CIRCULAR IMPACTS

The Circular Economy

A review of definitions, processes and impacts

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1 :: Introduction

The concept of the circular economy has its roots in several schools of thought and theories that challenge the prevailing economic system based on overconsumption of natural resources. In recent years the circular economy has received increasing attention worldwide due to, inter alia, the recognition that security of supply of resources and resource efficiency are crucial for the prosperity of economies and businesses. The concept has been taken up by several governments[1] and businesses around the world that consider the circular economy as a solution for reconciling what at first sight seem to be the conflicting objectives of economic growth and environmental sustainability (Lieder & Rashid, 2016; Preston, 2012; Ghisellini et al., 2016). Within the EU, the circular economy is also gaining momentum as documented in the Circular Economy Package, the European Commission's Work Programme 2017 and the Horizon 2020 research and innovation programme (European Commission, 2016a; 2015a).

At the same time, changing the linear economic model that has remained dominant since the onset of the Industrial Revolution is by no means an easy task and would entail a transformation of our current production and consumption patterns. Innovative transformational technologies such as digital and engineering technologies, in combination with creative thinking about the circular economy, will drive fundamental changes across entire value chains that are not restricted to specific sectors or materials (Vanner et al., 2014; Acsinte & Verbeek, 2015; Accenture, 2014). Such a major transformation would in turn entail significant impacts for the economy, the environment and the society. Understanding those impacts is crucial for researchers as well as for policy-makers for designing future policies in the field. This requires developing a good knowledge of the concept, the different circular economy processes and their expected effects on sectors and value chains. However, research on the circular economy appears to be fragmented across various disciplines and there are often different perspectives about the interpretation of the concept and the related aspects that need to be assessed.

This paper provides a review of the growing literature on the circular economy with the purpose of improving understanding of the concept as well as its various dimensions and expected impacts. It has the following structure. Section 2 explores the origins of the circular economy concept, the different available definitions as well as the issues that have received criticism. Section 3 first describes the main circular economy processes and then presents three examples of how these processes can be applied in different sectors. This is followed by a presentation of the main economic, environmental and social impacts of the circular economy transition according to the existing evidence in the literature (section 4). The last section draws some conclusions for policy-makers and researchers based on the research conducted for this study. The analysis in this paper is based on a desk-based review of the available literature in the field of circular economy (reports, scientific articles, policy publications, etc.). Additionally, the research team conducted structured telephone interviews with six experts from policy, business and academia in order to collect their views on the issues

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[1] See Dutch Ministry of Infrastructure and the Environment and Ministry of Economic Affairs (2016) and Scottish Government (2016) for examples of circular economy strategies being actively pursued by governments in Europe.

addressed in this paper. The interviewed experts are listed in an Annex at the end of this paper.

The paper is the first deliverable of the WP2 (Theoretical framework for the circular economy and associated markets) of the Circular Impacts project.[2] The project will develop an assessment based on concrete data and indicators of the macro-economic, societal, environmental and labour market impacts of a transition to a circular economy. The assessment should support the European Commission in its discussions with the Member States on progress in the circular economy transition and the implications for the EU economy especially in the context of the European Semester. This paper focuses on the theoretical dimensions of the concept and aims to improve understanding of the impacts of the circular economy transition. The next deliverable of the project will focus on the policy dimensions and specifically on the interplay of the European Semester and the circular economy.

2 :: The circular economy

2.1 Origins

The term circular economy appears to be formally used in an economic model for the first time by Pearce & Turner (1990). Drawing on the principle that 'everything is an input to everything else', the authors took a critical look at the traditional linear economic system and developed a new economic model, named the circular economy, which applies the principles of the first and second laws of thermodynamics.[3] The relationship between the economy and the environment is prominent in this model, which incorporates three economic functions of the environment: resource supplier, waste assimilator and source of utility.[4] Their work and line of thought were inspired by the work of Kenneth Boulding and others who discussed a few decades earlier the biophysical limits of the present economic system built on overconsumption and a growing ecological deficit. Boulding (1966) introduced the concept of closed systems and envisaged a future economy that would operate by reproducing the limited stock of inputs and recycling waste outputs. Such a 'closed' economy would seek to maintain the total capital stock[5] and would stand in stark contrast with the 'open' materials-reliant industrial economy of the past.[6]

[2] For information on the project, see http://circular-impacts.eu/.

[3] The first law of thermodynamics stipulates that neither energy nor matter can be created or destroyed and therefore any natural resources used will return to the environment in the form of solid waste or emissions. According to the second law of thermodynamics, there are physical boundaries that prevent the set-up of a system in which all waste is recycled and transformed back into natural resources with 100% efficiency (Pearce & Turner, 1990; Čiegis & Čiegis, 2008).

[4] In this model resources are an input to the production process, which in turn provides consumer and capital goods for consumption. Consumption of goods then creates utility or welfare. Waste is produced at all three stages: resources processing, production (in the form of emissions and solid waste) and consumption of goods (Pearce & Turner, 1990).

[5] Notably, Boulding's (1966) conception of capital also included human capital and knowledge, in addition to "the set of all objects".

[6] Boulding (1966) used the terms "spaceman economy" and "cowboy economy" to contrast the two different economies: the closed economy of the future (spaceman economy) and the open economy of the past (cowboy economy).

Over the last several decades, a growing body of literature from various disciplines has emerged that has influenced our present understanding and interpretation of the circular economy (Lieder & Rashid, 2016). Industrial ecology is a research discipline underpinned by a systems approach and involving a holistic perspective when dealing with human economic activity and sustainability (Garner & Keoleian, 1995). Central to this discipline is the notion that the natural ecosystem and man-made industrial system operate in a similar way and are characterised by flows of materials, energy and information (Erkman, 1997; Ehrenfeld, 2007). The shift towards a sustainable industrial economy would require structural and technological changes combined with economic and cultural evolution in order to achieve energy and materials optimisation (Graedel & Allenby, 1995). In this context, Frosch & Gallopoulos (1989, p. 149) argued that optimising the entire system requires improved manufacturing processes "that minimize the generation of unrecyclable wastes (including waste heat) as well as minimize the permanent consumption of scarce material and energy resources''. In their view, innovation in the manufacturing and design of products and processes is required to effectively direct materials back to the production process that were previously thought of as waste. Industrial symbiosis applies the industrial ecology principles at the company level and foresees the development of synergistic collaboration between companies involving the exchange of resources and by-products (Chertow, 2000). This collaboration is not necessarily restricted by geographical proximity and can lead to the development of networks that share knowledge and promote eco-innovation (Lombardi & Laybourn, 2012).

Cradle-to-cradle design is an adjacent systems approach aimed at transforming the industrial material flows. In contrast to traditional sustainability concepts that focus on reducing or eliminating the negative environmental impact of human activity,[7] cradle-to-cradle design seeks to maintain and even enhance the value, quality and productivity of material resources in order to have a net positive environmental effect (Braungart et al., 2006; Ankrah et al., 2015). A basic tenet of cradle-to cradle is that there are two types of materials that can be optimised through the design of products, manufacturing processes and supply chains: biological materials and technical materials. The former are biodegradable and can be safely returned to the environment after their use, while the latter are durable materials that can be reprocessed after their use and continue flowing within a closed-loop system. The utilisation of knowledge produced by networks of information flows amongst the actors in the value chain would be a key driver to maintaining or enhancing the value and productivity of these materials (Braungart et al., 2006). Beyond the material aspects, additional key principles of cradle-to-cradle are the use of renewable energy sources and the promotion of biodiversity as well as cultural and social diversity (McDonough & Braungart, 2002).

