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# Renewable materials in the Circular Economy

**Commissioned by** Essity, Tetra Pak, IKEA and Royal DSM

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# Summary and key messages

The most widely used definition of the Circular Economy (CE), that of the Ellen MacArthur Foundation, distinguishes between technical and biological cycles. However, when addressing renewable (bio-based) materials it places a strong emphasis on their biodegradability. In doing so it tends to overlook the contribution that renewable feedstock and reuse and recycling of renewable materials can have on improving circularity and environmental performance.

This report therefore aims to highlight the role and benefits of responsibly sourced renewable materials in products of the CE's technical cycle. Renewable material and resources used in the technical cycle link the concepts of bioeconomy and CE. It is argued that given the importance of both concepts in the transition to a sustainable society, it is crucial that neither strategy ends up in the shadow of the other. The contribution of renewable materials to the United Nations Sustainable Development Goals is also discussed with focus on goals 8, 12, 13 and 15.

The report emphasises that the ongoing benefits and contribution of renewable materials to the technical cycle of the CE concept requires increased recognition for the following reasons:

- Reuse and recycling of renewable materials within the technical cycle is environmentally beneficial.
    - Collection and recycling of a renewable material normally requires less energy than production of comparable renewable material from virgin feedstock, with typical reductions of 0.5 kg $CO_2e$ per kg of product (paper, board). The greenhouse gas (GHG) emissions leading to climate impact are largely linked to energy use in the product life cycle.
    - For many renewable materials, it is more sustainable to re-use or recycle them, instead of letting them biodegrade in the biological cycle or to incinerate them.
    - When recycled to new products, renewable products will partly replace virgin renewable products (thus saving energy and related GHG emissions), partly other recycled renewable products (with similar GHG emissions), and partly fossil-based products (which will save GHG emissions). Increased recycling of renewable products will therefore in the long run lead to less fossil carbon dioxide in the atmosphere.
- There are inherent environmental benefits of renewable based products compared to fossil-based ones.
    - During growth, renewable resources absorb carbon dioxide. Whilst these resources are kept in the technical system, they act as carbon storage. When they are ultimately managed as waste, e.g. incinerated or composted, they will not contribute to net emissions of carbon dioxide into the atmosphere, as opposed to fossil-based products.
    - Use of renewables instead of fossil feedstock means less depletion of resources.
    - When renewable products are taken out of the (technical) cycle, natural degradation processes (e.g. through composting or biogas recovery) release the nutrients enabling materials to be incorporated into new products. This is typically a low or net positive energy (e.g. where biogas is recovered) process.
- Renewable/bio-based materials are already used, reused and recycled in the technical cycle.
    - They have a fundamental role in the economy and constitute a significant share in many segments of the technical cycle, having a large market value for many

sectors such as packaging, textiles, chemical and construction markets. There are also growing markets for renewables in sectors such as composite materials and manufacturing industries.
    - There is a wide variety of evidence showing the importance of renewables, the environmental benefits of using them as feedstock and reusing or recycling them, with at least 11% of the currently used renewable materials being recycled in the EU (based on Eurostat figures). For paper and board, over 70% is recycled.
- The potential of technological and societal innovations for new applications of renewables and increased cyclic use of renewables can be further emphasized.

The primary message is that the field of CE should recognise more fully, in its approach and communication, that sustainability can be increased through the utilisation of renewables in the technical cycle. A major contribution is the reduction of climate change impacts, whilst other environmental impacts may require closer scrutiny depending on individual product circumstances.

Finally, the bioeconomy and the CE are mutually supportive concepts, but this needs to be communicated more effectively to policy makers and a wider public, in order to facilitate the transition to a sustainable society.

# Sammanfattning och huvudbudskap

Två olika begrepp står idag högt på hållbarhetsagendan: Bioekonomi och Cirkulär Ekonomi (CE). I den mest utbredda och välkända modellen av CE, den som etablerats av Ellen McArthur Foundation, har två olika typer av kretslopp definierats, ett tekniskt och ett biologiskt. Bio-baserade, förnybara, material har i denna modell kommit att förknippas med biologisk nedbrytbarhet, vilket riskerar leda till att biobaserade materials roll i det tekniska kretsloppet inte får den uppmärksamhet de förtjänar, till exempel i fråga om deras bidrag till tekniska systems cirkularitet och miljöprestanda.

Syftet med den här rapporten är därför att lyfta fram på vilka sätt och i vilken omfattning ansvarsfullt framtagna biobaserade material spelar en roll och positivt bidrar till CE-s tekniska kretslopp. Förnybara material och resurser i tekniska kretslopp sammanfogar de två koncepten bioekonomi och cirkulär ekonomi. Eftersom båda koncepten *områdena* är viktiga i omställningen till ett hållbart samhälle är det angeläget att de båda kan verka i samklang. Förnybara materials bidrag till FNs hållbarhetsmål diskuteras också i rapporten och specifikt till målen 8, 12, 13 och 15.

De fördelarna med förnybara material som framhålls i rapporten är:

- Återanvändning och återvinning av förnybara material inom det tekniska kretsloppet är resurseffektivt och ger miljöfördelar
    - Insamling och återvinning av förnybara material innebär normalt sett mindre energiåtgång än produktion från nyråvara. och typiskt motsvarar det en minskning av klimatgasutsläpp om 0.5 kg CO2-ekvivalenter per kg produkt (papper, kartong), utifrån att energiåtgång är starkt kopplat till utsläpp av växthusgaser.

  - För flertalet förnybara material är det miljömässigt fördelaktigt att återanvända eller återvinna dem till nytt material istället för att låta dem brytas ner i biologiska processer eller att förbränna dem.
  - När produkter av förnybara material återvinns till nya produkter kommer dessa delvis att ersätta produkter gjorda av förnybar nyråvara (vilket sparar energi och relaterade växthusgasutsläpp), delvis andra produkter av återvunnen råvara (med likartade utsläpp), och delvis fossil-baserade produkter (vilket medför att utsläpp sparas). På sikt kommer därför återvinning av förnybara produkter att minska utsläppen av växthusgaser till atmosfären.
- Produkter gjorda av förnybar råvara har inneboende miljöfördelar jämfört med fossilbaserade produkter
  - Återväxande råvara tar upp koldioxid under sin växtperiod. Under tiden som produkter från sådan råvara stannar i det tekniska kretsloppet verkar de som kolinlagring. När dessa produkter slutligen hanteras som avfall, till exempel förbränns eller komposteras, bidrar de inte med netto-emissioner av koldioxid till atmosfären, i motsats till vad som är fallet för fossilbaserade produkter.
  - Inom ramen för förnybara råvarors återväxttakt innebär användningen ej en utarmning av resurser.
  - När produkter av förnybar råvara lämnar det tekniska kretsloppet, kan biologiska nedbrytningsprocesser, till exempel via kompostering eller anaerob nedbrytning, frigöra näringsämnen som är bundna i materialet, vilket gör det möjligt för dessa att bidra till nästa växtcykel.
- Produkter av förnybar råvara används redan i stor utsträckning i det tekniska kretsloppet
  - träprodukter, pappersprodukter och förpackningar, naturfibertextilier, med flera produkter, har en viktig roll i den globala ekonomin och utgör en avsevärd andel av det tekniska kretsloppet i flera sektorer. Inom vissa områden är produkter baserade på förnybar råvara på stark frammarsch, till exempel kompositmaterial och i tillverkande industri
  - Det finns ett rikt underlag som pekar på förnybara materials viktiga roll i det tekniska kretsloppet i ekonomin liksom deras miljöfördelar. Totalt återvinns 11 % av den totala användningen av förnybara material inom EU. För papper och karting uppgår siffran till mer än 70 %.
- Potentialen för innovationer i näringsliv och samhälle baserat på nya tillämpningsområden för förnybar råvara kan också framhållas

Sammanfattningsvis kan man konstatera att CE-konceptet i större grad än hittills bör inkludera det faktum att förnybara material används i det tekniska kretsloppet och på många sätt bidrar positivt till mer hållbar utveckling. Tydligast är de förnybara materialens bidrag till att minska utsläpp av fossila växthusgaser, medan det för andra miljöaspekter kan vara mer eller mindre fördelaktigt beroende på fallspecifika förutsättningar.

