biobased production and transfers natural resources into sustainable products and services in processing and service industries (Bioökonomierat 2015b).

The EU’s strategy is based on a broad bioeconomy concept which provides a useful basis to address the current demanding challenges that humankind faces, because it encompasses the transformation of renewable resources and waste streams into value added products drawing on Member States’ strong innovation potential (European Commission 2012). The EU’s strategy places a lot of emphasis on agriculture and food production, which overshadows other parts of the strategy. That said, the EU bioeconomy strategy relies on three well-defined blocks:

- bioeconomy requires investments in research, innovation and skills;
- bioeconomy can be built only on reinforced policy interaction and stakeholder engagement;
- creating bioeconomy requires enhancement of markets and competiveness.

What could be achieved by successful implementation of bioeconomy strategies? From our analysis, the European discussion generally pinpoints:

Economic growth and job creation. Drawing on research and innovation, the transition to a bioeconomy helps European industry to renew, develop new sustainable products and achieve improved competitiveness in global markets. Because bioeconomy increases profits and jobs in advanced industries (like forest, chemical, pharmaceutical and energy industries), it boosts demand for biomass and increases income and jobs in rural areas, leading to a more balanced and socially more equitable economic growth.

Replacement of fossil resources. The need to replace fossil fuels is ever more urgent. The bioeconomy has a crucial role in reducing GHG emissions. New bioproducts help to reduce dependence on coal, gas and oil in power production, heating and transport. They facilitate carbon-neutral development in cities and rural areas alike. While rural areas benefit from producing biomass, cities gain new businesses from manufacturing new products. The replacement of fossil resources insulates better against price fluctuations, which are typical of fossil resources, and helps businesses by creating a more stable economic environment.

Enhancement of environmental sustainability. The bioeconomy is based on the sustainable use of natural resources and processing them to high value-added products. By improving resource efficiency and promoting the cascading use of resources, the bioeconomy can save pristine resources. By increasing the value of biomass production, the bioeconomy makes it more profitable to maintain biological resources in a good state. Finally, the bioeconomy aims to replace non-renewable resources, which strengthens the sustainability of economies, and often also resource security, such as energy security. By and large, the bioeconomy provides a chance to rebuild industry and society in a sustainable fashion.

In general, the messages associated with the bioeconomy above have provided the basis for the argument that promoting bioeconomy promotes sustainability in all its dimensions; economic, ecological and social sustainability. Recent discussion about these claims and about the implementation of bioeconomy strategies does not, however, take them for granted.

2.3 What are the gaps and needs for new insights?

There is a rather strong consensus about bioeconomy objectives, but how these objectives should be achieved in practice is a subject of debate and requires an assessment of the strengths and weaknesses of the strategies. Focusing mostly on Europe, for instance, Priefer et al. (2017), Pfau et al. (2014), Ollikainen (2014) and McCormick and Kautto (2013) identify the existing gaps and needs for incorporating new insights into existing understanding. In general, these gaps relate especially to issues such as climate and the environmental sustainability of the bioeconomy, possible impacts on the land use sector (LULUCF), the sufficiency of the supply of biomass, and recreational amenities of forests and landscapes.

As comprehensive as previous discussions on the above aspects have been, they have hardly tackled a new and important ingredient in the EU's policy: the circular economy.[3] The EU identified the transition to a circular economy as essential to develop a sustainable, low carbon, resource efficient and competitive European economy. This new initiative has important implications for the bioeconomy. In 2015, the European Commission adopted the Circular Economy Package, which includes revised legislative proposals on waste. This and the related Action Plan include long-term targets to reduce landfill and to increase preparation for the reuse and recycling of key waste streams, such as municipal waste and packaging waste, and propose measures covering the whole cycle: from production and consumption to waste management and the market for secondary raw materials. The Action Plan includes EU targets for recycling 65% of municipal waste and 75% of packaging waste by 2030. Economic incentives for producers to put greener products on the market and support recovery and recycling schemes are

3 Circular economy as concept is not new, e.g. Germany has a circular economy law (Kreislaufwirtschaftsgesetz) since 1997.

to be developed in several priority areas like plastics, construction and demolition, food waste, and critical raw materials as well as biomass and biobased products.

The bioeconomy receives a new standing due to global agreements: the Paris Climate Agreement and the UN Sustainable Development Goals (SDGs). Replacing fossil raw materials and promoting sustainable circular bioeconomy can contribute considerably to achieving the goals of these agreements. Drawing on previous literature, the EU's circular economy policy and the goals of the two agreements, we suggest a closer linking of the EU and other bioeconomy strategies to following societal goals and policies.

Climate and environmental policies. Many strategies seem to take as a given that bioeconomy development is sustainable in terms of climate and the environment. The reason for this assumption is that using biomass does not add new carbon in carbon circulation, in contrast to fossil resources which increase the carbon stock in circulation. However, the link to climate mitigation and LULUCF policies has been weak this far. Clearly, a general and high enough carbon price is needed to boost bioeconomy development, as well as possibly compensation to forest owners for enhancing carbon sinks. One example of extending climate policy to the forest sector is the New Zealand Emissions Trading Scheme, in which forest landowners can participate in the emissions trading programme as sellers; selling carbon credits from their forests. Nabuurs et al. (2017) suggest a notion of Climate Smart Forestry (CSF), which is also useful for bioeconomy considerations. CSF is based on a wider approach than just storing carbon in the forest ecosystem. It considers the sustainable climate mitigation potential of the whole forest and wood product chain, including material and energy substitution and accounting for local circumstances. It not only aims towards climate mitigation, but also concentrates on its essential precondition of forest health and resilience, and the need for the adaptation of forests to climate change. It tries to achieve possible synergies with other forest functions, such as biodiversity, ecosystem services and the bioeconomy. CSF tackles multiple policy goals by reducing or removing greenhouse gas emissions, adapting and building forest resilience, and sustainably increasing forest productivity and incomes. It stresses the need to redefine the way the bioeconomy is understood, and clearly shows the need for government policies and using efficient policy instruments.

Special role of forests and the forest sector. In the EU and its Member States' bioeconomy strategies, the role of forests and the forest sector is mostly neglected (with Finland and Sweden as exceptions), and the main emphasis placed on biomass from agriculture. Forests are, however, the biggest biological infrastructure in the EU, covering around 40% of the land area. In the EU context, forests do not compete with food production like biomass production from agriculture, and forests provide a large supply potential of biomaterial. In principle, wood can replace almost all products made out of fossil materials (see Chapter 4). Most importantly, forests can play a twin role in the bioeconomy: they can be managed in a way that promotes forests as a carbon sink and as a raw material supplier to forest industry. A very important feature of the forest industry is that it facilitates a resource-efficient cascading use of various parts of wood materials, side streams and waste. In many ways the forest industry has been a forerunner of recycling and many circular economy ideas. The forest sector also has the potential to provide inclusive growth. The EU has 16 million private forest landowners (more than farmers), and one-third of forests are owned by states (tax payers). Compared to fossil resources, forests generate income and wealth that can be spread to a much larger group of EU citizens, and importantly also to rural areas. Given the facts above, there is a need to place the EU forest sector in a more prominent role in bioeconomy strategies than has been done in the current EU bioeconomy strategy.

Recreation and ecosystem services from rural landscapes and forests for all citizens, including urban residents. The welfare of citizens is the ultimate goal of each nation. Besides market goods, renewable resources provide a large range of non-market ecosystem services like biodiversity and recreation. These important aspects have been largely omitted in the strategies and discussions on the bioeconomy. It is vital that the bioeconomy and biodiversity are mutually reinforcing: the bioeconomy is viable when it maintains a good status of biodiversity; and rich natural diversity helps the bioeconomy to adapt to the changing forest environment due to climate change, thereby securing the biological capital on which the bioeconomy

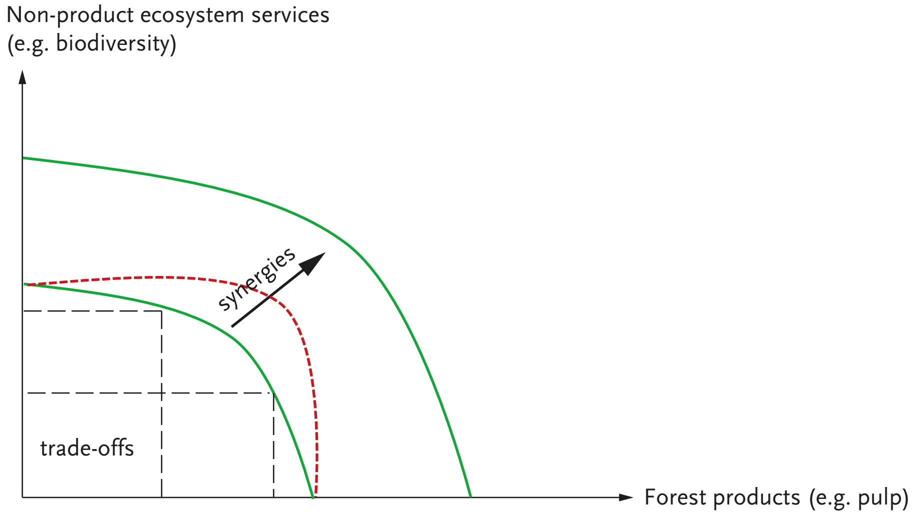


Figure 5. Illustration of forest-based bioeconomy production possibility frontier with trade-offs and synergies between forest products and non-product ecosystem services.

The vertical axis describes non-product ecosystem services (such as biodiversity, water quality, recreation, tourism, carbon sink) and horizontal axis forest products (e.g. pulp, sawnwood, bioenergy). Figure 5 illustrates a bioeconomy, which can use forest resources to produce both material forest products and non-product ecosystem services at the same time, and can choose alternative combinations of both production types. The green curves, or the so called *production possibility frontiers*, indicate maximal combination of outputs (e.g. biodiversity and pulp) for a given amounts of inputs (forests, capital, labour). The location of the frontier is determined by technological constraints and resource availability. By picking any point on the green line one can read in the axes the respective amounts of forest products and non-product ecosystem services (see Chapter 1.3). The red dashed frontier illustrates the case of not increasing the end points in the x- and y-axis, but pushing the rest of the frontier outwards. This could take place if the bioeconomy produced 'more from less', for instance, due to synergies in the innovation of forest industry.

relies. The strategies also fail to note the important role and economic contribution of nature tourism. The nature tourism industry needs increasingly old growth stands and rural landscapes that have high biodiversity values and often high cultural values. For many countries tourism is built on coastal amenity benefits, rural landscapes and pristine and old growth forests. In bioeconomy strategies there is a need for a more balanced treatment of the industrial and commercial use of biomass and maintaining other ecosystem services, such as, biodiversity, landscape and forest amenities for citizens. However, there is still a lack of practical showcases in this application area.