Based on the argument that a shift towards business models that focus on the result delivered rather than the product sold can improve competitiveness and deliver environmental benefits, product-service systems (PSS) is a research field that emerged in the mid-1990s (Tukker, 2015). According to Tukker & Tischner (2006, p. 1552), PSS

[7] Braungart et al. (2006) criticise the traditional sustainability or eco-efficiency approaches (see footnote 19 for more details about the eco-efficiency concept) that aim to achieve 'zero waste' and/or 'zero emissions' on the grounds that they do not challenge the fundamentals of the present industrial system with linear material flows. They also argue that the efforts to reduce the environmental impact of industrial processes and products will eventually reach a point where any further dematerialisation would need to be achieved at the expense of economic growth and innovation. In this context, they bring forward the concept of 'eco-effectiveness', of which a central component is cradle-to-cradle design, which aims to enhance the environmental, social and economic traits of goods and services.

"consist of a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs''. Such systems prioritise the "final functionality or satisfaction that the user wants to realise as a starting point of business development''. Although PSS theoretically have a great potential to enhance competitiveness and sustainability, their net impact depends crucially on several factors that need to be carefully assessed in all cases[8] (Tukker, 2015; Tukker & Tischner, 2006). The 'blue economy' is another relevant concept that addresses the business case for sustainability and resource efficiency. In this context, innovation is considered to be a fundamental lever in guiding businesses towards a transformation of practices influenced by the design and functions of natural ecosystems. One example is the use of waste from one product as an input in another production process, thereby generating a cash flow (Pauli, 2010).

2.2 Definitions

Since the first formal use of the circular economy term by Pearce & Turner (1990), there have been various attempts to define the circular economy influenced by several concepts, including the ones described above. A number of authors have provided resource-oriented definitions and/or interpretations, emphasising the need to create closed loops of material flows and reduce the consumption of virgin resources and its attendant harmful environmental impacts. For instance, Sauvé et al. (2016, p. 49), suggest that the circular economy refers to the "production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste (including pollution)''. In their view, the primary focus of the circular economy is the reduction of resource consumption, pollution and waste in each step of the life cycle of the product. According to Preston (2012, p. 1), "circular economy is an approach that would transform the function of resources in the economy. Waste from factories would become a valuable input to another process – and products could be repaired, reused or upgraded instead of thrown away''. In a similar vein, EEA (2014, p. 11) claims that the circular economy "refers mainly to physical and material resource aspects of the economy – it focuses on recycling, limiting and re-using the physical inputs to the economy, and using waste as a resource leading to reduced primary resource consumption''.[9] Mitchell (2015) goes further and emphasises the importance in a circular economy of keeping resources in use for as long as possible as well as extracting the maximum value from products and materials through using them for as long as possible and then recovering and reusing them.

In the available literature there are also several interpretations of the concept that attempt to move beyond the notion of management of material resources and incorporate additional dimensions. For example, Heck (2006) claims that in the circular economy debate the use of sustainable energy has not yet managed to gain an equal standing compared to recycling and waste management. To this end, the transition to a circular economy would require addressing the challenge of establishing a sustainable energy supply as well as decisive action in several other areas such as agriculture, water, soil and biodiversity. In view of the policy discussions in China, Su et al. (2013)

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[8] For example, in some cases these models may motivate consumers to either treat these products with less caution than the products they own or return them earlier to the service provider (Tukker, 2015).

[9] It should be noted, however, that another publication by EEA (2016, p. 9) suggests that "the concept can, in principle, be applied to all kinds of natural resources, including biotic and abiotic materials, water and land''.

point out that the focus of the circular economy gradually extends beyond issues related to material management and covers other aspects such as energy efficiency and conservation, land management, soil protection and water. Bastein et al. (2013, pp. 4-5) emphasise the economic dimensions of the circular economy and suggest that this transition "is an essential condition for a resilient industrial system that facilitates new kinds of economic activity, strengthens competitiveness and generates employment''. According to Ghisellini et al. (2016), the radical reshaping of all processes across the life cycle of products conducted by innovative actors has the potential to not only achieve material or energy recovery but also to improve the entire living and economic model. The French Environment and Energy Management Agency stresses that the objective of the circular economy is to reduce the environmental impact of resource consumption and improve social well-being (ADEME, 2014).

One of the most-frequently cited definitions that incorporate elements from various different disciplines has been provided by the Ellen MacArthur Foundation (2013a, p. 7) which describes the circular economy as "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models''. Drawing on cradle-to-cradle principles and systems thinking, this interpretation of the concept involves the distinction of two different types of materials:[10] materials of biological origin that can return to the biosphere as feedstock (e.g. forest products) and technical materials, which cannot biodegrade and enter the biosphere (e.g. plastics and metals). Under this framework, the circular economy aims to keep both types of these materials at their highest utility and value at all times through careful design, management and technological innovation (Ellen MacArthur Foundation, 2013a; 2015a). The overall objective is to "enable effective flows of materials, energy, labour and information so that natural and social capital can be rebuilt'' (Ellen MacArthur Foundation, 2013b, p. 26).

At the EU level, the European Commission (2015a, p. 2) has included a description of the concept in its Communication "Closing the loop – An EU Action Plan for the circular economy",[11] which is part of the Circular Economy Package.[12] Specifically, the circular economy is described as an economy "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised''. The transition to a more circular economy would make "an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy''. In this context, the EU Action Plan includes a series of measures aimed at addressing the full product cycle from production and consumption to waste management and the market for secondary raw materials.

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[10] It is worth noting that according to Vanner et al. (2014) there are cases, such as the example of biodegradable plastics, in which this division does not easily apply.

[11] The Action Plan includes a series of actions to be carried out by the Commission centred on different thematic areas. In particular, it features actions targeted at all stages of the product's life cycle as well as at five priority sectors that were selected due to their specific value chains, products, environmental footprint or importance for reducing the EU dependency on raw materials: plastics, food waste, critical raw materials, construction and demolition, biomass and bio-based products (European Commission, 2015a).

[12] In addition to the Action Plan the Package includes proposals to amend the following Directives: 2008/98/EC on waste, 94/62/EC on packaging and packaging waste, 1999/31/EC on the landfill of waste, 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment.

The description and measures included in the Action Plan reflect a shift in the focus of EU waste policy that had traditionally concentrated on end-of-life disposal and management of materials. Still, comparing this description of the circular economy with the available literature, it could be argued that some important elements are missing or are not very explicit. One example is the notion of maintaining products and materials at their highest value and utility. Additionally, although the Action Plan mentions that the circular economy can create local jobs at all skills levels and opportunities for social integration and cohesion, one could argue that more emphasis could have been given in its role in improving social well-being. Similarly, despite the use of the term "resources", which can also refer to energy resources, it could be said that the importance of using sustainable sources of energy in the system as well as the link between the circular economy and the energy challenge could have been more prominently featured in the description.

Table 1 below summarises the circular economy definitions and interpretations presented in this section.

Table 1. Circular economy definitions and interpretations

Source	Definition/interpretation
Sauvé et al. (2016)	Circular economy refers to the "production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste (including pollution)''.
Preston (2012)	"Circular economy is an approach that would transform the function of resources in the economy. Waste from factories would become a valuable input to another process – and products could be repaired, reused or upgraded instead of thrown away".
EEA (2014)	Circular economy "refers mainly to physical and material resource aspects of the economy – it focuses on recycling, limiting and re-using the physical inputs to the economy, and using waste as a resource leading to reduced primary resource consumption''.
Mitchell (2015)	A circular economy is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extracting the maximum value from them whilst in use, then recovering and reusing products and materials.
Heck (2006)	The utilisation of sustainable energy is crucial in a circular economy. The transition to a circular economy would require addressing the challenge of establishing a sustainable energy supply as well as decisive action in several other areas such as agriculture, water, soil and biodiversity.
Su et al. (2013)	The focus of the circular economy gradually extends beyond issues related to material management and covers other aspects, such as energy efficiency and conservation, land management, soil protection and water.
Bastein et al. (2013)	The circular economy transition "is an essential condition for a resilient industrial system that facilitates new kinds of economic activity, strengthens competitiveness and generates employment''.
Ghisellini et al. (2016)	The radical reshaping of all processes across the life cycle of products conducted by innovative actors has the potential to not only achieve material or energy recovery but also to improve the entire living and economic model.