Bioekonomi och Cirkulär ekonomi bör tydligare framhållas som ömsesidigt till nytta för varandra i vår strävan mot hållbar utveckling.

# 1 Introduction

The concept of a circular economy has been used since the 1970s but it was with the publication of Ellen McArthur Foundation's version of the Circular Economy (CE) (Ellen MacArthur Foundation 2013a) that the concept gained momentum. However, there is no agreed and standard definition of CE (CIRAIG, 2015; Rizos, Tukkos and Behrens, 2017). This publication uses the Ellen McArthur Foundation (EMF) definition for the discussion (see Figure 1): "*A circular economy is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times. The concept distinguishes between technical and biological cycles. As envisioned by the originators, a circular economy is a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields, and minimises system risks by managing finite stocks and renewable flows. It works effectively at every scale.*".

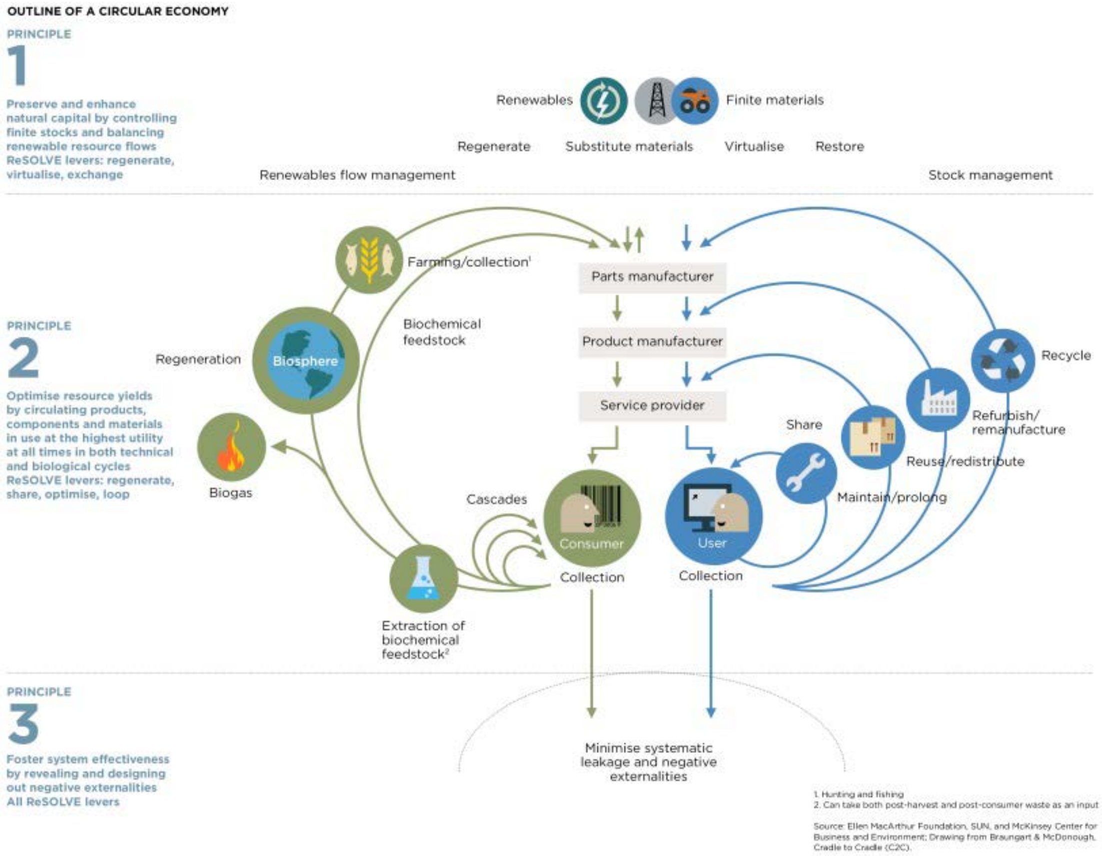


**Figure 1: Outline of a Circular Economy, as defined by Ellen MacArthur Foundation (From https://www.ellenmacarthurfoundation.org)**

This paper aims to highlight the risk of the current focus of the CE field to focus merely on the biodegradability of renewable (bio-based) materials[1]. In doing so it tends to overlook the contribution that renewable feedstock, as well as reuse and recycling of renewables, can have in improving circularity and environmental performance. Given the influence that the CE concept

[1] In this report the use of the term renewables is in line with that provided by ISO 14021: "Material that is composed of biomass from a living source, that can be tree or crops, and that can be continually replenished."

currently has, there is a clear risk that the benefits of using and recovering the value of renewable materials at the end of use, will not be recognised and therefore potential benefits not fully attained.

China and Japan were among the first nations to actively start working towards a CE through regulations: Japan put its "Law for the Promotion of Effective Utilization of Resources" into force in April 2001[2][3] and in 2008, China passed a law on closed-loop economy (Geng and Doberstein, 2008; Mathews and Tan, 2011). Also in the EU and its member states, political strategy documents have been published, setting out strategies for implementing CE (EU, 2015, EU, 2017; SITRA, 2016).

In a CE, materials are kept in circulation for a longer time than in a linear economy thus aiming to minimise the use of virgin material and generation of waste. However, what is not sufficiently addressed in most descriptions of the CE is the role of renewable raw materials. It describes renewable resources mainly in their role as energy carrier, "food" and a few short rotation products and chemicals that stay in circulation a short time before they are brought back to the soil and eventually into new, renewable, raw material (Ellen MacArthur Foundation, 2015). The EMF acknowledges the fact that renewable raw materials are important but focus on the fact that they can be circulated back within the biological cycles (*ibid*). In a related document the RESOLVE framework (EMF 2015) has one of the few renewable examples (Rengerate) as "return recovered biological resources to the biosphere". This tends to further embed the risk of downplaying the role of renewables. It should however be mentioned that the same framework mentions extracting valuable bio-chemicals from waste streams and raises the question of whether Europe should develop a more bio-based economy. There is also a focus (at least in the prevailing visualisation of Figure 1) on cascading and biodegradability whilst not recognising the potential for reuse, refurbishment, remanufacturing or recycling.

This appears primarily due to the fact that EMF drew on the work of the Cradle to Cradle concept: "*A key insight in circular economy thinking is the division between biological and technical materials. Biological 'nutrients' (cf. Braungart & McDonough) are designed to re-enter the biosphere safely for decomposition to become valuable feedstock for a new cycle— i.e., 'waste equals food'. These products are designed by intention to literally be consumed or metabolised by the economy and regenerate new resource value. Technical 'nutrients' are materials that either do not degrade easily or cause contamination within the biological nutrient flow. These durable materials and products are designed by intention to retain embedded quality and energy.*" (EMF 2013)

However, there is a wide variety of evidence showing the importance of renewables, the environmental benefits of using them as feedstock and also reusing and recycling them. Given the influence that the CE concept currently has, there is a clear risk that the benefits of using and recovering the value of renewable materials at the end of use, will not be recognised and therefore potential benefits not fully attained. For instance, Figure 2 shows the fundamental role of renewable materials in the economy, but also how much is recycled and composted. At least 11% of the currently used, reused, composted or recycled materials are renewable (the quantities of renewables in plastic and other is not known). This is astonishing given the physical mass of metals and minerals. Importantly, there is massive potential for increased reuse and recovery of both renewable and non-renewable materials.