2.4 Policies to maximize synergies and minimize trade-offs

The objective of bioeconomy strategies and policies should be to maximize the synergies and minimize the trade-offs between bioeconomy, biodiversity and climate mitigation. The role of synergies and trade-offs is illustrated in Figure 5, adapted from Hetemäki (2017).

In economic terms, the green curves show a forest bioeconomy *production possibility frontier*, when there is a trade-off between the outputs that forests can provide. The frontier describes all output combinations when outputs are produced efficiently. It is of course possible that society is operating inefficiently and would be located under the production possibility frontier.

As Figure 5 suggests, the more intensively forests are used for forest products, the less societies can produce ecosystem services like biodiversity, and vice versa. The challenge for society is to find a sustainable combination of both. The role of synergies is important, because they can move the frontier outwards, and by this, alleviate the trade-offs. In Figure 5, the frontier may move outward in two ways: either via more from more, or more from less. In both cases more forest products and non-product ecosystem services are produced. The outward movement of the frontier is in principle possible via three ways:

- technological change (innovation) and learning-by-doing (e.g. better management experience);
- increasing production inputs (e.g. higher forest growth, afforestation);
- a combination of these two.

The new frontier is usually not possible in the short-term. However, in the long-term, when technology and innovations are introduced, or more production inputs can be utilized, movement is possible. Innovations and technological progress (including better institutions and management) are key to producing more from existing resources. The case of more from more takes place when, e.g., better forest management practices increase forest growth, or it becomes profitable to allocate abandoned land to forestry.

Figure 5 illustrates that the bioeconomy can be advanced in different ways, and therefore *it would be optimal to provide policy incentives that help to minimize the trade-offs and maximize the synergies between different components of the bioeconomy*. By increasing the profitability of forest management and possibly forest land areas, a well promoted bioeconomy enhances the possibilities to take care of biodiversity. But the opposite is important as well. Successful adaptation to climate change and extreme weather conditions (increasing forest fires, storms, pests and other hazards) is imperative to provide a basis for the bioeconomy.

So, a key question for circular bioeconomy is, how can the synergies be made stronger and trade-offs minimized with policies? Here, we focus on the general enabling policies relevant for the whole bioeconomy, rather than the sectoral level. So, for example, although renewable energy policy has been instrumental in the past for advancing the bioenergy sector of the bioeconomy, we do not discuss it here. Instead, we focus on policies related to innovations, circularity, biodiversity and land-use. These policies should be advanced in a coordinated and linked manner to generate policy synergies and efficiencies.

Innovation policy. Given that biotechnology and innovation especially from advanced life sciences lies at the heart of the bioeconomy, synergies with general innovation policy have a crucial role. In general, the EU emphasizes the following aspects: a skilled workforce, sound business environment, strong system of knowledge creation and diffusion, policies encouraging entrepreneurial activities and a focus on governance and implementation. Education, public support for research and development, and creating technology clusters are examples which have a large potential to contribute to the bioeconomy.

Circular economy. Even though biomass and biobased products are identified as a priority, the EU Circular Economy Package fails to connect the circular economy to the bioeconomy, despite the fact that the EU Bioeconomy Strategy was approved in 2012. As seen in Chapter 1, a major task in developing a deeper understanding of the bioeconomy is to unify the concepts of bioeconomy and circular economy – to a *circular bioeconomy*.

Biodiversity conservation. The EU promotes the conservation and maintenance of biodiversity through multiple channels. They were all formulated prior to the acceptance of the Bioeconomy Strategy, but no real link has been built between the Bioeconomy Strategy and biodiversity. The most relevant documents and programmes are the *Convention on Biological Diversity, Natura 2000* under the *1992 Habitats Directive,* and the *EU's biodiversity strategy.* In general terms, these documents call for effective actions to halt the loss of biodiversity, preserve the most valuable habitats and accelerate the transition towards a resource efficient and green economy. As noted above, an effective bioeconomy strategy must cope with biodiversity and ecosystem services. Nearly 50% of Natura 2000 habitats are forests, for example. Interestingly, the EU's biodiversity strategy also indicates that forest management plans based on the principles of sustainable forest management are key instruments for ensuring a balanced provision of multiple goods and services and maintaining and enhancing biodiversity.

Land-use policies. The EU will include carbon sinks in the land-use, land-use change and forestry sector (LULUCF) in its climate policy. The LULUCF proposal tends to look at the climate policy in a silo, not linking it to other societal challenges and objectives, and limiting the options of this sector too much. Yet, it is increasingly acknowledged that reaching the Paris Agreement climate targets will require fundamental changes in economies and societies, and therefore climate policy should be planned in connection to this systemic change (Rogelj et al. 2016), also in land use. Effective climate policy should try to seek to build upon interconnections with other societal policy goals, and minimize the trade-offs between them. Without this, there is a danger that climate policy targets will politically not be possible to implement.

Key messages

- Existing bioeconomy strategies have been helpful in demonstrating the need to advance the use of renewable biomass to substitute for fossil-based raw materials and products to create a more sustainable society.
- However, many strategies have gaps or need updating due to major recent changes (e.g. the EU strategy from 2012). For example, they have shortcomings due to taking environmental sustainability as a given, they do not link the bioeconomy to the circular economy, and several relevant policies (e.g. climate policies). In addition, the agricultural and food sector dominates, at the cost of failing to acknowledge the potential of the forest-based sector.
- A key question for circular bioeconomy is how policies can help to maximize synergies, and minimize the trade-offs between biomass production and other ecosystem services.
- General enabling policies such as innovation, circular economy, biodiversity and land-use should be advanced in a coordinated and linked manner.

3. Requirements for successful circular bioeconomy development

3.1 Background

Bioeconomy strategies typically inform about *why* the bioeconomy is necessary and what opportunities it provides (Chapter 2). But, the crucial question is *how* the (circular) bioeconomy strategies should be implemented. Given that bioeconomy strategies are supported by action plans, or platforms responsible for supporting strategy implementation, the how question is also usually addressed. Yet, given the cross-sectorial nature of circular bioeconomy, and our view that it should be mainstreamed to the whole economy - not just to a sector - it is clear that large numbers of different types of measures and actions are needed. Here we focus on some key enabling measures that we consider *major priorities*. The criteria of choosing these priorities is based on the authors' views, as well as the advice we received from our *Foreword* writers.

3.2 The importance of narrative and social inclusiveness

Narratives have been increasingly recognized as important to engage society in different movements and changes (Davidson 2016). There is a growing body of research in fields such as psychology, cognitive science, political science and sociology showing that people do not make decisions through a purely rational process, and that emotion and a range of cognitive biases are important. Narratives are central to the mental models and social beliefs and practices that guide individuals' decision-making and behaviour, and are important in bringing about change. For circular bioeconomy development to succeed and be implemented in practice, it is necessary to be able to tell a narrative that engages most of the people (voters).

According to Eurostat data, built-up areas – defined as cities, towns and suburbs – provide a home to almost three quarters (72.4%) of the EU28's population, and this share is predicted to increase in future. It is difficult to see how the circular bioeconomy could succeed without engaging and receiving support from these urban citizens. Yet forestry and bioeconomy is often advanced in bioeconomy strategies and political rhetoric in manner that appeals to the rural population: more rural jobs and income for forest owners living in rural areas. The EU has a rural development policy which is funded through the European Agricultural Fund for Rural Development worth EUR 100 billion for 2014–2020. Similarly, many European national governments have rural programmes to enhance livelihoods in rural areas. If the urban population is aware of the circular bioeconomy at all, they may easily relate it to these types of rural programmes. The challenge is that, like the EU Common Agricultural Policy policy, urban citizens may view it critically. To simplify, perhaps these policies are seen as taking tax income away from their pockets to support rural people. For the circular bioeconomy to succeed in the long-run, it would need to change this view. There is a need for a circular bioeconomy narrative that engages the urban population and gets its support.

This narrative is also important for another reason. People may not necessarily see the point of the bioeconomy, especially in those European countries in which most of the population have had no direct experience of forestry, or have limited understanding of how wood and forests enters their daily life in many ways. An evidence-based narrative about the forest-based bioeconomy is needed, told in a way that appeals to the urban population. That narrative could be different things in different regions and cities, elaborating on the specific features that are important to these regions. The narrative should tell about the renewable, cyclical nature of forests, and how wood and forests enter into the daily life of the urban population, from morning to evening in many different and important functions and forms. If wood was not used, it would mean using some other material instead, which very often is non-renewable or fossil-based, difficult to recycle (circulate), and therefore possibly not sustainable in the long-term. Or it could be, for example, a narrative of how a sustainably managed forest helps to support the clean water supply of the city.

One necessary part of the narrative is also *social inclusiveness*. This relates, e.g., to the ownership of the resources, and how widely the income and job benefits of the circular bioeconomy spread to a society.

In Europe, there are 16 million private forest owners, and one-third of the European forest land is owned by states, i.e., the citizens. Often this spread of forest ownership to large number of small private forest owners is seen as a challenge for the bioeconomy and efficient forest management and wood markets. Indeed, it clearly is an issue. However, from another perspective, it helps to increase the societal inclusiveness and acceptance of the sector. This is true especially when compared to the ownership of fossil-based resources. Generally, in the EU very few people own oil, gas or coal assets, or benefit from the income stream these generate. In principle, the conditions for more inclusive growth appear to be much better for the forest-based bioeconomy than fossil-based economy. In addition, EU forests provide multiple non-wood products and services, such as capturing 10% of the EU's CO_2 emissions, biodiversity, tourism and recreation, clean water, and other regulatory functions. These benefits can be produced in synergy with bioproducts, and can increase the societal inclusiveness of the forest-based bioeconomy.

It is essential to engage all of society - including the urban population - and pay more attention not to give an image that it is mainly of interest to the rural population and the forest sector only. The question is not about which is more important, urban or rural, but about the connection between urban and rural lives, and how one needs the other. Finally, whatever the narrative, it is very important that it is supported by science-based facts, otherwise it will most likely lose its credibility, and therefore power.

3.3 Environmental sustainability

Sustainable development needs to be at the heart of the bioeconomy. At its onset, in the late 20th century, sustainable development was about seeking harmony between the economy, society and the environment. Now it is perceived as economic development that supports the prosperity and wellbeing of the whole human society, but within given environmental boundaries at local, regional and planetary scale (Griggs et al. 2013). This new approach to human development can create synergies with ecosystems and their biodiversity (Muys 2013), and are translated in the Sustainable Development Goals (see Chapter 1 and 2).

History shows that markets do not automatically lead to or produce sustainability. Policies are needed to avoid resource depletion and other unwanted externalities that markets can create, and to place value on ecosystem services that are not traded in markets. In particular, policies are needed to monitor, assess and ensure the sustainability of the bioeconomy. By doing so, unwanted outcomes can be avoided, and a circular bioeconomy can create huge opportunities for people and our planet.