ADEME (2014)	The objective of the circular economy is to reduce the environmental impact of resource consumption and improve social well-being.
Ellen MacArthur Foundation (2013a; 2013b; 2015a)	Circular economy is "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models''. The overall objective is to "enable effective flows of materials, energy, labour and information so that natural and social capital can be rebuilt''.
European Commission (2015a)	The circular economy is an economy "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised''. The transition to a more circular economy would make "an essential contribution to the EU's efforts to develop a sustainable, low-carbon, resource-efficient and competitive economy''.

2.3 Criticism

Over the years the circular economy concept has also attracted criticism on several grounds. A key issue that emerges from the above discussion concerns the different definitions of the concept. The circular economy has achieved a broad appeal among the academic, policy and business audiences (Vanner et al., 2014; Ghisellini et al., 2016), but its interpretation and application have been very diverse. This can in turn generate confusion as well as reduced opportunities for international cooperation (Preston, 2012). The interpretation issue is also linked to the challenge of assessing the impact of the circular economy transition. As shown later in more detail, in recent years several studies have emerged suggesting that the circular economy holds the potential to deliver economic, environmental and social benefits. Nevertheless, their focus and the aspects they measure are often varied. Furthermore, according to EASAC (2015), this research field is still in its early phase, and therefore the applied quantitative models are sometimes based on simplifications and assumptions that could be challenged.[13] Added to this, it could also be questioned whether these models sufficiently take into account the myriad challenges related to transforming linear structures and business models that have been in place for many decades.

Another source of debate refers to the need to place greater weight on the social dimension of the circular economy. According to Murray et al. (2017), key social equality aspects such as gender, racial and financial equality, inter- and intra-generational equity and equality of social opportunities are often absent in the existing conceptualisations of the circular economy. There are also concerns over the net environmental impact of some circular economy practices and processes. For example, Demailly & Novel (2014) claim that although sharing models[14] offer new opportunities for innovation on the benefit of the 'green' transition, their net environmental benefits

[13] For instance, EASAC (2015) claims that in some cases the methodology of these models involves scaling up the data from a representative product or a representative company to a country or EU level. The rebound effect presents another parameter that is not sufficiently covered by the existing models since it is not yet clear how will consumers spend the money saved through, for example, reduced energy consumption.

[14] As explained later, sharing models present one the main circular processes identified in this paper.

depend on several different parameters which frequently require careful consideration.[15] Similarly, the breakdown and recycling or reusing of products designed for a long life might require more energy than products with shorter life spans.[16] This may be the case for renewable technologies, such as wind farms and solar panels, which are made of technical materials that may be difficult to recycle (Murray et al., 2017). Furthermore, Ghisellini et al. (2016) stress that although the current focus of the circular economy worldwide is the decoupling of economic growth from resource use, the concept cannot support the endless economic growth model due to the physical limitations of recycling.

3 :: Circular economy processes

Drawing on the review of the available definitions and interpretations of the circular economy concept, this section goes further and identifies the main processes that can fit under the umbrella of circular economy. These circular economy processes can be adopted by companies and countries and may entail economic, environmental and social impacts (see section 4). At the business level, these processes can be understood to represent the different circular practices a company takes up in order to move from a linear business model to a circular one by providing a circular product or service. Following the discussion on the definitions of circular economy, a description of the circular economy processes serves the purpose of developing an understanding of how businesses and sectors can implement in practice the circular economy. This section first identifies and describes the main circular economic processes (3.1) and then applies these processes to different sectors in order to illustrate the expected effects (3.2).

3.1 Identification of main circular economy processes

The research team has identified the following eight processes that can be further classified into three different categories, namely i) using less primary resources, ii) maintaining the highest value of materials and products and iii) changing utilisation patterns. The processes are presented in Box 1 below and then discussed in more detail. It should be emphasised that the categories of circular processes are not mutually exclusive. Many of their elements are often interlinked, while in some cases businesses can adopt a strategy that involves multiple circular processes (see, for example, Rizos et al., 2016). Moreover, several of the concepts described in section 2 can be relevant to multiple processes; for instance, as shown below, industrial symbiosis can be linked to both the utilisation of renewable energy resources as well as to remanufacturing practices in the building sector.

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[15] These parameters may refer to the quality of shared goods (it is important to design these products for increased durability), the potential need for increased transport of goods entailing environmental impacts and the possible change in the consumer patterns that can in turn affect the environmental balance (whether, for instance, consumers will be motivated through these sharing models to replace their products more frequently) (Demailly & Novel, 2014).

[16] Murray et al. (2017) provide the example of bamboo chopsticks that in their view would be more easily recycled and returned to the biosphere than longer-lasting plastic forks.

Box 1. Main circular economy processes

USE LESS PRIMARY RESOURCES

- Recycling
- Efficient use of resources
- Utilisation of renewable energy sources

MAINTAIN THE HIGHEST VALUE OF MATERIALS AND PRODUCTS

- Product life extension
- Remanufacturing, refurbishment and re-use of products and components

CHANGE UTILISATION PATTERNS

- Product as service
- Sharing models
- Shift in consumption patterns

Source: Authors' own elaboration.

Recycling. Recycling has been defined by United Nations et al. (2003, p. 79) as "the re-introduction of residual materials into production processes so that they may be re-formulated into new products''. For many decades it has been the most traditional way of implementing circular economy principles by capturing the value of existing products and materials and decreasing the use of primary materials. Reducing the extraction of primary resources through recycling can provide multiple environmental benefits (EEA, 2016) and also help reduce GHG emissions associated with material resource use. With regard to the latter, on the global level, there is a direct relationship between resource use and climate change. Behrens (2016) shows that GHG emissions account for 83% by weight of global material output, making the atmosphere by far the largest dumping site for the disposal of global waste.

As indicated by the definition provided by United Nations et al. (2003), recycling should not be understood only as mere recovery of materials, but also as redirecting the recovered materials towards their next lifecycle. The issue of quality is important to this end since achieving high quality recycling is a prerequisite for effectively re-introducing materials in the production process.

Increased recycling can be cost-effective for industries, while for those sectors that depend on primary materials, the use of secondary materials may decrease the need to purchase or extract primary materials. For example, a study of the UK economy has estimated a potential of cost savings of £18 billion from reduction of waste for one year (Oakdene Hollins, 2011).[17] In addition, the use of recycled material may reduce price volatility associated with primary raw materials and dependency on imports of materials (World Economic Forum et al., 2014). With regard to the latter, an example is the recycling of critical raw materials (CRMs) that are often imported from third countries (European Commission, 2014).

[17] While this study looks not only at recycling but also at reduction of waste in other means, recycling is understood to be a central manner in which landfilled waste is reduced.

Chemical recycling[18] of plastic waste presents an additional interesting example in this context. This process involves the recovery of the petrochemical constituents of the polymer in order to be used for plastics re-manufacturing or the production of other synthetic chemicals (Hopewell et al., 2009). It should be noted, however, that the further growth of chemical recycling would require the development of economically viable innovative technologies as well as addressing the presence of substances of concern in plastics (Ellen MacArthur Foundation, 2016; European Commission, 2017a).

Another example is the utilisation of biological resources (e.g. forest side streams, such as sawdust) for the production of other products (SITRA, 2016). This may entail thinking in terms of an industrial symbiosis where sectors look across value chains and use the side streams of production from other sectors. It can also entail the creation of collaboration among different industries to discover ways how waste from one process may be used as raw material in another (Jacobsen, 2006). In general, industrial symbiosis can lead to a reduction in the consumption of primary material and energy through the sharing and exchange of waste, material, by-products and energy (more examples of industrial symbiosis are presented later in the paper).