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[2] https://www.env.go.jp/en/laws/recycle/06.pdf
[3] http://www.env.go.jp/en/focus/docs/files/20120301-28.pdf

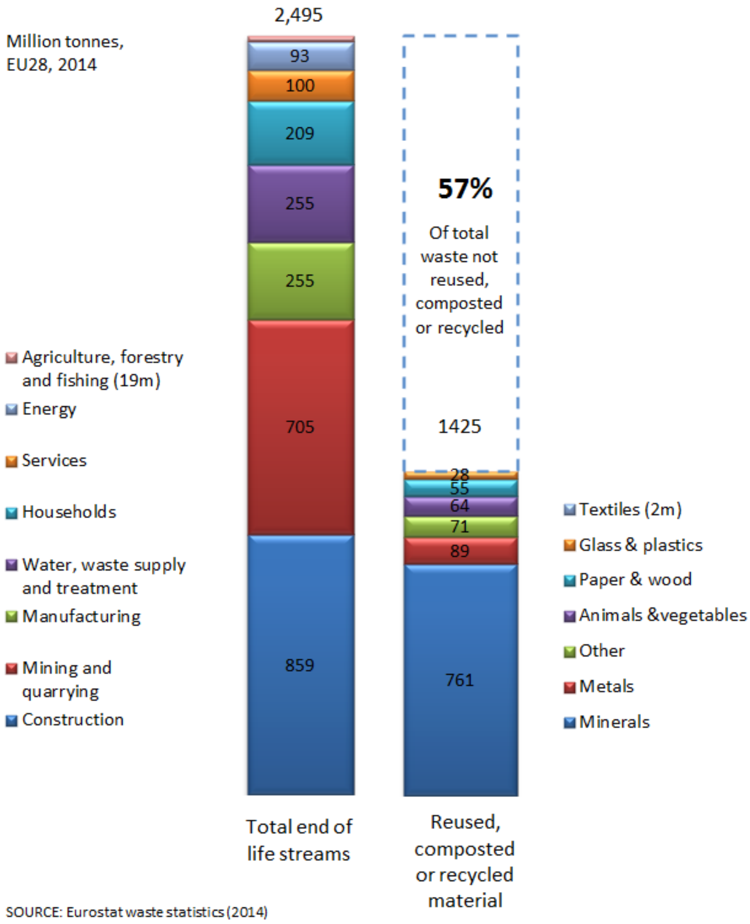


**Figure 2: Quantities of materials that are recycled, composted, reused or wasted in EU28**

# 2 Contribution of renewables to a sustainable society

## 2.1 Use of renewables contribute to several SDGs

In 2015, the UN passed a resolution that contained (in paragraph 54) a set of 17 Sustainable Development Goals, officially known as Transforming our world: the 2030 Agenda for Sustainable Development (UN, 2015). The use of renewables specifically contributes to the following goals:

- Goal 12, Ensure sustainable consumption and production patterns
- Goal 13, Take urgent action to combat climate change and its impacts
- Goal 8, Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

- Goal 15, Protect, restore and promote sustainable use of terrestrial ecosystem, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 15 is the basis for promoting renewables, as sustainably produced biomass from e.g. agriculture and forestry has the potential to halt and reverse land degradation such as deforestation (replanting is a fundamental part of modern and sustainable forest management) and desertification. It also promotes sustainable use of terrestrial ecosystems. The discussion in this report takes this aspect of sustainable production of renewables as a fundamental starting point.

In recent years, increased attention has been given to sustainable production and consumption patterns, as explained in goal 12. The use of responsibly sourced renewables contributes to goal 12 both as fresh input and when recycled. This is highlighted in the sub-goals related to the use of natural resources, environmentally sound management of chemicals and all waste throughout their life cycle as well as waste generation through prevention, reduction, recycling and reuse. The use of Life Cycle Thinking is valuable in assessing a product's or material's performance in relation to this goal. The sourcing of renewables is surrounded by many different standards aiming at ensuring a high degree of traceability and sustainability of the raw material and its production system regarding factors such as protection of sensitive areas and species, ensuring re-growth, etc. Examples are the standards of the Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), Rainforest Alliance, Organic/Bio and Sustainable Biomass Partnership (SBP). Adding to the benefit of renewables is that when they eventually reach the point where they cannot be kept in circularity, they can either be biodegraded or used for energy production that does not contribute to increased amount of circulating carbon.

Use of renewables contributes to goal 13, combat climate change, provided that they are responsibly grown and sourced i.e. all carbon pools (above ground, below ground soil and dead organic matters) are kept stable or are increasing and used in a resource efficient way and that the energy used in the processing system is renewable. This mitigation effect is a consequence of the biogenic origin of the carbon, which will not add carbon to the atmosphere when it is released back to the atmosphere at the end of its life cycle. Use of renewables in the technical cycles also contributes to goal 8: For example, according to Nova Institute, the "technical sector" of the renewable economy in EU represented 3.2 million jobs in 2013 (Piotrowski, 2016). The use of renewables in products in the technical cycle also contributes to sub-goal 8.2 as this has stimulated technical diversification and innovation and new business sectors have been created. Sub-goal 8.4 relates to decouple economic growth from environmental degradation. EMF acknowledges in their report "The New Plastics Economy" (Ellen MacArthur Foundation, 2013b) that renewables indeed contribute significantly to this decoupling.

## 2.2 CE in relation to bioeconomy and sustainability

This section reviews the link between the CE and the bioeconomy concepts, and sustainability.

### 2.2.1 CE link to sustainability

There is a general perception that the CE field is aimed at sustainability, although circularity per se does not guarantee sustainability, and the concept is not without its critics. A number of research groups (e.g. Linder, et al, 2017; de Man and Friege, 2016) also point out that the current definition and visualization of CE creates confusion on how to deal with certain aspects, e.g. how to address the benefits of renewables and resource efficiency. As a result, many actors use CE and sustainability interchangeably and/or make their own definitions of CE (CIRAIG, 2015), which in the end can be counterproductive (Geissdoerfer et al, 2017) for constructive discussions going forward. Multiple definitions of CE might eventually jeopardize the credibility of the concept and its important features and intentions. This is observed by Linder et al, (2016) who point out that because the relationship between CE and sustainability has not been sufficiently assessed, there is a risk that CE's potential becomes diluted.

There is growing acknowledgement that the link between CE and sustainability needs to be made clearer in order to maximize the robustness of the CE development:

- The EU Science Hub[4] acknowledges that a sustainability aspect must be added to the circular approach: *"JRC scientific and technical support to policies for a more circular EU economy is necessarily based on a lifecycle approach, which considers all relevant interactions associated with a product, service, activity, or entity from a supply-chain perspective. This approach requires attention to social, economic and environmental considerations and assessments (such as resource supply and use, social imbalances, and the emissions into air, water and soil that occur along the value chain)."*
- EU also states the need for additional measures to assure sustainability of a circular economy in its amendment proposal to the Waste Legislation, put forward in March 2017[5]: *"In order to make the economy truly circular, it is necessary to take additional measures on sustainable production and consumption, focusing on the whole life cycle of products in a way that preserves resources and closes the loop.***"**

In summary, the above examples show that a broad range of stakeholders express the need for a clear link between the concepts of CE, bioeconomy and sustainability.