The first essential feature of a circular bioeconomy is that environmental sustainability issues are addressed at an early stage, e.g. in the **design phase** of production chains and consumption patterns. This means that companies and governments address potential sustainability issues using the best available knowledge and information on environmental aspects, in addition to market and technological issues. Sustainable R&D of new products/materials includes **screening** for potential high environmental risks or unacceptable burdens. This screening may use predictive tools and can lead to significant environmental efficiency and business gains, as the lessons learned from history indicate. In the past there are examples of promising new technologies which later proved detrimental for humans or the environment, like DDT, CFCs or asbestos cement. The regulatory role of public authorities is to apply the precautionary principle to foster sustainable progress, but without inducing immobilization – *'nothing ventured, nothing gained'*.

The other essence of the circular bioeconomy is **life cycle thinking** from cradle to cradle. Potential environmental impacts should be avoided along the whole life cycle of products and services, from resource extraction through the production process into the use phase, and eventually the multiple reuse of recycled resources in new products. At the end of life, disposal is avoided, e.g. for a wood product by gasification with energy use and recuperation of ashes as a fertilizer or a building material. Life cycle thinking can be mainstreamed by policies stimulating industrial symbiosis, giving value to waste, and putting a high price or ban on disposal.

Environmental issues along the life cycle are either *input-related*, i.e. caused by the extraction of resources from the natural environment, or *output-related*, i.e. caused by emissions to the natural environment during the production, use or end of life. **Input-related** environmental risks are very relevant for the bioeconomy, because it is an economy essentially relying on **biotic resources** such as biomass, and on in-demand **land resources** to grow it. The challenge is to use these scarce resources in a sustainable way.

A huge asset of **biotic resources** is that they are **renewable** - they grow back after being harvested, again and again. This is not the case for abiotic resources like petrol, metal ores or phosphates, for which once a rich deposit is depleted, their extraction stops forever. But the condition for a biotic resource to be renewable is its **sustainable use**, i.e., not letting the resource base become extinct. But this requires management. In forests, for example, it requires planning that regulates harvesting by keeping the standing biomass stock in the forest at a high enough level to ensure its continued growth. This principle of sustainable use is less simple than it looks, but forest science has a long history of developing tools to survey, monitor and predict the annual allowable cut of forests in complex, highly variable landscapes.

Unsustainable harvesting could be best avoided with policies placing value on well-stocked forests, like a carbon price or carbon sequestration compensation to forest owners. Before these are effective, other measures will be needed. Indeed, the EU and several countries are planning regulatory measures to control solid biomass extraction for bioenergy use. A cost-efficient alternative could be a **stress test** checking how far the regular instruments of sustained yield like cutting licenses, management plans, certification schemes and so on are in place and operational in regions and countries. A stress test like this could also form one of the innovative sustainability indicators needed for the bioeconomy (Wolfslehner et. al. 2016)

The other input-related category is **land use impacts**. Replacing fossil-based resources with bio-based can lead to increasing land scarcity, which would boost land prices, and may enhance potential conflicts between land use options. A well-known example of conflict between land use options is the **food versus fuel** debate that emerged when corn ethanol subsidies in the US contributed to food scarcity and the global food price crisis of 2007-2008. In fact, allocation problems are inherent to any land-based economy, but can be solved through proper policies and management supporting land use optimization and taking environmental and social issues into account.

Sustainability challenges have led to a particular focus on land use. Land sparing and land sharing, two contrasting approaches to sustainable land management practice are being promoted (Phalan et al. 2011). According to the **land sparing** approach, a part of the land is 'set aside'. There is increasing scientific evidence that a considerable amount of land, globally and regionally, needs to have a predominantly unmanaged status, ensuring **biodiversity conservation** (e.g. space for conservation is essential for the bioeconomy; Lefèvre et al. 2014), and global ecosystem services like climate stabilization and rainfall recycling over land. In a sustainable bioeconomy this is not lost land as it contributes to the earth system's resilience to the benefit of all, while providing many local co-benefits such as controlled levels of ecotourism and high value products from nature.

According to the **land sharing** approach, there is also increasing evidence that land use intensification has reached its limits for a number of reasons (Ripple et al. 2017). In forestry, this happens mainly through monoculture plantations contributing to soil impoverishment and suffering pest outbreaks and climate stress, all affecting the system's resilience and the very base of biological production. In response, R&D and policy efforts trying to move agriculture and forestry from high input maximum output towards either medium input high output, or low input high diversity systems (Matson et al. 1997; Tilman et al. 2006). Recent research on the **functional role of biodiversity** to support productivity, production resilience and ecosystem multi-functionality, needs to be given the opportunity to further develop from fundamental research to viable land management systems (Liang et al. 2016; van der Plas et al. 2016).

The circular bioeconomy of the future can mitigate land use related risks through land use optimization addressing trade-offs and synergies between multiple ecosystem services (see Figure 5), targeting a clever mix of land sharing and land sparing options at landscape scale depending on local needs and opportunities (Grau et al. 2013; Pedroli et al. 2013). In this way forests with high biodiversity can be maintained and managed that show more resilience under climate change conditions (see Box 3). Forestry has a long tradition in Europe of creating human value while keeping land use impact low. Intensified biomass harvest, e.g., for bioenergy holds important opportunities for conservation of species of open habitats (van Meerbeek et al.

2016), forest fire prevention and forest adaptation to climate change induced drought.

As to the **output-related** environmental issues, biobased products have clear advantages over fossil-based ones. They are often less toxic and biodegradable, which facilitates their re-use, recycling and disposal. Also for the mitigation of global warming, bioeconomy products have inherent useful qualities. First, biomaterials can store carbon just like forests do, with usually increasing benefits coming with higher **product longevity** (Brunet-Navarro et al. 2016). Stimulating well-designed Life Cycle Assessment (LCA) based **cascading use** of biomaterials, where materials are recycled several times into new products before the very end of the life cycle, can lead to more carbon sequestration, more energy substitution and more added value per unit of resource input, all key features of the transition to a circular economy. In short, circular bioeconomy needs to focus on its strengths, i.e. in the diversity of **biomaterials and their applications, biorefinery-based resource-efficient systems** and **non-material ecosystem services** (e.g. tourism, environmental regulation), and avoid overemphasizing just one

Box 3: The importance of adaptation to climate change

A biobased economy that relies on a constant delivery of raw materials from ecosystems is particularly vulnerable to changes in environmental conditions, particularly climate change. Without proper measures to adapt to climate change, sustainable management of biotic resources is not possible, nor can the mitigation effect on climate change through carbon storage or substitution be achieved. This applies to all ecosystems such as forests, but also to agricultural systems and fishery. Here, we use the example of forestry, based on a study on the economic impacts of climate change on forests (Hanewinkel et al. 2013), but similar strategies should also apply to agriculture and fisheries.

The current three general adaptation strategies for forests to climate change are (Bolte et al. 2009): (a) the conservation of forest structures, (b) active adaptation, and (c) passive adaptation. The conservation of forest structures, i.e. a business-as-usual approach (a) assumes low adverse impacts of climate change, high resistance to climatic stress and a high likelihood that conservative interventions will improve the stability. Passive adaptation (c) means to halt management interventions and to use spontaneous adaptation processes in terms of successional dynamics and species migration. Both strategies are only promising under milder climate scenarios (a) or for forest ecosystems with low economic importance (c). For intensively managed forests in Europe, active adaptation (b) seems to be the most appropriate strategy, especially when assuming 'high end' climate scenarios to be the likely future. Active adaptation strategies include the introduction of new species that are better adapted to drier and warmer conditions and which show a higher resistance to potentially increasing impacts of pests and diseases. Active adaptation means also to maintain or increase the genetic adaptive capacity of the species to be used in the future (Lindner et al. 2010) using a variety of genetic adaptation strategies such as assisted migration, traditional or molecular breeding and gene conservation (Fady et al. 2016). Improved seed transfer guidelines should be applied to prevent the use of maladapted seed sources. Besides inter-specific assisted migration, within-species assisted migration, defined as the purposeful movement of provenances to areas where they are better adapted in the future should be applied. Together with silvicultural measures such as the change of production times and thinning regimes, fire and pest management with an intensive pest- and diseases monitoring system is considered an important part of an integral adaptation strategy. To safeguard the mitigation potential of forest ecosystems against climate change through an array of regionally adapted measures, 'Climate Smart Forestry' has recently been discussed (Nabuurs et al. 2016). A similar concept has also been implemented in agriculture.

subsector, like the bioenergy subsector. There is a need to create a level playing field.

In summary, the emergence of the bioeconomy is a clear recognition of the crucial value of natural capital and its ecosystem services for sustainable human development (Costanza et al. 1997a,b). However, bioeconomy development so far has been mainly technology and economy orientated. This section shows that there are multiple pathways to develop the bioeconomy, and that not all have the same sustainability potential. Therefore, there is a need to invest more in sustainability research to design the policies, tools, indicators and monitoring systems to support the development of a truly circular and sustainable bioeconomy.

3.4 R&D, technological change and skills

In order for the European circular bioeconomy to support the SDGs and the Paris Agreement, and the more specific EU policy objectives, it is clear that current products and technologies are not sufficient. We need to create new, more resource-efficient, sustainable and more circular biobased technologies, products and services. The source and base of these will be R&D&I.

R&D supporting the development of new forest-based technologies and products has advanced during this century. For example, traditional forest industry companies have been willing to take these as part of their new strategies (Näyhä and Pesonen 2013). As result, there already are new forest-based products, such as packaging products that substitute plastic, more environmentally friendly textile materials, engineered wood-based elements and modules, and second generation biodiesel (Chapter 4). Yet, we are still at the early stages of new biobased product and technology development, and to speed up and extend the process we need R&D investments.

Despite the change in industry strategies, R&D investments are still at a low level in a number of countries, and in some cases even declining in forest-based industries, for example, in traditional major forest industry regions such as North Europe and North America. There are many reasons, including the traditionally low level of R&D investments in the industry, the declining relative contribution of forest industry to the national economy, corporate restructuring, low industry profitability, a focus on short-term issues, cost cutting, and inadequate prioritisation of R&D for long-term business growth and sustainability. Low R&D investments tend to be an even bigger problem for small and medium scale (SME) companies, which are often wood product (e.g., sawnwood, plywood) producers. This needs to change for innovation and new business opportunities to be realized to a greater extent. The situation also heightens the importance of new players, for example, start-ups, chemical, textile, consumer goods and construction companies, with an additional supply of resources and investments.