Recycling should not be confused with reuse as the latter does not require the reprocessing of materials into new products, materials or substances. Reuse is covered in the ensuing category named "Remanufacturing, refurbishment and reuse of products and components". However, the process of recycling or reusing water can be included in this category. In the literature, the terms water recycling and water reuse are often used synonymously and refer to the use of properly treated waste water for other purposes (Lazarova et al., 2012). In the EU, water reuse can help reduce pressure on over-exploited water resources as well as contribute to nutrients recycling and substitution of solid fertilisers (European Commission, 2015a). Regarding the latter, for example, phosphorus can be trapped at waste water treatment plants and be used as fertilizer, while localised food systems have high potential to achieve significant environmental benefits through this process (Jurgilevich et al., 2016).

Efficient use of resources. Another process that can lead to the use of less primary resources is efficiency of resources use. This process is linked to the concept of cleaner production,[19] which focuses on achieving material and energy resources efficiency in processes (UNEP & Sida, 2006) and can involve both the careful use of resources and the replacement of resources that are hazardous or have a short life span (Nilsson et al., 2007). Cleaner production refers to improvements to both industrial production processes and products. In the case of the former, it can refer to raw material conservation, reduced material inputs, reductions in consumption of energy and water, avoidance of toxic substances in processes and reduction of toxic emissions and waste. In the case of the latter, it can refer to the reduction of impacts (environmental, health and safety) along the whole life chain (from raw material extraction to the final disposal) (Hinterberger & Schneider, 2001; Hilson, 2003; UNEP, 2001).

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[18] Chemical recycling is also known as feedstock recycling (Hopewell et al., 2009).

[19] Eco-efficiency is a similar concept linked to the more efficient use of resources, which focuses on creating more goods and services while consuming less resources and reducing the environmental impacts of production. According to Nilsson et al. (2007, p. 21), the concepts of eco-efficiency and cleaner production are almost synonymous and "the slight difference between them is that eco-efficiency starts from issues of economic efficiency which have positive environmental benefits, while cleaner production starts from issues of environmental efficiency which have positive economic benefits''. It should be noted that the concept of eco-efficiency has attracted criticism by Braungart et al. (2006) (see more details in footnote 7).

Improving the efficiency of resource use is also linked to the concept of eco-design, which can incorporate not only elements related to recycling, remanufacturing and product life extension (see below details on remanufacturing and product life extension), but also other aspects such as dematerialisation and material selection (Almeida et al., 2010). For example, in the building sector, improved design of concrete, careful materials selection and enhanced technological and building techniques can allow the use of less materials or materials that are less CO_2-intensive (Habert et al., 2010; Bribián et al., 2011).

Preventing the generation of waste along the life-cycle stages of production and consumption can help avoid the loss of resources and the environmental impacts associated with waste management. For instance, in the food sector, where significant quantities of food are wasted,[20] new technologies such as precision farming, effective surplus management and educational measures can help prevent the generation of waste in the supply chain (Jurgilevich et al., 2016; Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015). Additionally, in agriculture there are several measures available to improve the efficiency of the use of phosphorus and reduce its inputs, such as optimisation of land use, improvement of fertiliser application techniques and adjustment of livestock densities to available land (Schröder et al., 2011). The food sector furthermore presents an example of a sector where more efficient processes could lead to a decrease in the consumption of energy resources. For instance, Pimentel et al. (2008) estimated that in the US food system, a reduction of fossil energy inputs of 50% could be achieved through changes in food production, packaging, processing, transportation and consumption.

The issue of improving the sustainability of primary sourcing can also fall within this category of circular processes, although it does not entail directly a reduction in primary resource use. An example is the mining industry where improved technologies, sound process control, enhanced site design and reclamation of abandoned mines aim to reduce the environmental impacts of mining (Hilson, 2003). In this industry, the application of life-cycle assessment methods can help address the environmental impacts of the mining process or over the life cycle of the mineral products (Balanay & Halog, 2016).

Utilisation of renewable energy sources. As indicated by some of the definitions presented in section 2, the increasing use of renewable energy sources is a core requirement for the transition to a circular economy. The combustion of fossil fuels for energy generation is by definition not restorative. Yet oil, natural gas and coal together still constitute almost three-quarters of total energy consumption in the EU28 (European Commission, 2016b). The negative side effects are manifold, including pollution, greenhouse gas emissions and import dependence.

Various renewable energy technologies exist to replace fossil fuels in the electricity, building and transport sectors. Currently, biomass and renewable wastes, hydro, wind and solar dominate the EU's renewable energy mix (European Commission, 2016b). While the focus on these technologies alleviates many of the environmental, social and economic concerns related to fossil fuels, they also pose new challenges. For example, electricity from some renewable energy sources is likely to face barriers related to intermittency, requiring new market design options to optimally integrate them into the energy mix (DNV GL et al., 2014). Similarly, many renewable energy technologies

[20] According to Jurgilevich et al. (2016), the literature contains divergent estimates of the amount of wasted food due to the use of different definitions and counting methods.

depend on the availability of special metals (rare earth metals), which may cause a lock-in into new import dependencies (JRC, 2011a). Biofuels and other biological energy sources, on the other hand, are criticised for their impact on land use, as well as the need to better assess their life-cycle environmental impacts (JRC, 2016a).

Waste can be another source of energy. The use of biodegradable waste in energy production or as fertiliser can have positive environmental impacts (European Commission, 2017b). For example, instead of landfilling, using one tonne of biodegradable waste in biogas production or as fertiliser has the potential to prevent up to 2 tonnes of CO_2 equivalent emissions. Energy recovery from waste, however, needs to be assessed carefully within the context of a circular economy. According to the EU waste hierarchy,[21] recycling is a more beneficial option than the combustion of waste for energy generation. Therefore, while waste-to-energy solutions may have in some cases positive environmental impacts, the European Commission (2017b) highlights that the most energy-efficient techniques should be used.[22] Understanding the net impact of energy recovery compared to recycling, requires a consideration, inter alia, of two main questions: i) How much energy can be recovered (how energy efficient is the recovery process) and ii) what type of fuel is being by the energy produced from waste?

Plastics is an example of a material with a high calorific value and which therefore might be suitable for burning to use for energy recovery. Nevertheless, in line with the waste hierarchy, it would be better to recycle the plastic as recycling would result in higher overall economic and environmental benefits (JRC, 2011b). Carbon capture and utilisation also falls under the scope of renewable energy sources utilisation, as this technology enables re-using the captured carbon inter alia in fuels or chemicals (Aresta et al., 2013). While this technology is still under development, it could provide an avenue for the use of carbon as raw material. It may lead to decrease in extraction of other materials with positive environmental implications by reducing CO_2 emitted to the atmosphere.

This may entail thinking in terms of an industrial symbiosis where sectors look across value chains and use the side streams of production from other sectors. It can also entail the fostering of collaboration among different industries to discover how waste from one process may be used as raw material in another (Jacobsen, 2006). In general, industrial symbiosis can lead to a reduction in the consumption of primary material and energy through the sharing and exchange of waste, material, by-products and energy (more examples of industrial symbiosis are presented later in the paper).

Industrial symbiosis is demonstrated by the collaboration between the paper and pulp sector and the energy sector. Industrial symbiosis between the sectors can arise through the use of biological resources (e.g. wood residues) and sludge from the pulp and paper industry in energy production, with positive environmental impacts on greenhouse gas emissions and particulate matter formation. In a case study by Sokka et al. (2011), net environmental improvements, occurring in particular via heat and electricity produced for the local town, were estimated to be between on average 5% to 20%. As less electricity and heat need to be purchased from other sources, fewer GHG emissions are produced.

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[21] The EU Waste Framework Directive includes a waste hierarchy with five steps: i) disposal ii) other recovery iii) recycling iv) preparing for re-use and v) prevention (European Union, 2008).

[22] Four waste-to-energy processes are highlighted by the European Commission (2017b): i) co-incineration in combustion plants, ii) co-incineration in cement and lime production, iii) waste incineration in dedicated facilities (e.g. the use of heat pumps) and iv) anaerobic digestion, i.e. the upgrading of biogas into bio-methane for further distribution and use.