## 2.2.2 CE link to the bioeconomy concept

The bioeconomy concept can be defined as an economy where the basic components for materials, chemicals and energy are derived from renewable biological resources (McCormick and Kautto, 2013). An increased use of renewable materials is a necessary element for the development towards a sustainable society. This has been acknowledged by the scientific community (Asveld, 2011; Pfau et al., 2014) as well as in political strategies and agendas (OECD, 2009; The White House, 2012; Federal Ministry of Education and Research in Germany, 2011; SITRA, 2011). Above all, the strength of renewables lies in their ability to be substituted for fossil and other finite resources, whilst (in the majority of cases) reducing climate change impact (EU, 2014). Some governments have initiated programs such as the Biopreferred Program[6], initiated and managed by the U.S. Department of Agriculture, and the European Lead Market Initiative, a European program. The goal of both is to increase the use of renewable based products that reduce adverse environmental effects by substituting fossil materials.

[4] https://ec.europa.eu/jrc/en/research-topic/green-and-resource-efficient-europe
[5] http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P8-TA-2017-0070+0+DOC+XML+V0//EN&language=EN
[6] https://www.biopreferred.gov/BioPreferred/faces/Welcome.xhtml

The UN has stated that "growing more forest and the use of long-lasting forest products are currently the most effective forms of carbon capture".[7] This is supported by recent research (see for example: Ni et al. 2016; De Aquino Ximenes et al. 2011). However, there are also studies that have identified the lack of a link between the CE and bioeconomy concepts (e.g. D'Amato 2017). In addition, certain countries and organisations are calling for more alignment:

- Finland, being a country with a well-developed forest industry, has identified the lack of link between their strategy for a bioeconomy (SITRA, 2011) and the circular economy and has included forest-based materials to the technical cycles in their strategy for transition to a CE (SITRA, 2016).
- OECD (2016) discusses the alignment of bioeconomy with circular economy. They state that they are tightly linked but do not explicitly describe this link.

Nonetheless, the importance of the link is beginning to be recognised by research and mainstream politics:

- The German Bioeconomy Council has made a synopsis of the bioeconomy policies in the G7 nations (2015). All these nations acknowledge that increased use of renewables is a vital part of the transition to a circular economy.
- In 2016, the European Research Infrastructure for Circular Forest Bioeconomy (ERIFORE), an infrastructure development programme under Horizon 2020, was formed. This aims to facilitate the development of technologies based around value-added products from forest biomass.
- The EU Commission Expert group for Bio-based Products hosted a workshop in December 2016, entitled "Bio-based Products in a Circular Economy: Functionality and Sustainability". From the workshop report is quoted: "*Bio-based products, made with renewable raw materials, have great potential to contribute towards achieving a number of important EU objectives on sustainable growth, whilst addressing grand societal challenges, like climate change, establishing both circular and bioeconomies and creating high value jobs and growth*[8]."
- In its renewed EU industry policy strategy "Investing in a smart, innovative and sustainable Industry" published on 13 Sept 2017, the EU stated "*A stronger development of the bio-economy can also help the EU to accelerate progress towards a circular and low-carbon economy improving production of renewable biological resources and their conversion into bio-based products and bio-energy*". [9]

As D'Amato et al. (2017) note, both the bioeconomy and CE concept still imply economic growth based development. Both are focused on relative decoupling (of the economy and growth) but propose different paths to sustainability. For CE this decoupling is currently centred on technological innovation, around the so called inner loops of reuse and remanufacturing and recycling. On the other hand, the bioeconomy concept does not explicitly refer to circularity or resource efficiency, but focuses on substituting non-renewables with renewables. Hence the bioeconomy concept does not explicitly guarantee sustainability, because renewable resources are functionally finite, and a large increase in utilisation of renewable resources could quickly tend to unsustainability (D'Amato et al. 2017).

[7] https://www.unece.org/ab/info/media/presscurrent-press-h/forestry-and-timber/2017/un-says-that-growing-more-forest-and-the-use-of-long-lasting-forest-products-are-currently-the-most-effective-forms-of-carbon-capture/doc.html
[8] https://ec.europa.eu/docsroom/documents/22902
[9] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2017:479:FIN

It is therefore evident that both concepts have their challenges in terms of aligning robustly with sustainability. However, it suggests that the two concepts can provide learnings to one another and a closer analysis and merging of the two concepts would be mutually beneficial.

# 3 Circular opportunities for renewables

In reality, a fully circular economy is currently unattainable with today's recycling technology and products. Additionally, it will be necessary in the foreseeable future to continue to draw upon primary raw materials (Cullen, 2017; de Man and Friege, 2016) due to factors that include: the dispersion of material through wear and tear; but also due to the continuing growth in the size and affluence of the global population. This applies to both renewables and finite primary materials. It is therefore arguable that the role of renewables should be increased to contribute to sustainability. Nonetheless, even though the substitution of fossils with renewables often has a beneficial effect of environmental performance (including climate impact), this should be evaluated for each case (Radhakrishnan, 2016).

This chapter highlights the role and advantage of renewables in the technical cycles (see Figure 1). The existence and function of renewables in these cycles is significant already today and will become even more important through technical, biological, chemical and societal research and innovations.

## 3.1 Renewable materials in the technical cycles of CE

### 3.1.1 The importance of recycling renewable materials

Cyclic use of responsibly sourced renewables, through their life cycle, generally has a more favourable climate impact than fossil-based feedstock, although it is important to recognise that this depends on a variety of factors (Carus, 2017). Furthermore, reuse and recycling of products based on renewable feedstock is generally more climate efficient than burning it for energy recovery (Finnveden and Ekvall, 1998; Tyskeng and Finnveden, 2010).

Life Cycle Assessment (LCA) is a recognised and standardised (ISO 14040; 14044) methodology for assessing the environmental impact across the life cycle of a product. It has been used since the 1990's to compare the impact of product options. For instance, Finnveden and Ekvall (1998) used LCA to compare recycling of paper packaging with incineration. They found that in all seven studies, including 12 cases and 27 scenarios, total energy use is consistently lower when paper packaging materials are recycled rather than incinerated. Similarly, the European Environment Agency reviewed 9 LCA studies, containing 73 scenarios which concluded that recycling results in less overall environmental impacts than both landfilling and incineration (EEA 2006).

Similarly, Tyskeng and Finnveden (2010) concluded that recycling of material fractions generally leads to lower environmental impacts. However, it is important to recognise that this is only valid if the source material is well separated and clean fractions can be efficiently recycled and replace virgin production. Meanwhile, textiles of which cotton represents about 35% of global demand has significantly lower impact when reused (Palm et al. 2013).

A study that compared the recycling of shopping bags (Dahlgren and Stripple 2016) concluded that recycled paper bags used 36.8% less energy across the life cycle (Figure 3).

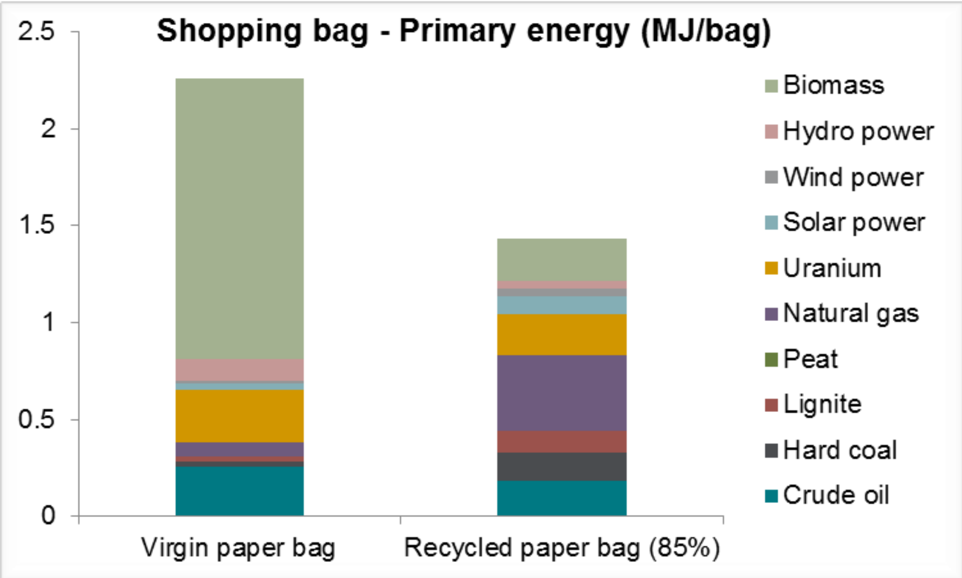


**Figure 3: Primary energy demand, of virgin versus recycled paper bag (adapted from Dahlgren and Stripple 2016).**

The comparison of numerous LCA studies on the difference between recycling, incineration and landfill found that the vast majority were strongly in favour of recycling, see Figure 4 (WRAP 2010). Therefore, there is ample evidence that the recycling of renewables can have lower environmental impacts, particularly in terms of lower energy use. The associated climate change impacts are however dependent upon the energy source used for recycling.