Bioeconomy research has so far been very much focused on biotechnology, engineering and chemistry (Lovrić & Mavsar 2017). This is understandable, given the need to develop new innovative products. However, the research on markets, policies, and social sustainability related to bioeconomy has been at a very low level, giving also an impression that its importance is not yet well understood (see also 3.3). For example, Horizon 2020 is making available around EUR 3.8 billion funding in support of research and innovation in the bioeconomy over 2014-2020, but socio-economic bioeconomy research has been at a relatively low level, with most of the funding going to technology-related research (Lovrić & Mavsar 2017). Now that new bioeconomy products are already entering the markets, there is an increasing need to understand the market-policy-society developments related to them (Hetemäki & Hurmekoski 2016). For example:

- What are the market prospects and competitive advantages for different products and in which regions should their value chains be located?
- What is the biomass resource market availability outlook in different regions?
- What are the impacts on employment trends and skill requirements for the future?
- What are the environmental sustainability and life cycle impacts of the new products and processes?
- How can we best incorporate the circularity perspective into the products and processes?
- How can we use digital technology, big data and artificial intelligence to optimize, identify and appreciate new pathways and value chains, process data, and create indicators to monitor all dimensions of the sustainability of bioeconomy?

The impacts of changing regulations, consumption behaviour, trade patterns, CO_2 and energy prices, the development of other sustainable energy technologies, biomass resources, etc. need to be assessed to better grasp the impacts they might have on the overall circular bioeconomy system. Also, a mechanism for continuous foresight and scanning should be established, to steer activities in response to future developments and changing conditions.

Related to R&D, there is also a need to develop the right kind of skills and talents. Technological and societal history shows that paradigm shifts – which moving to circular bioeconomy also implies – have required new skills and talents. Circular bioeconomy will consist of increasingly diverse activities, based on knowledge generated in many different areas and sources. We need to invest in the right kind of skills and talent to manage this knowledge. For example, there are not yet enough Masters' programmes at European universities in sustainable forest bioeconomy. There is a gap between the hopes and strategies related to the bioeconomy, and the fact that we are not training enough people for its needs.

The new R&D also needs to be applied in practice, and there needs to be a platform bridging science and practice. To this end, in July 2017 the European Commission launched a new *Bioeconomy Knowledge Centre (BKC)* to better support EU and national policy makers and stakeholders with science-based evidence. BKC will not primarily generate knowledge, but will collect, structure and make accessible knowledge from a wide range of scientific disciplines and sources on the bioeconomy. It is based on the Commission's in-house science service, the Joint Research Centre (JRC). This knowledge hub is very welcome. However, it is not sufficient for the science-policy interface, even at the EU level, not to mention the Member States and non-EU countries in Europe. The science evidence supporting policy making should be used also to analyse EU policies, their strengths and weaknesses, including possible alternatives. Yet as an in-house service, it is difficult for JRC to criticise and propose changes to EC policies, even if there would be a need for it. The BKC work is valuable, but also needs to be supported with science-based policy support work which is independent of the European Commission, yet can fruitfully support it with a more extensive knowledge base, and with the ability to analyse and provide implications in relation to EU policies.

3.5 Risk-taking capacity

New investments and innovations are a must for circular bioeconomy development, yet they also involve high risks. It is to be expected that a substantial share of new business innovations can fail. Failure does not necessarily mean that investment has been wrong or useless, because societies can learn from failures and better understand what conditions and direction are necessary. But circular bioeconomy development will also need policies which help to reduce or share the risks, and high-risk financial mechanisms, such as *venture capital funding*. For example, in 2016 the EU launched a pan-European Venture Capital Fund(s)-of-Funds programme, that could also be used to support circular bioeconomy investments (European Commission 2016a).

Another promising instrument could be *green bonds* (European Commission 2016b; OECD 2017). Since 2007–08, a market for bonds specifically regarded as 'green bonds' has emerged. These are differentiated from a regular bond by their commitment to use the funds raised to finance or refinance 'green' projects, assets or business activities. The market for green bonds has been growing very rapidly, with the annual issuance rising from just USD 3 billion in 2011 to USD 95 billion in 2016. It has been estimated that the global volume of annual green bond issuance for 2016 ranged from USD 70 to USD 100 billion (OECD 2017). According to OECD (2017), green bonds can offer several important benefits for green investment including:

- providing an additional source of green financing;
- enabling more long-term green financing by addressing maturity mismatches;
- enhancing issuers' reputation and clarifying environmental strategy;
- offering potential cost advantages;
- facilitating the 'greening' of traditionally brown sectors;
- making new green financial products available to responsible and long-term investors.

However, the evolving green bond market faces still a range of specific challenges and barriers, which several policy measures could address (see OECD 2017).

The public sector can support high-risk investments especially when they are thought to have more extensive positive spill-over impacts besides direct support for one business case. This could be e.g.

R&D spending to reduce knowledge-related risks, or investment support for pioneering pilot or demonstration projects and mills. Another important tool could be *public procurement policies*. Public authorities spend approximately EUR 1.8 trillion annually, representing around 14% of the EU's gross domestic product (InnProBio 2017). Procurement principles tend to support the cheapest alternative on the market. Often this implies traditional products and services which include very little, if any, innovation. Public procurement policies could be redesigned to include risk-taking and promote products and services in line with a circular bioeconomy, also promoting innovation. The European Commission's Public Procurement of Innovative solutions (PPI) seeks to facilitate diffusion of innovative solutions on the market (European Commission 2017). In a circular bioeconomy many of these applications and solutions may be closely linked to the public sector.

One approach to tackle risk issues, especially for SMEs, is to find symbiosis or 'business ecosystems' between large and small companies, such as in the case of the Metsä Group Äänekoski bioproduct or biorefinery mill in Finland (Palahí & Hetemäki 2017). The mill started operation in August 2017 and was a EUR 1.2 billion investment. Although it is a specific case, it is interesting in terms of describing the general direction which the bioeconomy could take in other places in Europe. The circular bioeconomy concept aims to process products resource-efficiently, minimize waste, and maintain the value of products, materials, and resources in the economy as long as possible. At the heart of Äänekoski biorefinery is pulp production, around which there is an ecosystem of production activities and a number of SME companies that produce, e.g., electricity, heat and steam, transportation biogas, plywood for wood construction, wood composite musical instruments, and agri- and forest fertilizers. The organic by-products, e.g., resulting from debarking of wood, will be used as soil roofing materials and soil improvements. In essence, *one company's waste is other company's raw material*. The biorefinery processes are based totally on renewables, and it is a significant net energy generator. It is important to analyse how this biorefinery develops in practice, to gain lessons for other similar projects.

The European Investment Bank (EIB) surveyed the hurdles for investments in biobased industries (BBI) and discovered that 77% of the projects (33 out of 43 projects) faced access-to-finance issues (Leoussis & Brzezicka, 2017). Moreover, "79% of all respondents reporting access-to-finance issues indicate that the lack of interest from private financial market participants is related to the specificities and associated lack of understanding of the BBI". This suggests that there are systemic barriers to financing BBI. EIB recommends developing a new EU risk-sharing financial instrument dedicated to bioeconomy and potentially taking the form of a thematic investment platform that can mobilise public-private capital from different sources.

The key challenges were found to be the risks related to the market (demand) prospects, and uncertainties related to the regulatory environment. The first means that the demand for new bioeconomy products is still more uncertain than for the existing products. The latter relates to uncertainties over whether regulations affecting the markets in future are well known, consistent and stable in the long-term. These are issues that have been raised by many studies for many years at the EU and Member State level, but which appear not to have been solved. Changes will not happen only by supporting new developments, there is a need to debase 'old', less efficient solutions too (Kivimaa & Kern 2016). Policy actions should demonstrate long-term regulatory commitment to support bioeconomy alternatives to fossil-based products targeting the entire products sector (now biased to bioenergy) and value chains while allowing free market forces to operate sufficiently (Leoussis & Brzezicka 2017).

Interestingly, the EIB report does not address *bioeconomy services*, neither does it discuss the possible investment *risks related to sustainability*. The first generation biofuels lesson is that these can be significant, and also need to be addressed. Markets will not automatically solve externality issues.

3.6 Regulatory environment and public-private sector collaboration

What was the most important decision that made Europe the most advanced and successful mobile phone region in the world in the 1980s and 1990s? The answer often given is the creation of the Global System for Mobile Communications (GSM) -standard that was adopted in 1987 (Temple 2010). A group of 13 European countries decided to develop and deploy a common cellular telephone system across Europe, and EU rules were passed to make GSM a mandatory standard. Following this decision, mobile operators from across Europe started to invest in new GSM networks. Within a year, the whole of Europe had been brought behind GSM in a rare example of unity and speed. For example, the US did not have a common standard, lacked the enabling conditions for an efficient mobile phone operating environment, and fell behind Europe in development.

The lesson this has for circular bioeconomy development is that European-level common standards and regulations should be designed for new products and services. A good example is wood construction (Chapter 4), in which the lack of common standards and regulations (such as fire regulations) hinders the large scale deployment of wood construction in high-rise buildings (Hurmekoski 2016). Europe would benefit from a common biomarket environment, with a certain amount of common rules and standardization, which could significantly reduce business risks and boost R&D.

Common regulation and standardisation is clearly also an example of the need for cooperation between the EU and Member State governments, also for business and government collaboration. The more complex the operating environment for business, the more there tends to be a need for this type of cooperation. For example, this is the case with developing clean technology or artificial intelligence and robotics (also for circular bioeconomy). However, government should not be a business operator itself, but rather the facilitator. It has a necessary and indispensable role in creating *enabling architecture* for emerging businesses. This is needed for the European circular bioeconomy to develop meaningfully and efficiently. How can the EU design policies and cooperation platforms in a way that society can take maximum benefit from a sustainable circular bioeconomy? There are also attempts to provide quality criteria for desirable bioeconomy development, such as the Nordic Council of Ministers (2017) criteria for Nordic Bioeconomy.

Key messages

- An evidence-based narrative on circular bioeconomy is needed for a circular bioeconomy strategy and to engage the urban and rural population in Europe to support its implementation.
- The circular bioeconomy recognizes the essential role of natural capital in socio-economic development, as it is based on the maintenance and management of biological resources and their diversity, and the sustainable use of renewable resources from nature.
- Without proper measurements to adapt to climate change the sustainable management of biotic resources as foreseen by the circular bioeconomy is not possible.
- There is a need to create new, more resource-efficient, sustainable and more circular biobased technologies, products and services. The necessary, although not sufficient, requirement for these is increasing R&D&I investments.
- To raise capital for pioneering but risky circular bioeconomy investments, *venture capital, green bonds and public procurement policies* are needed. *Biomill ecosystems* (e.g. Äänekoski) help to boost synergies between big global companies and SMEs, and can also reduce the risks, especially for the SMEs. A long-term, stable policy environment is key to reducing uncertainty and risks for circular bioeconomy investments.
- EU-level common regulation and standardisation for new bioeconomy products and services can speed up circular bioeconomy development. This requires cooperation between the EU and Member State governments, and between business and government.