Remanufacturing, refurbishment and reuse of products and components. Remanufacturing, refurbishment and re-use are all ways in which used products are recovered after their use and are given a 'next life'. In refurbishment and remanufacturing, the products' 'core' parts are restored so as to maintain the value added of the materials. While both terms 'refurbishment' and 'remanufacturing' are used, the latter entails the idea of more in-depth process aiming to restore the product into an 'as-new' condition. Refurbishment, on the other hand, is understood as referring to less in-depth restoration of a product or a component's value (Van Weelden et al., 2016). Reuse of a product is direct re-usage and/or re-sale of either the whole product or a part of it (JRC, 2011b). All these processes have the potential to change the revenue streams for business since they can allow them to earn a second or third (or more) income from selling the product.

Remanufacturing is commonly applied to certain, often high-value parts of products such as computers or cars (De Jong et al., 2015; Ellen MacArthur Foundation, 2013a). Such practices are closely linked to eco-design: when remanufacturing options are already considered during the design phase of the product, this facilitates, for instance, its disassembly and remanufacturing of parts (Prendeville & Bocken, 2015).

Remanufacturing can reduce costs for manufacturers as well as result in environmental benefits when fewer resources are being used (Pigosso et al., 2010). This was manifested in a UK study that estimates that, in general the carbon footprint of remanufactured products is at least 25% lower than that of new products, while in some cases this figure can reach 80% (Oakdene Hollins, 2011). The Ellen MacArthur Foundation (2013a) has estimated that in the steel sector, refurbishing can result in a drop in the demand for iron ore, globally up to 4% to 6% of expected 2025 levels. In addition, remanufacturing presents a significant economic opportunity; in the UK, Chapman et al. (2010) have calculated the value of the remanufacturing and reuse industry at £2.4 billion,[23] while Lavery et al. (2013) have estimated that the total value of remanufacturing and reuse in the electrical, electronic and optical products, machinery and equipment and transport equipment sectors could reach an annual value of between £5.6 and 8 billion.[24] Economic and environmental impacts may occur e.g. via benefits achieved from energy savings. According to estimates by Lavery et al. (2013) based on figures of energy spending in 2010, savings may amount to £1.9 billion annually.

Remanufacturing prompts companies to retain control over their products and materials, therefore requiring investment into takeback systems and post-use phase of the product. It also involves a behavioural change as consumers are motivated to return products to manufacturers (Prendeville & Bocken, 2015). Remanufacturing is labour-intensive and often requires craftsmen at the local level, therefore creating jobs in small companies (EEA, 2016). It also requires skills and education on combining design and remanufacturing and may therefore lead to further job creation (Gray & Charter, 2006).

Product life extension. Interlinked to the previously discussed economic processes, circularity can be implemented via practices of product life extension. As in the case of remanufacturing, product life extension requires an increased emphasis on the design phase of the product life cycle (Bocken et al., 2016). This translates for example into standardisation of components in terms of size or material. In the building sector, e.g.

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[23] It is also estimated that carbon savings are over 10 million tonnes CO_2 e per year (Chapman et al., 2010).

[24] The study also estimates that these sectors could also provide between 310,000 and 320,000 additional jobs (Lavery et al., 2013).

product life extension is put to use by designing modular components used in construction. These standardised components can be re-used in new buildings or repurposed and used in infrastructure or in another industrial sector (ARUP, 2016).

However, product life extension goes beyond the design of products for remanufacturing or re-use. It can also refer to products and components that are designed with the objective of having a long-term durability and long life spans. One example is the design and use of LED[25] light bulbs, which can be more durable and energy-efficient than conventional light bulbs. The performance of LED light bulbs in buildings can also be monitored and optimised through the use of digital technologies such as the Internet of Things (IoT) (ARUP, 2016). A similar case is that of 'luxury products' (such as high-quality luxury watches), which can be seen as 'classic long-life products' that are sold as 'high-end products'. These types of products come with qualities of durability and focus on customer service, e.g. via repair services (Bocken et al., 2016).

Importantly, in the case inter alia of electronic products, product life extension practices deal not only with extending the lifetime of the hardware but also with the durability of the software. This is related to expanding the product lifetime by tackling planned obsolescence. Planned obsolescence may entail negative environmental impacts such as excessive use of natural resources and environmental damage. Selling the product as service, rather than the product itself (see more details about this process below) may be a way to deal with this issue (Valant, 2016).

While the process of product life extension is generally considered to have a positive environmental contribution, there are also some concerns regarding its net benefits. In particular, it has been suggested that in some cases this process might postpone the market penetration of new technologically advanced products. This could be particularly the case for products such as household appliances and cars in which the transition from one 'generation' to another could entail significant benefits (for example, reduced energy or fuel consumption) (Demailly & Novel, 2014).

Product as service. Product as service refers to the concept of offering the product as a service which challenges the traditional business approach of selling tangible products. It can be implemented via practices of leasing, renting, pay-per-use or performance-based business models. Tukker (2004) has identified eight categories of product-as-service models.[26] They include, inter alia:

i) Paying per service unit where the consumer pays for the output of the product according to the level of use (e.g. pay-per-print services offered by copier producers). The business selling the service is responsible for costs in the entire lifecycle of the product.
ii) Renting or sharing the product where the consumers purchases access to the product for an agreed period of time.
iii) Leasing the product where the consumer has a continued access to the product.
iv) Product pooling where many customers use the same product at the same time. This sub-category is closely linked with the sharing models that are described below (for example, car sharing).

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[25] This stands for light-emitting diodes.

[26] The eight categories identified by Tukker (2004) are as follows: 1) product-related service, 2) advice and consultancy, 3) product lease, 4) product renting and sharing, 5) product pooling, 6) activity management, 7) pay per unit use and 8) functional result.

In all the above-mentioned cases, the company retains the ownership of the product in question and offers the customer access to the product. In this way, the company maintains the material resources at its disposal. This practice can bring environmental benefits as the model motivates the company to repair and maintain the product in use for a longer period of time (Accenture, 2014). Through practices of recycling and refurbishment, waste created during the lifetime of the product may decrease (Beuren et al., 2013). Other environmental benefits may also occur from product as service models; for instance HP (2016) estimates that customers that choose their product as service model can reduce their printing-related energy by up to 40%.

While these environmental benefits have been reported in previous studies (see for example Baines et al., 2007), there are also concerns about the net environmental benefit of these models, as explained in section 2.1 (see Tukker, 2015; Tukker & Tischner, 2006). Criticism has also been directed specifically at the energy consumption impact of product as service models. In particular, it has been argued that the energy efficiency of product as service systems depends on the development of efficiency improvements that are introduced between new product generations. As leasing models hand over to the manufacturer the ownership of the product, the energy savings achieved depend on the optimal replacement pace for each product and how replacement behaviour changes between the circular and the linear model (Intlekofer et al., 2010).

The 'product as service practice' is often closely linked to the previously described process of 'product life extension'. Such economic processes have in addition been adopted in the domestic appliances and consumer electronics sectors, for instance, in the form of pay-per-use models in washing machine use. These traditional product as service models have more recently been complemented by elements enhanced by digital technologies. As an example, new business models connect launderette washing machines to the internet, allowing consumers of launderettes to check availability of the washing machines (Valencia et al., 2015).

Sharing models. Sharing models are inextricably linked to the circular economy concept since they seek to reduce under-utilisation of products and thereby support the more efficient use of resources. Sharing models can also contribute to the creation of genuine social capital (JRC, 2016b) and to a sense of community. This finding is demonstrated in research by Albinson & Perera (2012) on non-monetary-based sharing events, which have been found to be used by organisers and participants as venues to share knowledge and possessions for ideological and practical reasons. Notably, in addition to the sharing of products and services among individuals, this circular process can also possibly take the form of sharing of technologies and infrastructure among industry partners (Balanay & Halog, 2016).