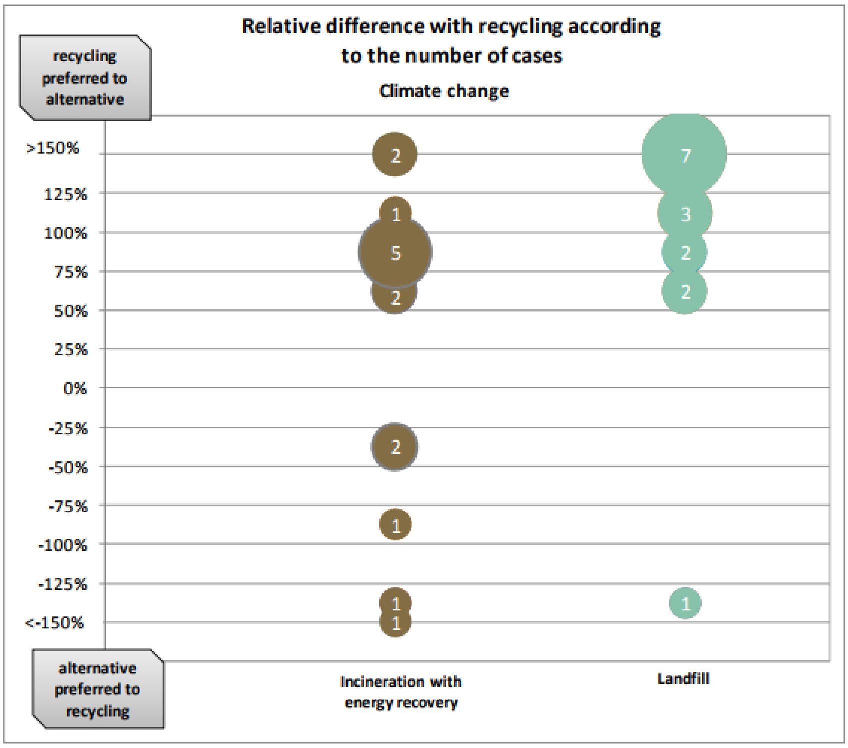


**Figure 4: Relative difference between the impacts from the different end-of-life options vs. recycling for climate change for paper. The size of the "bubble" is proportional to the number of cases coming up with a value within the same range as another (WRAP 2010).**

### 3.1.2 Renewable materials as feedstock

It is important to also recognise the contribution that using renewable materials as feedstocks can have in reducing environmental impacts. In addition, evolving materials and production techniques have the potential to increase this contribution in a future circular economy. Innovative renewable materials are starting to emerge that improve both the product functionality and the products' environmental performance. For example, materials such as composites and polysaccharide-based materials are receiving increasing attention in literature. Polysaccharides are renewable materials used in food, clothing, construction and paper packaging. They have been shown in an LCA study to have better environmental performance in each stage of the life cycle than conventional counterparts (farmed cotton or petrochemical polymers) when used in textiles, engineering materials and packaging (Shen and Patel, 2008). Table 1 summarises the savings in energy use and greenhouse gas emissions (GHG) for the LCA of various polysaccharide-based products.

Likewise, hybrid poly butylene succinate composite, a biodegradable polymer made from renewable feedstocks, was shown to have superior environmental performance for six of ten LCA indicators (Moussa and Young, 2014). This included reductions in cumulative energy demand by 40%, global warming potential by 35% and eco-toxicity by 45%. However, the renewable product had higher impacts for acidification and eutrophication of 14% and 76%, respectively.

By combining innovative materials and production techniques Braskem's sugar cane based polymer (green plastic) removes 3.09 $kgCO_2e$ per kilogram produced material. This is achieved through an industrial symbiosis approach where the by-product bagasse is used for electricity cogeneration which is used in the production process.

**Table 1: Cradle-to-factory gate non-renewable energy (NREU) and GHG emissions savings by non-conventional polysaccharide-based materials in the EU-25. Source: Shen and Patel (2008)**

| Polysaccharide products | Energy saving (MJ/kg) | GHG emissions saving (kg CO2eq/kg) | Production volume in EU (kton) | Total energy savings in EU (PJ) | Total GHG emission savings in EU (kton) |
|---|---|---|---|---|---|
| Man-made cellulose fibres (viscose vs. polyester) | 55-65 | 0.4-2.2 | 416 | 23-27 | 170-915 |
| Total natural fibre in automotive applications (china reed or hemp vs. fiberglass composite or ABS) | 28-65 | -0.9 to 2.5 | 85 | 2.4-5.5 | -76 to 213 |
| Starch polymers (TPS vs LDPE or HDPE) | 23-52 | 1.1-3.7 | 30 | 0.7-1.6 | 33-111 |
| | | | **Total savings** | 26-34 | 122-1,240 |

Replacing fossil with renewable polyethylene in beverage cartons can reduce GHG emissions per carton by over 50% as shown in a LCA study conducted for Nordic markets (ifeu, 2017).Due to the feedstock of renewable polyethylene there are some increases for other impact categories, which is the result of current production and agricultural techniques.

Another example is using wood in building frames, which in most studies reviewed by Ekvall (2006) generates lower $CO_2$ emissions during the life cycle of the construction than compared materials, here steel and concrete building frames. The overall results are shown to be quite dependent on scenarios defined for end-of-life management of the building, notably the fuel mix assumed to be replaced by incineration with energy recovery of the wood.

## 3.1.3 Summary

This section has highlighted that renewable materials have the potential to reduce environmental impact both when used as feedstock in place of non-renewable materials, and when reused or recycled. Renewables already play a significant role in the technical cycles, for example in construction wood, paper and board, plastics, chemicals, additives and textiles. For many renewable materials, it is more sustainable to re-use or recycle instead of letting them biodegrade in the biological flow or incinerate them (Finnveden and Ekvall, 1998 and Tyskeng and Finnveden, 2010).

The main message is that the field of CE needs to recognise that sustainability can be increased through utilisation of renewables in the technical cycle. This aspect also needs to be communicated more fully by the CE field. A major contribution is the reduction of climate change impacts, whilst other environmental impacts require closer scrutiny depending on individual product circumstances.

## 3.2 Illustrating examples; paper and board, plastics, chemicals and packaging

For plastics and packaging, there is often the understanding that the prefix "bio" means that they are biodegradable and that their value lies in this property. Here, the term "bio" refers strictly to the fact that the feedstock is bio-based and focus of the discussion lies on materials intended for reuse and recycling.

Paper and board is an illustration of large-scale use of renewables in the technical cycle. For these materials, there are already collection systems and recycling technologies in place in many countries and regions and the products made from recycled cellulose fibres have a market and an economic value. In Europe, the recycling rate for paper and board is above 70%.[10] When the fibre quality is no longer good enough for paper products, they can be used in other products such as thermal insulation or be incinerated contributing with renewable energy.