4. Bioeconomy contribution potential: examples

4.1 Background

In bioeconomy strategies, the potential of the forest-based sector is often hidden in the shadows of the agriculture sector. However, there are regions where forest-based bioeconomy has received attention in regional strategies (e.g., Nordic countries), and these could also show potential for some other regions. In this Chapter, we focus on bioeconomy examples from the forest-based sector to highlight its potential.

Wood has four main components: *cellulose*, *hemicellulose*, *lignin*, and *extractives*. Cellulose and lignin are amongst the most abundant source of organic polymers on earth. Forest bioeconomy uses these four components of wood to produce construction materials, chemicals, biofuel, heat, power, bioplastics, packaging materials, food, livestock feed, ingredients, textiles, health and pharmaceuticals, etc. Often forgotten, but important, is that the forest-based bioeconomy also includes the *services* directly related to forests (e.g. recreation, nature tourism, water supply, hunting, etc.) and those connected to forest management, wood processing and forest products (R&D, extension, consulting, marketing, sales, immaterial rights, maintenance services, etc. (Hetemäki 2014; Näyhä et al. 2015).

4.2 Economic and environmental impacts

According to JRC, the EU28 bioeconomy in 2014 had an annual turnover of about EUR 2.2 trillion and employed 18.6 million people (JRC 2017). This figure includes everything under bioeconomy, e.g. food, beverages, tobacco, forestry, fisheries and agriculture sectors. If we narrow the data to sectors in which the forest-based bioeconomy is a major contributor, but also including some agro and waste-based production, we have the following sectors: biobased electricity; biofuels; biobased chemicals, pharmaceuticals, and plastics; manufacture of paper and paper products; biobased textiles; wood products and furniture; and forestry. The turnover for these sectors in 2014 was EUR 700 billion and

Table 2. Hypothetical example of 1% market share for forest-based products in different sectors

Market	Construction *(cement/concrete)*	Plastics	Textiles	TOTAL
Global market size in 2050	> 5 000 Mt	1 124 Mt	250 Mt	6 374 Mt
Growth rate *assumption*	Peaking soon	4x by 2050	4x by 2050	
Price* *(value per unit)*	80–2 650 €/ton	650–1 580 €/ton	600–2 300 €/ton	
Forest-based 1% solution *(European forest-based materials gain 1% share of the global market volume)*				
Production	13.7 Mt**	11.2 Mt	2.5 Mt	27.4 Mt
Revenue	~ 1–36 billion €	~ 7–18 billion €	~ 1.5–6 billion €	~ 10–60 bill. €
Wood use	68 Mm^3	*(no primary use – based on side-streams)*	15 Mm^3	> 83 Mm^3

Table is modified from unpublished manuscript by Hurmekoski et al. (2017), Markets for new wood-based products, European Forest Institute.
*Based on Finnish customs statistic; ** Wood density (500 kg/m³) is different from that of concrete (1850 kg/m³) – 3–4 times less (tons) wood needed to substitute the same volume (m³) of concrete.

employment 4.3 million.[4] In 2014, the turnover of only EU pulp and paper and solid wood production was about EUR 300 billion and the employment 1.5 million (EUROSTAT). These two industries represented 43% of the turnover, and 35% of the employment, of the 'forest-based' bioeconomy sector. However, it is very difficult to obtain precise indicators for aggregate forest-based manufacturing and service activities, since they tend to be classified under many industries and sectors, and not only under forest industries.

To illustrate the potential market implications of emerging forest-based products, we will consider three cases: *wood construction, forest-based textiles and bioplastics* (for more examples, see e.g. Hetemäki, 2014; Ministry of Economic Affairs and Employment, Finland, 2017). We ask what would be the economic and roundwood consumption impacts if European wood-based products gained a **1% market share** of the global construction, textile and plastics markets, that are currently very much dominated by cement, synthetic fibres, and petrochemicals. This '1% solution' is clearly a hypothetical one, and also based on very rough estimates. The market share could clearly be smaller or bigger, and the unit prices depend very much on what stage of the product value chain the price refers to. Yet, it is illustrative to try to quantify potential impacts. Table 2 shows that this could generate a revenue for the European wood-based bioeconomy in the scale of **EUR 10–60 billion** (depending on the assumptions made). This would amount to 3% - 20% of the current total turnover of the EU forest industry. The additional industrial roundwood use would be at least 83 million m^3, which would be 23% of the total industrial roundwood production in the EU in 2016 (355 million m^3, data FAOSTAT).

4.3 Construction market[5]

The EU28 *building construction sector* has large economic and social significance - its turnover was EUR 581 billion and employment 3,6 million in 2015 (EUROSTAT). There is no data available for the share of *wood construction*. However, according to our estimations (based on EUROSTAT data), its turnover was EUR 85 billion and employment 680,000. In other words, its share was 15% of the turnover and 19% of the employment of the total building construction sector.[6]

Wood has traditionally been used in single family buildings: around 8-10% of single family buildings in the EU have a wooden frame. However, this varies regionally from over 80% in the Nordic countries to almost insignificant in a number of southern European countries. With the emergence of *engineered wood products* (EWP) in recent years, wood has increasingly also been used in large-scale construction, such as multi-storey residential buildings, office buildings, schools, hospitals, and industrial and sports halls. In particular, the move to prefabricated production of glued laminated timber (glulam) and cross-laminated timber (CLT) elements and modules has enabled this development.

Yet, there are still misperceptions about wood as a building material, including fire hazards and issues with strength and durability. Often these perceptions are not in line with modern wood construction standards. Indeed, industrial wood construction could address many of the pressures faced by the construction sector, including: efficiency, environmental impact, and safety and convenience of workers. Wood as a material has a number of further possible benefits, including fitting accuracy, tremor safety (for earthquake-prone areas) and good insulation, as well as the possible beneficial impact of bare wooden surfaces on indoor air quality and human health (humidity buffering, soft acoustics, stress-relieving atmosphere).

The economic competitiveness of wood construction varies between regions and market segments. In wood frame multi-storey markets, wood-based building practices are still on average a few per cent more expensive when compared to established methods. This is still partly due to national construction regulations which treat materials unequally. However, in future one can expect wood construction to become cost competitive, due to

4 This turnover is equal to the sum of turnover in 2014 of the following eight European company giants: *Airbus, Bayer, Deutsche Telecom, Fiat, Nestlé, Siemens, Vodafone Group* and *Volkswagen*. They employed in total 2.1 million in 2014. (source: Financial Times European 500).

5 This case is heavily based on Hurmekoski 2017. How can wood construction reduce environmental degradation? European Forest Institute. http://www.efi.int/files/images/publications/efi_hurmekoski_wood_construction_2017_oct.pdf

6 These figures are based on assuming that 70% of the total activity of wood products manufacturing (excluding furniture) was wood construction related. According to EUROSTAT, the wood products manufacturing (except furniture) turnover was EUR 121 billion and employment 973,000 in the EU28 in 2015.

Figure 6. Construction of the Brock Commons student residence in Vancouver (UBC), the tallest cross-laminated timber (CLT) building in the world at 53m high. In many countries building regulations still limit the heights of timber buildings based on outdated regulations. Photo source: https://www.naturallywood.com/

learning-by-doing through an accumulating number of pilot projects, and ultimately the standardization of modern wood construction techniques.

Especially from the circular bioeconomy perspective, wood construction offers significant potential. The European building construction sector accounts for 42% of total energy consumption, 35% of total greenhouse gas emissions, 50% of extracted materials and 30% of water consumption (Hurmekoski 2017). Research literature recognizes the possible environmental benefits of substituting the most common building materials with wood-based products (Sathre & Gustavsson 2009). Results on the environmental impact of wood construction invariably conclude that wood-based construction practices cause less environmental burden compared to established practices. In particular, wood construction can reduce the energy consumption and CO_2 emissions related to the manufacture of construction products, as well as contribute to reducing the overall material use and thereby the amount of waste, and reduced transport weight and cost.

Wood-based products contribute to climate change mitigation by two main mechanisms: carbon storage and substitution. Firstly, substituting wood for steel, concrete, and other products that use more energy in their manufacture avoids larger fossil fuel consumption and consequent CO_2 emissions (**substitution**). Also, the use of sawmilling residues for bioenergy recovery improves the energy balance of wood products. Secondly, trees sequester CO_2 in standing forests through photosynthesis, and store the carbon in wood-based products for the duration of the life cycle of the product (**storage**).

Most of the emissions from buildings are caused by their use, particularly due to heating and cooling. While the choice of building material may have no decisive impact on the energy efficiency of buildings, wood-based solutions exist, for example, for energy façade renovations. However, with stricter energy efficiency requirements and a possibly changing fuel mix in energy generation in the future, the relative importance of the CO_2 emissions of the manufacture of building products is likely to rise.

Construction is one of the most significant sectors causing the depletion of natural resources. The resource intensity of construction means that circular thinking is increasingly important for the sector. Taking the perspective of the 'waste hierarchy', perhaps the clearest contribution of wood construction is that substituting a wooden frame for a concrete frame significantly reduces the total material input of a building, i.e., it avoids greater material use due to the 4-5 times lower weight of wood compared to concrete. A wood-based structural frame can cut the total material consumption of construction in half and the weight of the structural frame by 70% (Pasanen et al. 2012). A lighter structural frame also allows reduced material input to the foundation. Moreover, industrial prefabrication of wood elements and modules provides an efficient means for minimizing waste at the construction site.

The most significant waste streams related to buildings are created in renovation and at decommissioning of the buildings. The EU Waste Framework Directive (2008/98/EC) stipulates that 70% of non-hazardous construction and demolition waste must be prepared for re-use, recycled or undergo other material recovery by 2020. At the time of introducing the directive, the recycling rate of construction waste in the EU27 was on average 63%, and for wood 30%, with significant differences between countries. One-third of demolition wood is used directly for energy production, which from the waste hierarchy perspective is regarded as the least favourable option. Finding more efficient recycling options for demolition wood will be a challenge, also partly due to chemical impregnation of wood or the use of oil-based glues, paints and other material mixes. One important aspect in this regard will be cascading use, which means extending the lifetime of wood material in the production loop before combusting it, for example in the following sequence of applications: Beam > floor board > window frame > oriented strand board > fibreboard > combustion (Vis et al. 2016).

Wood sourcing in the EU builds on the principles of **sustainable forest management**. Thus, wood construction is not linked to global deforestation, which is primarily caused by competing land uses in developing countries. Wood construction may provide incentives for active forest management in order to maintain forests as a long-term carbon sink, as the majority of forest owners' revenues from selling wood comes from large diameter logs. However, the raw material impact of the possible increase of wood construction can remain moderate. It has been estimated that even a theoretical 100% market share of wood construction of all buildings in Europe would translate to a maximum direct demand of 400 million m^3 of wood (Hurmekoski 2017). This is equivalent to around 50% of the annual growth of EU forests, or 45 million m^3 more than the total industrial roundwood production in the EU in 2016. With realistic assumptions, the impact of increased wood construction on the demand for wood resources remains relatively small: for example, with a 20% market share the roundwood demand increase could be around 50 million m^3 in the EU.