Although it is generally agreed that these models have the potential to radically transform our consumption patterns to the benefit of the environment, one may argue that more research is required to better assess the magnitude of expected environmental benefits. In the case of car-sharing, for example, Demailly & Novel (2014) suggest that the net environmental impact depends on the durability of the car as well as on whether the sharing model has motivated the driver to increase his/her travelling with the car. Similarly, in the accommodation sector, it can also be debated whether sharing platforms can lead to an increased travelling with negative environmental impacts (Stegeman, 2015). Furthermore, social concerns on working conditions, labour rights and consumer protection have also been raised in the context of sharing models (JRC, 2016b).

Sharing models have been used in car-sharing and accommodation services and are facilitated by advances in digital technology. They are sometimes referred to as 'collaborative consumption' as they are often implemented via social platforms. Sharing models as well as the idea of product lifespan extension are also linked to idea of sufficiency as business model. Sufficiency is based on the principle of overall moderation of resource consumption, focusing on reducing demand by changing consumer behaviour via education. In order for product as service and sharing economy models to flourish, a change in consumer mind-set is required away from the need to own a product, such as a car (Bocken & Short, 2016).

Shift in consumption patterns. Technological advancements as well as improved information for consumers can result in a shift in demand patterns. For example, many consumers choose products or services that deliver utility virtually instead of materially. Examples include digital books, smart phones, music and online stores. At the same time, businesses can provide their products virtually using virtual channels (for example, selling digital products through online shops) and also increasingly communicate with customers virtually through web advertisements, e-mails and social media (Lewandowski, 2016; Ellen MacArthur Foundation, 2015c). These shifts may in turn lead to resource savings and productivity gains; it should be kept in mind, however, that there are also concerns about the scale of the sustainability benefits that could be enabled by these products and services due to rebound effects and the high energy consumption of data centres (Whitehead et al., 2014; Climate Group, 2008).

Food consumption is another area where changes in demand patterns can lead to the consumption of food products whose production is less resource-intensive. For example, information-based and education-oriented tools, such as labels, campaigns and educational programmes have the potential to raise awareness about the environmental and health impacts of different diets and motivate consumers to make more sustainable food choices (Jurgilevich et al., 2016; Reisch et al., 2013). Nevertheless, their potential in changing buying decisions is often untapped due to barriers at the institutional, informational, infrastructural and personal levels (Reisch et al., 2013).

The above-described circular processes can be applied to different sectors of the economy. The next step would be to develop an understanding of how this can be put into practice and which would be the associated effects.

3.2 Application in different sectors and expected effects

This section presents a set of examples of how the economic processes are applied in different sectors and what the expected effects are. Prior to presenting these examples, Table 2 below provides a mapping of the different sectors to which the processes can be applied. While not meant to be exhaustive, the mapping serves as a starting point for providing examples of how circularity affects businesses in a sector-specific manner.

There are several studies in the available literature that provide mappings of different circular processes at company level,[27] but for the purpose of this study the research team has developed an application for mapping different circular economic processes in various sectors. Previous research as well as the interviews with experts conducted for this study have been used as the basis for this categorisation:

Table 2. Mapping of application of circular economy processes in various sectors

	Circular process	Examples of sectors where circular processes can be applied
USE OF LESS PRIMARY RESOURCES	Recycling	Automobile industry, Textile industry, Building sector, Packaging sector, Critical Raw materials, Forest sector, Chemical industry
	Efficient use of resources	Building sector, Plastics industry, Mining and metals industry, Food sector
	Utilisation of renewable energy sources	Chemical industry, Food industry, Forest sector
MAINTAIN THE HIGHEST VALUE OF MATERIALS AND PRODUCTS	Remanufacturing, refurbishment, and reuse of products and components	Automobile industry, Manufacture of computer, electronic and optical products, Building sector, Furniture sector, Transport
	Product life extension	Manufacture of computer, electronic and optical products, Automobile industry, Household appliances, Building sector, Food industry, Textile industry, Defence industry
CHANGE UTILISATION PATTERNS	Product as service	Household appliances, Transport, Building sector, Printing industry
	Sharing models	Automobile industry, Transport, Accommodation, Clothing
	Shift in consumption patterns	Food sector, Publishing sector, E-commerce sector

Source: Authors' own elaboration.

Recycling of Critical Raw Materials

Critical raw materials (CRMs) [28] are raw materials with a high economic importance as well as high risk of supply shortage (European Commission, 2014). In the EU Action Plan for the Circular Economy, the European Commission (2015a) emphasises their importance and identifies the following barriers to improving their recycling rates: low-

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[27] See for example the studies by Ellen MacArthur Foundation (2013a), WRAP (2012), Accenture (2014) and McKinsey Center for Business and Environment (2016).

[28] The European Commission's (2014) Communication on the review of the list of critical raw materials for the EU provides the following list of 20 critical raw materials: Antimony, Beryllium, Borates, Chromium, Cobalt, Coking coal, Fluorspar, Gallium, Germanium, Indium, Magnesite, Magnesium, Natural Graphite, Niobium, PGMs, Phosphate Rock, REEs (Heavy), REEs (Light), Silicon Metal, Tungsten.

quality recycling, difficulties in collecting, dismantling and recycling products that contain such materials, limited information exchange between manufacturers and recyclers of electronic devices, absence of recycling standards and lack of data for economic operators on the potential for recycled critical raw materials. The supply of CRMs is important for several sectors described in Table 2 and can therefore be seen as a cross-sectoral issue.

Improving the recovery and recycling of CRMs could bring significant benefits to the EU, such as reduced dependency on imports from third countries. Recycling of these materials may increase security of supply for companies and bring material costs down once a secondary raw-material market is functioning. Use of recycled materials would possibly change demand patterns for primary materials leading to less extraction of primary material (European Parliament, 2011).

At the same time, there will also be some challenges for businesses that need to be taken into account. For example, CRMs are spread around a variety of consumer products and can often be found in small quantities in each of these products. Recycling of these materials therefore requires the establishment of sophisticated take-back systems that are different from those in use in other sectors, as recovery of CRMs requires a system with a detailed separation process enabled by advanced technology. This would in turn require high levels of investment. As an illustration, a report studying the recovery of critical metals in decarbonisation technology (such as electric vehicles) finds that designing and implementing take-back systems for recovery of rare earth materials used in the NdFeB permanent magnet technology[29] of electric vehicles would necessitate an investment of approximately €1 billion in the EU (JRC, 2013). Moreover, recycling and re-directing CRMs to be put to use in a sector where it has the highest possible value requires companies to establish new partnerships, logistics chains and cooperation with partners across value chains (EASAC, 2016).

At the product level, the effects of the circular economy are manifested in a study by Buchert et al. (2012) on recycling of critical raw materials from waste electronic equipment. Among other examples, the study analyses recycling of critical raw materials from notebook computers in Germany. It reports that in 2012, only a few small companies in Germany had the capacity to carry out a thorough manual disassembly. Therefore, business opportunities for new companies may arise in providing this service. Additionally, the current notebooks are designed in such a way that the critical raw materials are difficult to separate from other materials. Recycling of these materials is very labour-intensive and will remain so as the process can only be mechanised to some extent. Thus, job-creation effects may arise in manual disassembly of hardware containing critical raw materials. Taking back products, such as mobile phones or computers, also changes the manner in which businesses communicate with their customers. In the case of notebooks in Germany, there is no reliable data on the location of the devices that are not recycled (Buchert et al., 2012). For a take-back system to function, customer behaviour needs to change and in many cases this might require appropriate incentives for returning used products.

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[29] Most electric vehicles use a permanent NdFeB magnet (also known as a neodymium, NIB or Neo magnet) in their drive motor. The magnet is made from an alloy of rare earth elements (neodymium, iron and boron) (JRC, 2013).

Product lifecycle extension and remanufacturing in the building sector

Another example of changes that occur with circular economic processes is demonstrated in the building sector. Notably, construction is considered to be one of the sectors with the greatest costs-saving potential in introducing circular practices. A study conducted for the UK estimated the benefits of improving resource efficiency using 2009 as the base year. The study calculated that by reducing waste and improving material-resource efficiency the building sector had an opportunity to save £2,601 million in 2009 and achieve a potential reduction of greenhouse gas emissions of up to 1,638 KtCO2[30] (Oakdene Hollins, 2011).