Figure 5 shows the typical benefits for recycling a range of cellulosic renewable materials.

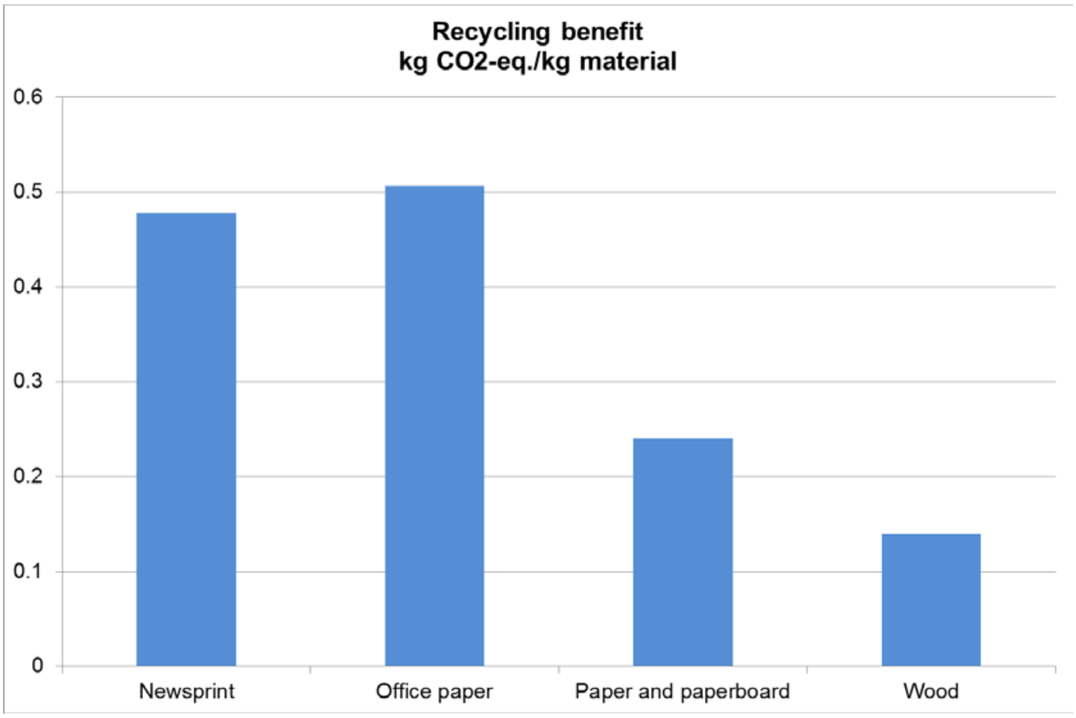


**Figure 5: Greenhouse gas emissions benefit for recycling of 1 kg of selected cellulosic materials. Combined data from Moberg et al, (2015); Elander et al (2013)**

Plastics in general are today reused and/or recycled to a very low extent; only 14% of plastics are collected worldwide (Ellen MacArthur Foundation, 2013b) and the share that is recycled is mostly

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[10] http://digibook.digi-work.com/Digibooks.aspx/Get/cepi/1641/KeyStatistics2016_Finalpdf

converted into lower-grade products. There are several reasons for this low circularity of plastics: technologies are lacking as well as standards for approved chemicals in recycled materials and there are also infrastructural challenges related to consumers' behaviour and collection systems. In their report The New Plastics Economy (Ellen MacArthur Foundation, 2015), EMF discusses the low collection grade of plastics and how to start improving the situation. EMF acknowledges that renewable resources can be used for production of plastics and thus can contribute to the decoupling of plastic production from the use of fossil and other finite resources, which is a benefit of renewables that is not reflected in their own Circularity indicator tool[11].

Bio-mass converted to the same plastics type as the fossil-based alternative, e.g. polyethylene (PE) made from sugar cane, is suitable for recycling within common material flows. The cradle-to-gate (from raw resource to product production) greenhouse gas emissions are similar for the renewable and fossil based product (Figure 6). PE from renewable resources has the same recyclability properties as fossil-based PE and the material can be circulated in an equal way. Thus the benefit of recycling renewable PE is equally big for the renewable product as for the fossil-based. In addition, if the renewable PE is ultimately incinerated, the net emissions of carbon dioxide will be close to zero, while the fossil-based PE will generate carbon dioxide emissions of around 3.2 kg CO2 /kg PE. This is because for the renewable PE; the same amount of carbon dioxide emitted during incineration will have been absorbed during growing of the sugar cane.

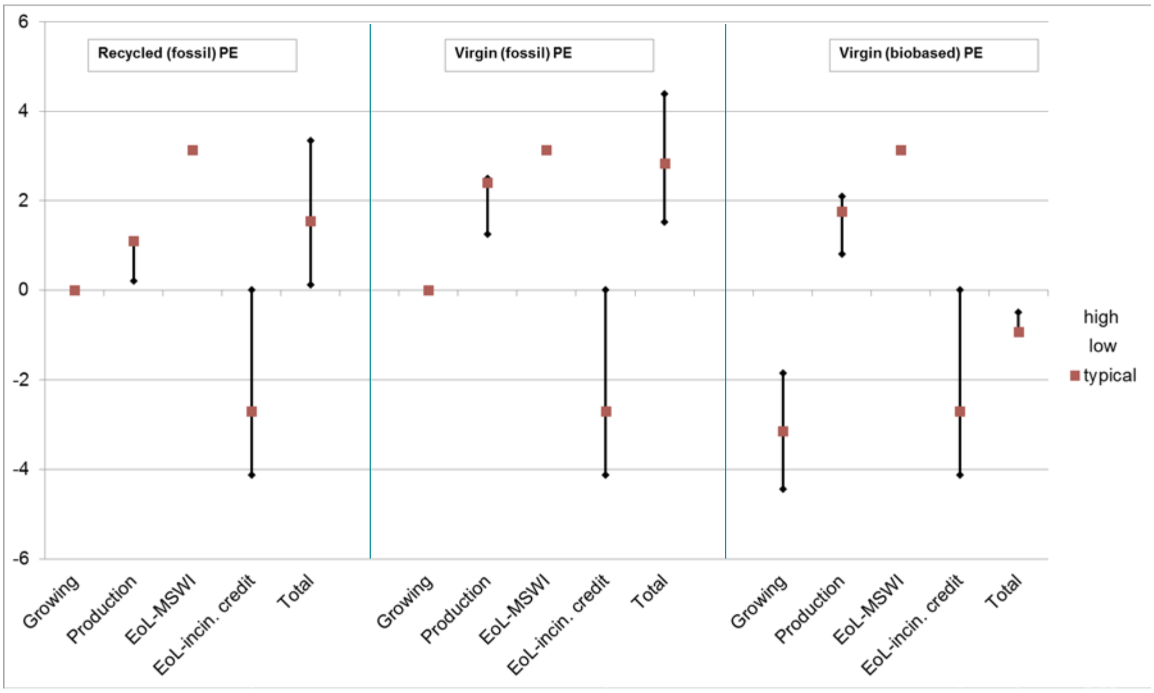


**Figure 6: Cradle-to-End-of-life (EoL) – excluding use phase - greenhouse gas (GHG) emissions for polyethylene, made of renewable raw material (sugar cane), fossil raw material, and recycled material (recalculated from Dahlgren and Stripple, 2016; Liptow and Tillman, 2012; Tillman et al, 1991). Variation lines depend mainly on: Land-use change aspects (for growing); difference i data sources (production); differences in choice and efficiency in replaced energy source (EoL-incineration credit).**

[11] https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators

For packaging materials in general, the picture is quite complex. Common packaging materials include wood, metal, cardboard, plastic, textile and glass. The main function of packaging is protection of a product and as such, the packaging material must be chosen accordingly. For some applications, there are currently no renewable alternatives available, e.g. large shipping containers, but for many others, alternatives exist. It is therefore not feasible to give a rule of thumb as to whether packaging made of renewables or non-renewables is more sustainable than the other but there are certainly cases where renewable feedstock is preferable over finite material (Radhakrishnan, 2016).