The manufacture of wood products also creates forest residues and side-stream raw materials, such as chips, sawdust and bark, which are used for producing wood-based panels, bioenergy and biochemicals that can substitute for fossil-based raw materials. The volume of these side-stream products currently exceeds 100 million m^3 annually in the EU28.

In summary, there is a range of policies at the EU and Member State level to enhance the sustainability and resource efficiency aspects of the building sector. These could directly or indirectly support the use of less environmentally burdensome materials, such as wood, in construction. The EU Construction Directive (Official Journal of the European Union 2011) does not address these needs. Consequently, the first step needs to be the creation of a level playing field for construction markets, by removing the unnecessary regulatory and cost burdens of wood construction in national construction regulations. As this is already the case in some countries, it would be useful to share these experiences with other countries.

4.4 Textile market[7]

The textile sector is one of the largest industries in the world and demand for textile fibres is growing rapidly. In 2015, global production of textile fibres was around 90 million tons, more than double the production volumes of 1990 (CIRFS 2017). Of the

7 This sub-chapter is heavily based on Hurmekoski et al. (2017). Markets for new wood-based products, unpublished manuscript. Diversification of the forest sector: Role of new wood-based products. European Forest Institute.

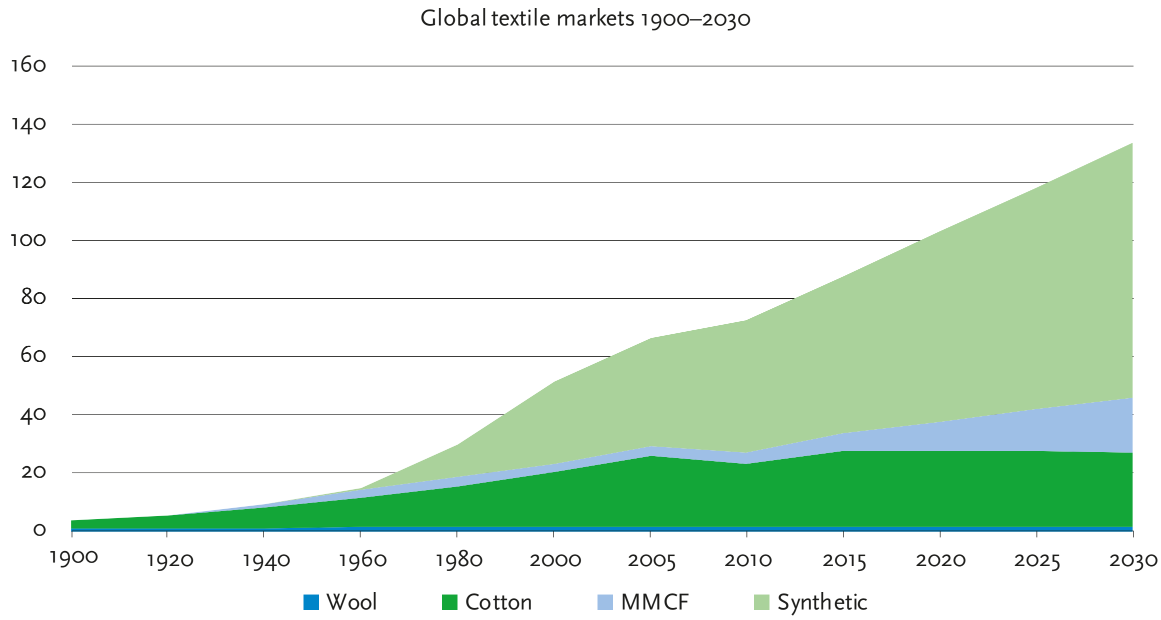


Figure 7. Evolution and outlook of global textile markets. *Source: Hämmerle (2011).*

global textile fibre markets, synthetic fibres (mainly polyester) accounted for 69%, cotton for 23%, and man-made cellulosic fibres (MMCF) for 7% in 2015 (CIRFS 2017). Due to population and income growth, global textile demand has been projected to grow to more than 130 million tons by 2030 (Hämmerle 2011), and to more than 250 million tons by 2050 (Alkhagen et al. 2015).

Despite the global growth prospects, *cotton* production is expected to stagnate due to the limited availability of arable land which is increasingly also needed for food production, and the large amount of irrigation that cotton production requires. According to WWF, it can take more than 20,000 litres of water to produce 1kg of cotton; equivalent to a single T-shirt and pair of jeans (WWF 1999; see also Antikainen et al. 2017). The irrigation of cotton is responsible for about 3% of global water use (Hämmerle 2011). On the other hand, there is a need to phase-out *oil-based synthetic textile fibres*. Moreover, cellulose fibres tend to be more user-friendly due to better moisture management (absorption) properties than synthetic fibres (Hämmerle 2011). These factors result in a high demand for MMCF (Figure 7). Given that the recent developments of new cellulosic fibres are successful, the growth rate of MMCF could be even higher than the Figure indicates (Alkhagen et al. 2015).

The demand for cellulosic fibres (e.g. wood-based) is likely to increase significantly in future decades. Indeed, there is already evidence of this. The raw material for MMCF is called *dissolving pulp*, and its global production has more than doubled during this century, from 2.9 Mt in 2000 to 6.3 Mt in 2016, and reaching 3.5% of overall wood pulp production volume (FAOSTAT). Around 75% of dissolving pulp is used for viscose production and subsequently in the textile industry, with the rest used in highly varying high end markets. With the dissolving pulp unit price being close to USD 1,000/ton, the market size is currently around USD 6 billion. From Europe, dissolving pulp is mainly exported to China and India, where most of the global textile production takes place. With growing global textile demand, an increasing number of paper pulp mills may be converted into producing dissolving pulp for the textile industry.

The MMCF market is dominated by viscose with a 96% share (Vehviläinen 2015). Viscose was created in the late 19^{th} century. Apart from some technical properties (e.g., becoming wrinkly), it has one major drawback, namely the use of a toxic chemical (carbon disulfide) in the production process. Recently, however, several alternative MMCF technologies have been developed to abate the downsides of contemporary viscose. All but one of the emerging technologies are based on using less hazardous solvents for dissolving pulp, typically also resulting in improved technical performance.

The conclusions of environmental impact assessments between viscose, cotton and polyester depend essentially on the emphases put on different criteria, which can vary a lot, particularly in the LCA studies produced by the businesses themselves (Viitala 2016). Shen et al. (2010) argue that all MMCFs (with some exceptions) have better environmental profiles than the main competing products. The water footprint of MMCF is 10–20 times less compared to cotton (Shen et al. 2010). However, the embodied energy of cotton is lower than that of contemporary MMCFs (Shen et al. 2010). The assumed form of energy production then influences how the products compare in terms of CO_2 emissions. In summary, MMCFs can have significant environmental benefits. In particular, new wood-based regenerative fibres (e.g., IONCELL-F Spinnova) may be able to overcome some of the disadvantages of contemporary viscose and thereby achieve even better environmental gains (Judl et al. 2016).

The growing and more affluent global population will increasingly demand clothing. The wood cellulosic-based textile fibres can provide a more sustainable source of raw materials for this purpose than synthetic or cotton-based textiles. However, there is still a need for R&D&I development in wood-based fibres to make them more environmentally friendly by removing the use of hazardous chemicals (Michud et al. 2016). Moreover, given that this will be a non-feed and non-food supply source, or even helping to increase the land that could be used for agriculture (by decreasing the need for cotton production), there is a case to advance wood-based cellulosic textile production. With the Spinnova technology, some news items argue that one could replace the whole global cotton production (25 million tons in 2014) with 60 million m^3 of wood. Others estimate that 10 million m^3 would be needed to replace 10% of the global cotton markets (Uusipuu 2017).

4.5 Plastics market[8]

Forest biomass is already today, and can be even more so in future, the raw material for a diverse range of chemicals and products. Here, we focus on just one category of applications, namely *plastics*. Plastics are typically organic polymers but can also contain other substances. The bulk of plastics in the market is synthetic, typically derived from petrochemicals, and is used in products such as packaging, PET bottles, trays, containers, and clothing (Figure 8). However, some are refined from non-synthetic renewable materials, such as hemicellulose and cellulose, which are the most abundant natural polymers. According to the World Economic Forum, plastics production has surged over the past 50 years, from 15 million tons in 1964 to 311 million tons in 2014, and it is expected to quadruple by 2050 to 1.1 billion tons (World Economic Forum 2016). Of all plastics, packaging is the most significant subsector, accounting for 26% of total plastics usage.

The production and use of petrochemical plastics is connected with major environmental sustainability challenges, CO_2 emissions, increasing non-degradable plastic waste in ecosystems (e.g., oceans), and waste problems. It has been estimated that 32% of plastic packaging escapes collection systems and generates significant economic costs by reducing the productivity of vital natural systems such as oceans and lakes (World Economic Forum 2016). In Europe, of all consumer plastics, 29.7% were recycled, 39.5% combusted, and 30.8% landfilled in 2014 (PlasticsEurope 2016). In a business-as-usual scenario, the ocean is expected to contain one ton of plastic for every ton of fish by 2025, and by 2050, more plastic than fish. According to the World Economic Forum, the cost of environmental externalities for plastic packaging, plus the cost associated with greenhouse gas emissions from its production, is at least USD 40 billion annually.

The *triple-environmental-problem with plastics* (disturbing ecosystems, creating landfill, causing CO_2 emissions) makes it a key material to which alternatives need to be found soon. The immediate action should be a major increase in the recycling and reuse of plastics. However, there is also a need to gradually replace plastics with environmentally less harmful materials. One promising solution is to use *forest-based bioplastics*.

The design of a circular bioeconomy requires rethinking all aspects of the plastics supply chain in terms of full life cycle (Prieto 2016). In this context, it is important to acknowledge that bioplastics are not necessarily biodegradable, but can be.

8 This sub-chapter is heavily based on Hurmekoski et al. (2017). Markets for new wood-based products, unpublished manuscript. Diversification of the forest sector: Role of new wood-based products, European Forest Institute.