In the building sector, practices of re-manufacturing and product life-cycle extension are already in use.[31] Product life extension in the building sector refers to prolonging the life of the asset, i.e. the buildings, by designing them to last for a longer period of time. For instance, the use of durable materials and high construction standards can increase the life span of the building leading to reduced maintenance costs. Businesses in the construction sector may increase their circularity by paying more attention to the design-phase, anticipating the possibility of re-use and re-purposing parts of the buildings (ARUP, 2016).

Circular practices in the building sector were implemented in the construction of the Olympic park in the context of the 2012 London Olympics as buildings were designed for deconstruction taking into consideration their use after the Olympic Games. This led to a change in the use of materials, for example, by replacing the use of concrete with steel in temporary bridge structures, as this made the structures easier to disassemble. In addition, construction sites used industrial symbiosis to retrieving construction material. Leftover gas pipelines from the energy industry were used in the structure of the Olympic stadium. This cross-value chain cooperation led to saving 2,500 tonnes of new structural steel and resulted in cost savings of approximately £0.5m. This indicates that circular practices in the building sector can translate into positive environmental impacts in terms of reduced waste as well as costs savings for the company (Moon & Holton, 2011).

Remanufacturing practices in the building sector require standardisation of products and elimination of hazardous materials so as to enable the re-use of building components. This can be achieved through improved design that requires initial investment but may be economically profitable for companies as they may restore the material or sell it in order to be used in another sector, for example in road infrastructure (WRAP, 2009). The introduction of new practices of remanufacturing may also entail other types of costs for the industry. For instance, according to a study by WRAP (2009), the introduction of these new practices would require on-site training of staff, storage space for materials and also an increase in management time.

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[30] The study assesses the potential benefits of improving resource efficiency in different sectors including freight, transportation, agriculture, retail, commercial offices, chemicals, metal manufacturing and construction (Oakdene Hollins, 2011).

[31] In addition to practices of product life extension and remanufacturing, changes in the building sector also occur due to the introduction of sharing models. Sharing platforms, among which the most known is Airbnb, allow individuals to rent out apartments via an online platform and may impact demand for accommodation in hotels. Such models can increase the utilisation rate of assets and according to some studies may be more environmentally friendly means of accommodation than hotels (ARUP, 2016). For example, a study conducted for Airbnb suggests that Airbnb guests in the US use 63% less energy than hotel guests (Cleantech Group, 2014). However, there are also concerns over the environmental impact of sharing models since they may lead to increased travelling (Stegeman, 2015).

While new business models may require investments, re-manufacturing has been estimated to be less costly than disposal of construction waste. In particular, a study on the construction industry in a region in China conducted a comparison of costs of treatment of used construction material. Based on a comparison of the costs of i) disposal of construction waste, ii) recycling the material and iii) recycling for the purpose of re-use, the study concluded the third option generates the lowest costs for the company (Liu & Wang, 2013).

Using biological resources in the forest sector

The forest industry presents an interesting example of using biological resources to generate new value. The production process in the forest industry leads to a large amount of side streams that are often not used to their fullest potential. Circular practices may be applied to produce products from these side streams (SITRA, 2016).

Specifically, while forest side streams have typically been used for energy recovery, these wood-based leftovers can also be used for the production of other products. For example, sawdust[32] can be used in the manufacture of fibreboard or renewable packaging material. In the case of Finland, the forest sector mainly produces paper which is exported abroad. For this reason it is challenging for the producer to retain the used product at the end of its lifecycle, and the use of side streams presents an opportunity to introduce circular practices (SITRA, 2016; SITRA & McKinsey, 2015).

Instead of using side streams of the forest industry in energy production as biomass, using them as materials shows positive economic and social effects. According to a study by SITRA & McKinsey (2015), the circular economy has the potential to create an annual value of €220-240 million in Finland in the forest sector. Not limited only to the forest sector, growth in the EU's bio-chemicals sectors, where bioplastics[33] are a significant product group, has been estimated at 5.3% per year. According to Domínguez de María (2016), using side streams in production of materials can result in larger employment benefits and greater added value than the production of energy. This in particular due to the longer supply chains generated by the creation of materials compared to energy recovery.

Creation of new products necessitates high up-front investment from companies and increased R&D spending. New companies outside the pulp and paper industry, which is part of the forest industry, might enter the market with the objective to bring new products to the market. This would require industrial symbiosis and cooperation between new businesses and the traditional forestry industry as new partnerships and logistics would need to be established. Companies in the forest sector develop new bioproducts directly in cooperation with their customers for example in the chemical sector. Via a case study on a chemical company, namely Arizona chemicals, SITRA & McKinsey (2015) demonstrated that knowledge of both the forestry and the chemical sector is important when commercialising a product, such as tall oil, for the use of the

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[32] Glucose and lignin are two other examples of such side streams that can be used for the production of products and raw materials for other industries (SITRA & McKinsey, 2015).

[33] Bioplastics are typically produced from renewable raw materials such as starch-based plastics, polylactide (PLA), polyhydroxyalkanoate (PHA), and cellulose-based plastics, relevant for forestry industry. (Detzel et al., 2013). While their environmental impact may be favourable compared to fossil fuel based options, the impacts on whole life cycle depend on the waste disposal scenario (Taengwathananukool et al., 2013). For example, a study on the use of bioplastics in Germany found that knowledge about the disposal of bioplastic packaging is very limited among consumers. While a high percentage of bioplastics was recovered, this was mostly done via waste incineration (Detzel et al., 2013).

chemical sector. As supply chains may be long-established, marketing a new product to a costumer and establishing customer relations may be a time-consuming process (SITRA & McKinsey, 2015).

Some of the side streams of forest industry are so small that their commercialisation might not be attractive to large companies. Therefore, these smaller side streams could create opportunities in particular for SMEs that do not aim to achieve large production volumes (SITRA & McKinsey, 2015)

4 :: Impacts at the EU and national level

As explained in the previous sections, the circular economy holds the potential to change the production and consumption models through the introduction of new processes and disruptive business models. Such a radical transformation of business practices and of the economy as a whole would entail significant economic, environmental and social impacts. In recent years, several studies have been published that assess the impacts of the circular economy at the EU or national level. Based on a desk-based literature review, this section presents an overview of some the available studies, focusing on their results and methodologies. The impacts are divided into three categories: economic impacts (GDP growth, employment, investment, etc.), environmental impacts (use of resources, emissions reductions, pollution reduction, etc.) and social impacts (gender, social opportunities and inequalities, etc.).

4.1 Economic impacts

At the EU level, Cambridge Econometrics & BIO Intelligence Service (2014) used a macro-econometric model to assess the impact of different resource productivity[34] targets for the EU. The study estimates that improving the EU's resource productivity[35] by 2% could help create two million additional jobs in 2030. It is also estimated that improvements of 2-2.5% in resource productivity could also have a small but positive net impact on EU GDP; however, any further improvements in resource productivity would entail net costs to GDP since abatement options become more expensive. Focusing on recycling and reuse across the EU, EEB (2014) built different scenarios around potential EU targets. Depending on the level of ambition in the targets,[36] EEB assesses that around 635,000-750,000 additional jobs could be created by 2025 and about 710,000-870,000 by 2030. The calculation of these figures is based on assumptions regarding the number of jobs that is created per thousand tonnes of reused textile and furniture material. An earlier study by Friends of the Earth (2010) applies co-efficients for jobs per thousand tonnes of recycled material in the UK to EU recycling data in order to calculate the potential for job creation through higher recycling rates. The study estimates that a recycling target of 70% at the EU level could

[34] Resource productivity is defined in the study as the unit of GDP produced with one unit of raw material consumption.