Regardless of this complexity surrounding the packaging industry, the same line of reasoning made for plastics and chemicals, apply to this sector. The bottom line is again that the potential benefit of using renewable resources is not sufficiently addressed in the CE.

In light of this, it is worth mentioning the recent amendment made to the EU waste directive, put forward in March 2017, in which renewable packaging is given special attention[12]: *Fostering a sustainable bio-economy can contribute to decreasing Europe's dependence on imported raw materials. Improving market conditions for bio-based recyclable packaging and compostable biodegradable packaging and reviewing existing law hampering the use of those materials offers the opportunity to stimulate further research and innovation and to substitute fossil fuel-based feedstocks with renewable sources for the production of packaging, where beneficial from a lifecycle perspective, and support further organic recycling*.**"** The wording in the amendment text is noteworthy as it specifically acknowledges the importance of recyclable bio-based packaging in increasing the sustainability of packaging.

# 3.3 Cascading

The term cascading refers to when a material is sequentially recycled into another type of product after its end of life (Ellen MacArthur Foundation, 2013; Carus, 2017). The term includes "downcycling" in which a material is converted to materials of lower quality and reduced functionality. Cascading is therefore a fundamental component of the CE and conscious cascading also contributes to increased resource efficiency in the whole system (Carus, 2017).

All materials generally change their properties through recycling processes but the mechanisms differ. Polymeric chains and cellulose fibres typically get shorter, whilst glass and metals gradually become contaminated with traces of other elements. Therefore, as discussed in section 3 a certain inflow of virgin resources is generally required to maintain the quality and function of material resources.

The benefit of recycled renewables over fossil-derived material in terms of climate mitigation is lower than for virgin materials as the carbon in the materials is already in circulation and there is no substitution effect. Carus (*Ibid.)* states that if climate mitigation is the priority, the most important is to keep the carbon sequestered in products for a long time before it is eventually used for energy.

Another aspect of the role of cascaded use of renewables is described by Bezama (2016): cascading the use of renewables contributes to spread feedstock geographically, which is an important factor

[12] http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+20170314+ITEMS+DOC+XML+V0//EN&language=EN#sdocta8 http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+20170314+ITEMS+DOC+XML+V0//EN&language=EN#sdocta8, amendment 17

for both the CE and the bioeconomy, making renewable feedstock available in regions where such resources are scarce.

# 4 Challenges

## 4.1 Availability of renewables

The basis for renewables is biomass which is not in itself unlimited and needs to be utilised in a sustainable and responsible way i.e. grown and harvested without excessively compromising, factors such as food production, local water resources, regrowth, biodiversity and other eco-systems. To secure future biomass availability only the annual growth quantity should be harvested yearly and not the "capital stock". Existing, "living" biomass can be viewed as a natural (and regional) capital, which must be carefully managed in order to ensure its continued regrowth and existence. In other words, biomass must be treated as all other material resources, i.e. limited in amounts. The main sources for biomass for technical use are forestry and agricultural biomass, although marine biomass is receiving increasing attention. As with all other resources, bio-resources should be used as efficiently as possible. Renewable products should be reused and recycled if the benefits of this exceed the costs and it is resource efficient.

## 4.2 Market availability of renewable feedstock

The market availability of renewable feedstock for products in the technical cycles of the CE depends on many factors such as the flow of biomass materials as well as the degree of collection, available recycling technologies and economic factors.

Recent developments and forecasts indicate that the market for the use of renewables in the technical cycles will continue to grow:

- A study by the German Nova Institute found that the global capacities for bio-based building blocks and polymers grew from approximately 4 Mt/y to 7 Mt/y during 2011 to 2016. They forecast that this would continue to grow to approximately 8.5 MT/y by 2021 (Nova Institute, 2016).

- In a survey of the packaging industry regarding their intentions for use of bio-based materials 43% intended to increase their use of renewable materials whilst only 14% responded that they will not (Nova Institute, 2016).

The future availability of renewable feedstock depends on economic, regulatory and technological factors. Numerous publications describe analysis and modelling of the influence of existing and potential drivers and barriers affecting the development of the market for renewable feedstock, such as policies (Ribeiro et al, 2016), trade and investment partnership (Beghin, 2016) and technology development (Clomburg et al, 2017).

## 4.3 Perception of renewables

According to a study by Lynch *et al.* (2017), the perception of the public towards the bioeconomy can be strongly influenced by knowledge and information. In the study involving Dutch citizens perception improved markedly as interviewees were provided with more facts about bio-based products, technologies and how the use of bio-based affects their every-day life. These findings show the importance of communication, and support a central message contained in this report, that it is important to communicate the current role of renewables and how they can further contribute to a sustainable bio-based and circular economy.

Knowledge diffusion could be supported by the development of standards for the measurement and monitoring of renewables in the CE. Central to this is the identification of suitable Key Performance Indicators (KPIs) that can assess circularity at different spatial and temporal levels. Recently, the EMF Circularity Indicators tool (Ellen MacArthur Foundation, 2015) and the Circular Economy toolkit[13] have emerged. These have been described and critiqued in recent publications such as Potting et al. (2017), Saidani et al. (2017) and Linder, Sarasini and van Loon (2017). These current approaches tend to focus too centrally on circularity and fail to adequately address the product's overall sustainability based on indicators such as climate impact or other environmental aspects. Linder et al. (2017) stress the importance of developing intuitive, transparent and credible KPIs that would contribute to an impartial perception of renewables among a wider audience, which is in line with the study by Lynch and co-workers.

# 5 Concluding remarks

This document has argued that currently the CE field tends to focus only on the biodegradability aspect of renewables, whilst largely neglecting their ability to be reused and recycled. In addition, the large potential for renewable feedstock to reduce energy use and GHG emissions (within a CE) has received little attention. Therefore, due to the considerable mainstream attention that the CE field is receiving, there is a risk that the significant contribution that renewables can play in progressing towards sustainability and circularity will not be fully realised. Environmental assessments using LCA consistently show that in the vast majority of cases the use of renewables as feedstocks and their recycling result in reduced energy use and environmental impacts. It is therefore critical to better communicate the central role of renewables in improving circularity and environmental performance of production and consumption. In bioeconomy literature the role of renewable materials are naturally central and there are clear parallels between the bioeconomy field and CE. One way therefore to raise the profile of renewables in the circular economy is to more closely align the two fields.

Crucially, it is important that examples which demonstrate the lower environmental impact of using, reusing, refurbishing and recycling products made from renewable materials begin to appear more prominently in the CE literature and mainstream.