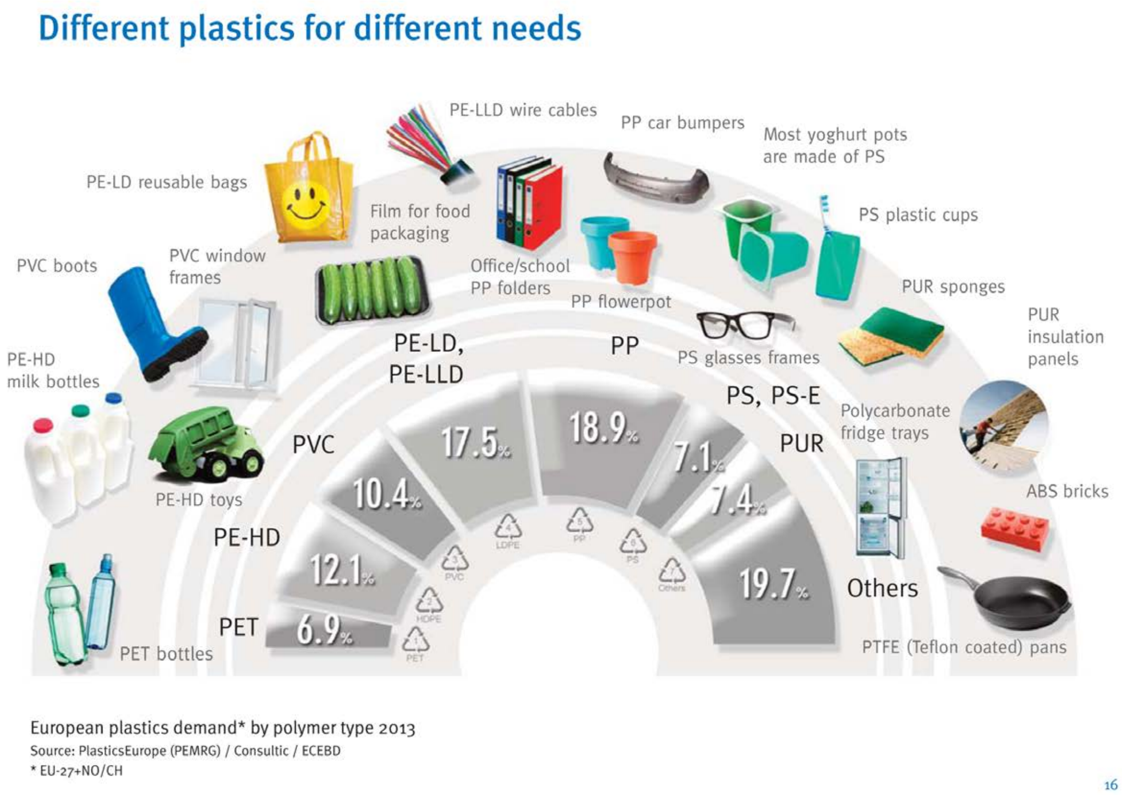


Figure 8. European plastics demand by polymer type. *Source: PlasticsEurope (PEMRG) / Consultic / ECEBD*

Bioplastics can be broadly broken down into two categories: durable and biodegradable. For example, the Coca-Cola PET PlantBottle is a durable bioplastic alternative to traditional petrochemical-based PET bottles. Made with up to 30% ethanol sourced from plant material, the PlantBottle won't decompose, but it can be recycled, like PET bottles. Biodegradable bioplastics, like PLA (polylactic acid), break down naturally in the environment or may be composted, unlike the vast majority of plastics today. Petrochemical plastics may degrade into smaller and smaller pieces, but most will not decompose or be absorbed by the surrounding environment. However, in most cases, biodegradable bioplastics (like PLS) will only break down in a high-temperature industrial composting facility, not in the average household compost bin. More in line with circular bioeconomy would be to place the focus on durable bioplastics that are made from forest biomass (or plant materials) and can be recycled for reuse. By this, valuable energy and material inputs can be kept in the production cycle for longer. It could also be more cost-efficient to build a biobased plastic that fits into existing infrastructure, rather than building an entirely new biodegradable plastic composting infrastructure from scratch. Yet, it is possible that both options may in the end be necessary to address the environmental sustainability issues of plastics.

Clearly, biobased plastics can support the movement to sustainable circular bioeconomy. However, given that bioplastic per se is not necessarily environmentally sustainable, but can be, policies and regulations will play an important role in directing it to the optimal path. For example, recycling and reuse will be crucial for both petrochecmical and biobased plastics, and this will not take place to a sufficient degree without regulations. Policies are also important to direct the diverse bioplastic sector to the most optimal development path in terms of economic and environmental sustainability.

What are the economic competitiveness and market potential of bioplastics? It appears that the easiest market entrance will be for the so-called *'drop-in'* biobased chemicals such as polyethylene terephtalate (PET), ethylene, propylene (PE) and xylene, chemically identical to their petrochemical counterparts but with a component of biological origin. They are followed by new polymers such as PHA and PLA with a significant market growth rate since 2014 with projections to 2020 (Prieto 2016). These chemicals have properties that directly fit to existing applications, and their demand can be determined mainly based on price and environmental footprint. The drop-in biobased chemicals sector is very likely to be on the brink of a strong expansion (De Jong et al. 2012). Market analysis shows potential growth per annum in the range of 10-30%. European plastics demand in 2013 was 46 Mt, turnover was EUR 320 billion and over 1.45 million people were employed (plastic manufacturers 134,000, and the rest in plastics conversion) (PlasticsEurope 2016).

The durability of plastics was originally viewed as a virtue; however, this durability has created environmental problems. Durability is also an issue for biobased drop-in plastics, which may impede the up-cycling of these materials in terms of circular economy and sustainability. In this context, waste management of biobased plastic is one of the most important issues in the near future in terms of the circular economy (Prieto 2016). Combined biodegradation and bioprospecting strategies have emerged to address this issue. In line with these developments, waste management of biobased plastics needs to be standardized and regulated by policymakers (Prieto 2016).

4.6 The role of services

The EU bioeconomy strategy identifies the following issues as major opportunities or challenges:

- ensuring food security;
- managing natural resources sustainably;
- reducing dependence on non-renewable resources;
- mitigating and adapting to climate change;
- creating jobs and maintaining European competitiveness (Wolfslehner et al. 2017).

As a result, the strategy mainly addresses issues such as new biobased products, bioenergy, and raw material use. This implies that only a very limited part of the biomass-based natural resource sector is analysed. There are number of *different types of services that natural resources, and especially forests and the forest sector can provide*.

The forest-based literature has distinguished three types of services categories: 1) *forest-related*, 2) *forestry-related*, and 3) *industry-related* services (Näyhä et al. 2015). *Forest-related services* are services that are directly related to forests as such, for example, nature tourism and recreation, hunting, mushroom and berry picking, soil and water services, and carbon sequestration in forests. *Forestry-related services* can include advisory services, forest management planning, forest inventory, administration, governance, R&D and education. *Industry-related services* are services that are linked to the manufacturing of forest-based products, such as product innovation, R&D and actual production processes, headquarters functions, as well as logistics and marketing of the products themselves. In this context, industry refers to all industrial activities engaged in the production of forest-based products; so, in addition to the forest industry, for example, the machinery and engineering industry, energy industry, chemical industry and food industry.

Major reasons for the lack of attention towards services in the bioeconomy strategies is probably the weak understanding of the economic, employment and natural capital regulatory functions that forest-based services can provide. They are not as concrete and apparent as traditional marketed forest products (e.g., pulp and paper, sawnwood, plywood) or the emerging products (see the case examples above). One reason for this is the lack of data, and difficulties in quantifying their role, and the still weak understanding of the role of natural capital supporting the bioeconomy.

The forest industry (manufacturing) and forestry (primary production) include several services activities that are not directly perceivable and measured in official statistics. Measurement problems are evident for forest-related services as well. In the manufacturing industry, services functions are often embedded in production processes, and official statistics do not reveal the value-added and employment generation of different services (tasks) within a product value chain.

Market goods and services from forests include, e.g., timber, wood fuel, berries and mushrooms; non-market goods and services include, e.g., water protection, soil protection, health protection, biodiversity protection, climate regulation, tourism, recreation, sports activities, spiritual services, cultural services and historical services (Wolfslehner et al. 2017).

Figure 9. Examples of forest ecosystem services. *Photo: Eeva Oinonen.*

The review by Näyhä et al. (2015) points out that there is a need to develop *knowledge, databases* and *metrics* of services and tasks to better assess the role of services in the natural resources sectors. For example, it would be important to identify and hopefully quantify the importance of specific services tasks in product value chains or ecosystem services. The *ambiguity of the services concept and phenomenon* has made it challenging to attract attention to services and their future potentials in the forest-based sector. Largely due to a lack of data and information, there are also *no outlook studies on services* in the forest-based sector. However, given their increasing importance in terms of economic value-added and employment generation, it would be important to be able to assess their future development and link them also to forest products and forestry outlook studies, such as those produced regularly by UNECE-FAO (e.g. UNECE/FAO 2011). Also lacking is an analysis of implications for policies and strategies for services development at the global, national or company level. Studies and 'narratives' can help make these services more visible, and help the policy makers to recognize them, even if they never fully show up on the market.

In summary, forest-based services should be better understood as an integral part of the circular bioeconomy. There is a need to update bioeconomy strategies, business models and policies in order to benefit from the value-added and employment potentials that services can generate in the future. Qualitative systematic foresight approaches are particularly needed, since there is very little data on forest-based sector services, a factor which limits or makes impossible the use of quantitative statistical or modelling approaches (Näyhä et al. 2015). In addition, there is a need to develop data and indicators to be better able to quantify and monitor the role of services, and therefore also help with investment planning.

Key messages

- In bioeconomy strategies, the forest-based sector is often left in the shadow of the agriculture sector. One reason for this is probably that the forest sector is seen as relevant only for the sector itself, and its larger cross-sectoral relevance and societal potential is still poorly understood.
- Today, forest-based products are used in major and growing sectors, such as construction,

plastics, and textiles. These sectors are currently dominated by environmentally problematic raw materials, and wood-based products often provide a more sustainable alternative.

- Modern wood construction (EWP) provides new innovative solutions in areas not seen before, such as high-rise buildings. Compared to e.g. concrete, the advantages of wood construction are: lower resource use, better CO_2 mitigation balance, faster and better controlled prefabricated building processes, and easier recyclability and cascading.
- Wood cellulosic-based textile fibres can provide a more sustainable source of raw materials for textiles than synthetic or cotton-based textiles.
- The *triple-environmental-problem with plastics* (disturbing ecosystems, creating landfill, causing CO_2 emissions) makes it a key material to which alternatives need to be found soon. Wood-based fibres have gained increasing interest; we are only at the start of this growing trend.
- In existing bioeconomy strategies, the potential of services is poorly addressed. Forest-based services offer diverse and growing economic and employment potential. Services should be put on an equal level with products in new circular bioeconomy strategies.

5. Conclusions and policy implications

The globally agreed 2030 Agenda for Sustainable Development and its Sustainable Development Goals and Paris Climate Agreement (in 2015) set the goals and framework to which European countries have committed. These goals imply more specific sub-goals, such as targets for CO_2 reductions, adaptation to climate change, minimising the use of fossil resources, developing urban and rural areas, creating new market and job opportunities, and developing a more sustainable economy across all possible dimensions. The EU and European countries have set beacons that let them to navigate to the harbour mapped by these global agreements. We argue that the circular bioeconomy will be a key strategy and tool to help to achieve the objectives.

It is in this general context that we set our conclusions and recommendations a for European circular bioeconomy strategy:

Analyse the gaps

At a more concrete level, there is a need to reflect on the EU Bioeconomy Strategy, which was published in 2012, and the related Action Plan and practical measures linked to it. Many European countries also have specific national or regional bioeconomy strategies. They show large heterogeneity in terms of when they were launched, which type of policies and actions they were supported by, and what their specific objectives were. Clearly, these strategies and actions have had a positive impact in recent years. The general knowledge about bioeconomy, its potential, and its advancement in Europe have progressed with the help of these strategies.

But the operating environment and knowledge has moved on. The SDGs and Paris Agreement impose new needs, while science knowledge and practical experience related to bioeconomy has also advanced. We need to analyse what the necessary ingredients of bioeconomy strategies could be under these changed circumstances, and the gaps in the current operating strategies. Within the scope of this report, we have only been able to address and draw attention to a limited number of key issues, mainly at a strategic level. Other studies and work is necessary to supplement and support in more detail (see e.g. Winkel 2017).

Address sustainability

Circular bioeconomy strategies should not take sustainability as a given, but address it explicitly. There have already been concerns about possible negative side-effects of the bioeconomy. Some researchers and NGOs have questioned its environmental sustainability, and have voiced concerns that it could lead to the exploitation of EU forests at the cost of biodiversity or that bioenergy may in the short-term cause more CO_2 emissions (EASAC 2017; Fern et al. 2017; Open Letter 2017). These views are understandable and important to consider, especially given sustainability problems experienced in the past.

Science also has mixed views on these issues, and the impacts also depend very much on how bioeconomy development will be advanced and monitored (Nabuurs et al. 2015; Berndes et al. 2016; Wolfslehner et al. 2016; Palahí 2017). The objective should be to maximize the synergies and minimize the trade-offs between bioeconomy, biodiversity and climate mitigation. *A circular bioeconomy can help to support biodiversity and climate mitigation, and biodiversity and climate mitigation are necessary for a successful circular bioeconomy.*

Ensure sustainable growth

There can be synergies between economic growth and improvement in the state of natural capital. As Helm (2015) argues "De-growth or zero growth has two major defects: it is not necessarily desirable; and it is never going to happen." Consequently, the *pace* of growth is not the problem, but rather the *quality* of growth. It requires the advancement of truly sustainable economic growth, and not the type of unsustainable growth often seen in the past. One essential requirement is that renewable resources are not used to the extent that they can no longer reproduce themselves, i.e. they become non-renewable. There are of course many other requirements for environmentally sustainable growth, and a circular bioeconomy strategy should address the policies needed to advance them.

Integrate natural capital accounting

There is also a fundamental need to understand and value the role that nature and ecosystems play in a circular bioeconomy. The key approach here is to advance *natural capital accounting* and integrate it into a circular bioeconomy. Natural capital is a necessary production input along with the traditional ones, i.e. capital, labour and technological development. Accounting for it will not be easy: how can you integrate the many dimensions of biodiversity into one common and measurable indicator, like CO_2, on which a value (price) could be placed? However, it would be helpful to have the value of natural capital in the economic accounting system and statistics (Helm 2015; Sukhdev et al. 2010; TEEB 2017). If this can be done satisfactorily, most likely environmental sustainability issues would be more easily addressed by markets and policies. Methods, like 'natural capital asset checks', can already help decision makers to understand how changes in the current and future performance of natural capital assets will impact on human wellbeing and the circular bioeconomy (UK Natural Capital Asset Tool). The circular bioeconomy strategy, or its action plan, could incorporate these.

Advocate for high enough carbon pricing

There are already, at least partial, success stories of bioeconomy-related policies. For example, the EU climate policy (Delbeke & Vis, 2015). Although there is still much to do, the evidence shows that much has already been achieved, for example, breaking the link in the EU between GDP growth and CO_2 emissions. Yet, *a proper price for CO_2 emissions would be a significant boost for a circular bioeconomy*. The emission allowance price for CO_2 in the EU (ETS) was under EUR 6/ton in August 2017. This was less than the price of a hamburger at McDonald's in Brussels (EUR 8). Clearly, the CO_2 price needs to go up significantly to start to have major impact on producer and consumer behaviour. From economics and past history, there is plenty of evidence how prices (taxes) can create an enormous change in consumers and producer behaviour.

Linked to this is the need to *stop subsidising fossil fuel production*. Recently, IMF economists estimated the true costs of fossil fuel subsidies (Coady et al. 2017), understood to include not only the direct subsidy costs, but also the indirect environmental costs like global warming and deaths from air pollution, amounts to 6.5% of global GDP in 2013. The top four subsidizers of fossil fuels are China, the US, Russia, and the EU (USD 295 billion). The key point is that policy makers and the public need to be aware of the true costs of fossil fuel subsidies that arise from pricing fossil fuels below their true social costs.

The SDGs and Paris Agreement indicate that world states have put the environment as a priority target. What is now needed is that they also do this at a policy level. *Imposing policies resulting in a high enough CO_2 price, and removing fossil fuel subsidies would be one important move towards achieving SDG and Paris Agreement goals. Therefore, advocating these measures should also be a key part of a circular bioeconomy strategy.*

Increase R&D&I investment

Research, development and innovation (R&D&I) needs to increase to strengthen the foundations of a circular bioeconomy. Funding needs to increase all along the innovation network, for example, basic research, applied research, education (a better suited curriculum for circular bioeconomy studies), and for piloting new products and services. In addition, there need to be platforms bridging science knowledge to policy making and actions. Often the bottleneck is not the lack of research, but a lack of synthesis knowledge, and framing the information in a format that it is connected to policy making and in a form that policy makers can absorb. In a research context, funding is not required only for biotechnology, engineering and chemistry sciences, but increasingly also for social and environmental sciences, and social sustainability and foresight research.

Focus on markets and services

In terms of biobased product markets development, the focus of bioeconomy strategies has been very much towards supporting the development of new products. The forest-based sector vision and strategy literature has been fascinated by the fact that from forest biomass one can in principle produce all those products that we are today producing from fossil-based raw materials. However, now that there are an increasing number of products entering the markets, or close to entering, the focus needs to be supplemented. "*The critical question does not appear to be what can be made of forest biomass, but rather what will be made, on what scale, where, and driven by what?*" (Hetemäki & Hurmekoski 2016). But in addition to products, the role of services should be better understood and advanced, as well as strengthening the resilience of forests and societies. They will be an integral part of a successful circular bioeconomy.

Prioritise targets

A good strategy has a realistic diagnostic of a problem the strategy wants to solve, and an objective it wants to achieve. The key problem is the unsustainability of our current way of living, and the objective is to help to achieve the UN SDGs and Paris Agreement targets. Second, a strategy needs to focus on the most important issues and find tools to advance them. It should not provide an endless list of suggestions to achieve world-class innovations, enabling technologies, smart environmental solutions, resource-efficiency, etc.; or a long list of new initiatives, platforms, funds and institutional reforms. Few could disagree with any of these, but that can precisely be the problem: *it is a commitment to everything and everybody, not a strategy*. Set a limited number of priority targets, and tools to achieve them. To deploy the strategy, you also need an action plan. This and other supporting documents can go in to more details. If the government is behind the circular bioeconomy strategy, the key minsters, including the prime minister, will have to commit to it in order to gain priority. A system to monitor the progress made towards meeting strategy targets and to secure the sustainability of development is also necessary.

Mainstream circular bioeconomy policies

It is evident that a circular bioeconomy, and therefore the strategy for it, has links to many policies in different areas. For example, to all natural resource-related policies, digital information policies, innovation policies, R&D policies, growth policies, etc. It is not fruitful to start to list all these in more detail, rather the key point is that circular bioeconomy needs to be mainstreamed and coordinated with all policies, one way or another. This involves innovating at a systems level, not just improving the performance of the components of that system or a sector.

Create a narrative

Bioeconomy needs to be seen as a key strategy for urban areas, not only for rural areas, as traditionally has tended to be the case. This is also related to the societal acceptance and inclusiveness of the bioeconomy. The circular bioeconomy will not succeed if an urban population does not see the relevance of it. To support societal engagement, a fact-based *circular bioeconomy narrative* and its efficient communication is needed.

The importance of the circular bioeconomy (and the strategy for it) and its urgency can also be viewed through a hypothetical question that is hopefully unrealistic. The question is: do we need a very hard and brutal shock, like climate change catastrophes and significant loss of natural capital, before we act - or do we act now? If we want to act now, a necessary, although not sufficient, tool for action is advancing the circular bioeconomy. The art and responsibility of politicians is to sell this to voters in a way that assures re-election, and thereby secures the continuation of this path in the long-run. For this, a fact-based circular bioeconomy narrative that has societal appeal and longevity needs to be formulated. *"No policy - no matter how ingenious - has any chance of success if it is born in the minds of a few and carried in the hearts of none".*[9]

Key messages

- A circular bioeconomy strategy will be a key tool to help to achieve the Agenda 2030 SDGs and Paris Climate Agreement.
- A circular bioeconomy can help to support biodiversity and climate mitigation; biodiversity and climate mitigation are necessary for a successful circular bioeconomy.
- A much higher price for CO_2 emissions is needed than the current level to advance the circular bioeconomy. Linked to this, there is an immediate need to stop subsidising fossil fuel production. The true costs of fossil fuel subsidies,

9 A quote from Henry Kissinger, former US Secretary of State and political scientist. In the original quote Kissinger referred explicitly to *foreign* policy, here we use it to apply to *all* policies.

understood to include both the direct subsidy costs and the indirect environmental costs, was almost USD 300 billion in the EU in 2013 (Coady et al. 2017).

- Investments in research, development and innovation need to increase in order to strengthen the foundations of a circular bioeconomy.
- In addition to enhancing the development of bioproducts, the role of services should be better understood and advanced. Services will be an integral and increasingly important part of a successful circular bioeconomy.
- Bioeconomy needs to also be seen as a key strategy for urban areas, not only for rural areas, as traditionally has tended to be the case. The circular bioeconomy will not succeed if the urban population does not see the relevance of bioeconomy. To support societal engagement, an evidence-based *circular bioeconomy narrative* and its efficient communication is needed.

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We are living in a time of accelerated changes and unprecedented global challenges: energy security, natural resource scarcity, biodiversity loss, fossil-resource dependence and climate change. Yet the challenges also demand new solutions and offer new opportunities. The cross-cutting nature of forests and the forest-based sector provides a strong basis to address these interconnected societal challenges, while supporting the development of a European circular bioeconomy.

The European Forest Institute is an unbiased, science-based international organisation that provides the best forest science knowledge and information for better informed policy making. EFI provides support for decision-takers, policy makers and institutions, bringing together cross-boundary scientific knowledge and expertise to strengthen science-policy dialogue.

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