[13] http://circulareconomytoolkit.org/

# 6 References

Asveld L., R. van Est & D. Stemerding (Eds), 2011, Getting to the core of the bio-economy: A perspective on the sustainable promise of biomass. The Hague: Rathenau Institut

Azar, C., Holmberg, J., Lindgren, K., 1996, Socio-ecological indicators for sustainability, *Ecological Economics*, vol 18, pp 89-112

Beghin, J., Bureau, J-C., Gohin, A, 2016, THe impact of an EU-US Transatlantic Trade and Investment Partnership Agreement on Biofuel and Feedstock Markets, *Journal of Agricultural Economics*, vol 68, issue 2

Bezama, A., 2016, Let us discuss how cascading can help implement the circular economy and the bio-economy strategies, editorial letter in *Waste Management & Research*, vol 34(7), pp 593-594

Budzianowsky, W., 2016, High-value low-volume bioproducts coupled to bioenerges with potential to enhance business development of sustainable biorefineries, *enewable and Sustainable Energy Reviews*, vol 70, pp 793-804

Carus, M., 2017, Bio-based economy and climate change – Important links, pitfalls and opportunities, nova-Institute for Ecology and Innovation (Germany)

CIRAIG: A critical literature review of concepts, 2015, CIRAIG International Reference Centre for the Life Cycle of Products, Processes and Services

Clomburg, J., Crumbley, A. and Gonzalez, R., 2017, Industrial biomanufacturing: The future of chemical production, *Science*, vol 355, issue 6320

Cullen, J.M., 2017, Circular Economy; Theoretical Benchmark or Perpetual Motion Machine?, *Journal of Industrial Ecology*, vol 21, issue 3, pp 483-486

Dahlgren, L., and Stripple, H., 2016. A comparative LCA study of various concepts for shopping bags and cement sacks. IVL report number U5732. Commissioned by BillerudKorsnäs AB.

Ekvall, T., 2006, Miljöaspekter på val av stommaterial i byggnader, Kompletterande kartläggning av kunskapsläget, IVL report B1663

Elander M, Holmström D, Jensen C, Stenmarck Å, Sundberg J, 2013, Indicators for a resource efficient waste handling, Waste Refinery Report WR53.

Ellen MacArthur Foundation, 2013a, Towards the Circular Economy. Economic and business rationale for an accelerated business.

Ellen MacArthur Foundation, 2013b, The New Plastics Economy, Rethinking the future of plastics.

Ellen MacArthur Foundation, 2015 , Circularity Indicators. An approach to Measuring Circularity.

European Commission, 2014, A Guidance on bio-based products in procurement

European Commission, 2015, Closing the loop – An EU action plan for the Circular Economy, Communication from the Commission to the European Parliament, the European Economic and Social Committee and the Committee of the regions, COM (2015) 614 final

European Commission, 2017, On the implementation of the Circular Economy Action Plan, COM(2017) 33 final.

European Environment Agency, 2006. Paper and cardboard — recovery or disposal? Review of life cycle assessment and cost-benefit analysis on the recovery and disposal of paper and cardboard. EEA Technical Report. No. 5/2006. https://www.eea.europa.eu/publications/technical_report_2006_5

Federal Ministry of Education and Research in Germany, 2011, National Research Strategy BioEconomy 2030, Our route towards a biobased economy

Finnveden, G., Ekvall, T., 1998, Life-cycle assessment as a decision-support tool – the case of recycling versus incineration of paper, *Resources, Conservation and Recycling*, vol 24, pp 235-256

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hulting E.J., 2017, The Circular Economy – A new sustainability paradigm?, *Journal of Cleaner Production*, vl 143, pp 757-768

Geng, Y.; Doberstein, B., 2008, Developing the circular economy in China: Challenges ans opportunities for achieveing "leapfrog development", *International Journal of Sustainable Development & World Ecology*, vol 15, pp 231-239

German Bioeconomy Council, 2015, Bioeconomy Policy Synopsis and Analysis of strategies in the G7

ifeu (2017). Comparative life cycle assessment of Tetra Pak® carton packages and alternative packaging systems for liquid food on the Nordic market. Available online: https://assets.tetrapak.com/static/se/documents/sustainability-downloads/lca%20nordic%20final%20report.pdf

Linder, M., Sarasini, S., van Loon, P., 2017, A Metric for Quantifying Product-Level Circularity, *Journal of Industrial Ecology*, vol 21, issue 3, pp 545-558

Liptow C and Tillman A-M, (2012) A comparative life cycle assessment study of polyethylene based on sugarcane and crude oil. J Ind Ecol 16:420–435

Lynch, D.H.J, Klaassen, P. and Broerse, E.W., 2017, Unraveling Dutch Citizens' perceptions on the bio-based economy: THe casse of bioplastics, bio-jetfuels and small-scale biorefineries, *Indsutrial Crops and Products*, vol 106, pp 130-137

de Man, R., Friege, H., 2016, Circular economy: European Policy on shaky ground, editorial letter in *Waste Management & Research*, vol 34 (2), pp 93-95

Mathews, J. and Tan, H., 2015, Progress Toward a Circular Economy in China, THe Drivers (and Inhibitors of Eco-industrial Initiative, *Journal of Industrial Ecology*, vol 15, no 3, pp 435-457

Moberg Å, Martin M, Rydberg T, Sundqvist J-O, Youhanan L. IVL Report U5585, December 2015.

Ni Y, Eskeland GS, Giske J and Hansen JP, 2016. The global potential for carbon capture and storage from forestry. Carbon Balance Manag. 2016 Dec; 11: 3. doi: 10.1186/s13021-016-0044-y

Nova Institute, 2016, Brand views and adoption of bio-based polymers

Nova Institute, 2017, Bio-based building blocks and polymers - Global capacities and trends 2016-2021

OECD, 2009, The Bioeconomy to 2030: Designing a Policy Agenda Main finings and policy conclusions

OECD, 2016, Building a sustainable bioeconomy: a framework for policy

Palm, D., Harris, S., Ekvall, T., 2013, Livscykelanalys av svensk textilkonsumtion, IVL report B2133

Pfau, S.F., Hagens, J.E., Dankbaar, B. and Smits, A.J.M., 2014, Visions of Sustainability in Bioeconomy Research, *Sustainability*, vol 6, pp 1222-1249

Piotrowski, S., Carus, M., and Carrez, D., 2016, European Bioeconomy in Figures, Nova-Institute for Ecology and Innovation (Germany)

Potting, J., Hekkert, M., Worell, E., Hanemaaijer, A., 2017, Circular Economy:Measuring Innovation in the Product Chain, Policy report, PBL Netherlands Environmental Aessment Agency

Radhakrishnan, S., 2016, Environmental Implications of Reuse and Recycling of Packaging, in Environmental Footprints of Packaging, edited by Muhtu, S.S., SGS Hong Kong Limited, pp 165-192

Ribeiro, L., Pereira da Silva, P., Ribeira, L., Dotti, F., 2017, Modelling the impacts of policies on advanced biofuel feedstock diffusion, *Journal of Cleaner Production*, vol 142, part 4

Rizos, V., Tuokko, K., Behrens, A., 2017, The Circular Economy, A review of definitions, processes and impacts, CEPS Research Report

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., 2017, How to assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework, *Recycling*, vol 2, issue 6.

SITRA, 2011, Sustainable Bio-economy: Potential, Challenges and Opportunities in Finland

SITRA, 2016, Leading the cycle. Finnish road map to a circular economy 2016-2025

The White House, 2012, National Economy Blueprint

Tillman, AM, Baumann H, Eriksson E & Rydberg T (1991). *Miljön och förpackningarna. Livscykelanalyser av förpackningsmaterial.* SOU 1991:77, Statens offentliga utredningar, Allmänna Förlaget, Stockholm, Sweden.

Tyskeng, S., Finnveden, G., 2010, Comparing Energy Use and Environmental Impacts of Recycling and Waste Incineration, *Journal of Environmental Engineering*, vol 745

UN, General Assembly, 2015, Transforming our world: the 2030 Agenda for Sustainable Development

Waste Resources Action Programme, 2010. Environmental benefits of recycling – 2010 update. http://www.wrap.org.uk/content/environmental-benefits-recycling

Ximenes FA, George BH, Cowie A, Williams J and Kelly G, 2012. Greenhouse Gas Balance of Native Forests in New South Wales, Australia. Forests 2012, 3(3), 653-683; doi:10.3390/f3030653.

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