[35] The following types of materials are covered in the study: food, animal feed, forestry, construction minerals, industrial minerals, ferrous ores and non-ferrous ores.

[36] For instance, the recycling target in the scenarios ranges between 55% and 60% for the year 2025 and between 60% and 70% for the year 2030.

lead to the development of more than more than 563,000 net new jobs. This figure includes 'direct' new jobs but also 'indirect' and 'induced' employment.[37]

Using economic modelling as well as information collected through 150 interviews with experts, Ellen MacArthur Foundation & McKinsey Center for Business and Environment (2015) estimate that in the mobility, food systems and built environment sectors technological advancements combined with organisational innovations would allow Europe's resource productivity to grow by 3% by 2030, translating to total annual benefits of €1.8 trillion.[38] This would in turn lead to a GDP increase of 7%. In line with the definition of the circular economy provided by Ellen MacArthur Foundation (see section 2.2), the economic analysis in the study goes beyond material reuse and encompasses several different aspects such as renewable energy, nutrient flows, management of both materials of biological origin and technical materials and optimisation of performance/efficiency of products. Notably, the authors emphasise that the estimates are only indicative and are based on several assumptions. Another report by Ellen MacArthur Foundation & SYSTEMIQ (2017) estimates that although some emerging business models such as electric vehicles and the sharing economy are quickly growing, circular investments represent only 10% of linear investments. The report goes on to estimate that in the three above-mentioned sectors[39] there is an additional investment opportunity[40] of €320 billion[41] that could be unlocked by 2025 through 'modest' action by policy-makers or industry; this could help achieve an additional GDP growth of 7%.

In an impact assessment of the review of waste management legislation, the European Commission (2015b) has estimated the job creation impacts of different proposals for EU waste legislation. Scenarios are based on policy options on recycling targets, limitations to landfilling of residual waste and possibilities of landfill bans on plastic/paper/glass/metals by 2025. The study estimated that different scenarios have the potential to create between 136,000[42] to 178,000[43] full-time jobs by 2025, with most jobs being created in the recycling industry. The study also noted that the largest job-creation benefit would manifest itself in those EU countries that have the greatest need for improvement in their waste management systems (European Commission, 2015b).

Turning to the studies available at the country level, Wijkman & Skånberg (2015) use an input/output model to estimate the effects of the circular economy in terms of job

[37] According to Friends of the Earth (2010), indirect employment may arise, for example, from the industry purchases of goods and services from other types of business establishments, while induced employment may arise from the spending of the wages of the employees in the recycling industry.

[38] This includes the primary resource benefit of €0.6 trillion as well as the non-resource and externality benefits (for example non-cash health impacts of accidents, pollution, noise, etc.) of €1.2 trillion.

[39] According to Ellen MacArthur Foundation & SYSTEMIQ (2017), the value chains in the mobility, food, and built environment sectors represent 60% of consumer spending and 80% of resource use.

[40] Investment opportunities are quantified on the basis of investment metrics, which are identified through a combination of desk-based research and expert interviews.

[41] Regarding the breakdown of this figure, €135 billion are in the mobility system, €70 billion in the food system and €115 billion in the built environment (Ellen MacArthur Foundation & SYSTEMIQ, 2017).

[42] The most moderate employment impacts would take place in case of 65% reuse/recycling target for municipal solid waste, 75% recycling/reuse target for packaging waste and landfill reduction target for municipal waste of maximum 10%. The landfill reduction target would entail member state specific deadlines for implementation (European Commission, 2015b).

[43] The highest employment impacts would take place in case of 70% reuse/recycling target by 2030 for municipal solid waste with possibility of a 5 year time-derogations for 7 member states and 80% recycling/reuse target for packaging waste (European Commission, 2015b).

opportunities in five EU countries. The following steps towards a circular economy are considered in the study: enhancing energy efficiency, increasing the percentage of renewable energy in the energy mix and organising manufacturing along the lines of a material-efficient performance-based economy. On this basis, the researchers first developed separate scenarios for each of these steps and then assessed their combined effects. The study estimates that pursuing these three strategies together can lead to the development of 75,000 additional jobs in Finland, 100,000 in Sweden, 200,000 in the Netherlands, 400,000 in Spain and around 500,000 in France. Despite these estimated benefits, the study also stresses that some sectors will benefit from this transition ('winners'), while others might suffer negative consequences in their economic activity and employment ('losers').[44] It should be noted that the use of the term 'additional jobs' by this study has been criticised by Horbach et al. (2015), who claim that the applied methodology does not allow the calculation of net employment effects. Wijkman & Skånberg (2015) furthermore conclude that meeting the demand of the circular economy transition in these countries would also require an additional level of annual investment in the range of 3% of GDP[45] until 2030. Investments would be needed to transform or upgrade several sectors such as agriculture, forestry, recycling, maintenance and repair, mobility, construction and engineering services. Once more, the authors emphasise that the results of the model should be treated with caution due to several limitations, such as lack of recent data for several countries.

Morgan & Mitchell (2015) conducted a study that assesses the job creation potential of the circular economy in the UK. Importantly, their interpretation of the circular economy includes the following activities: reuse, closed looped recycling, open loop recycling,[46] biorefining, repair and remanufacturing and servitisation.[47] It is estimated that at the current development rate the circular economy could create around 200,000 new jobs and provide a net employment growth of around 54,000 jobs by 2030. According to a more ambitious scenario that involves an extensive proliferation of circular economy practices,[48] the circular economy could create about 520,000 new jobs and achieve a net employment growth of around 100,000 jobs.[49] The study furthermore provides some information about the skill level of the new jobs. For instance, it is estimated that low-skilled workers would represent a significant fraction of employment in reuse and recycling, whereas other activities such as biorefining and servitisation would require more high-skilled labour. For the Netherlands, Bastein et al. (2013) first assess the impact of improving circularity in the metal and electrical sectors and using biomass waste streams and then scaled up these findings in order to estimate the overall

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[44] For example, service companies and businesses offering intelligent product design may increase their market share. At the same time, more traditional industries such as providers of virgin materials might experience revenue and job losses (Wijkman & Skånberg, 2015). EEA (2016) and Acsinte and Verbeek (2015) have also mentioned this issue.

[45] This figure translates into about €6 billion in Finland, €60 billion in France, €20 billion in the Netherlands, €30 in Spain and €12 billion in Sweden.

[46] Closed looped recycling refers to using waste in order to produce new products either by changing the properties of the recycled material or not. In both cases the quality of the material is maintained. Open loop recycling (often described as 'downcycling') refers to using recovered materials so as to produce products with lower value (Morgan & Mitchell, 2015).

[47] According to Morgan & Mitchell (2015, p. 5), "this refers to any system which increases the effective use of assets''.

[48] The scenario involving the transition to a circular economy at current development rate assumes, among others, a recycling rate of 70% and a remanufacturing rate of 20%. By contrast, the more ambitious scenario assumes, inter alia, a recycling rate of 85% and a remanufacturing rate of 50%.

[49] Interestingly, the study also estimates that the circular economy could moderate some of the job losses that are expected in mid-level occupations such as jobs in plant and machinery operatives.

economic impact on the Dutch economy. On this basis, they calculate that the circular economy could have an added value of €7.3 billion per year, accounting for 1.4% of the country's GDP, and also create about 54,000 jobs.

In addition, country-level analysis has been conducted by the Ellen MacArthur Foundation (2015b) with an estimation of benefits of circular economy for Denmark. It does so based on its 'toolkit for policymakers' (Ellen MacArthur Foundation, 2015c) where key sectors of the national economy with circularity potential are identified. After their identification, the report combines data from the National Statistical Authority with expert opinion and judgments to evaluate impacts in a quantitative or semi-quantitative manner. In the case of Denmark, the authors estimate the impact of circularity on five sectors: food & beverage, construction & real estate, machinery, plastic packaging and hospitals. The study finds that by 2035 circularity has the potential to increase Danish GDP by 0.8–1.4% and lead to the creation of additional 7,000–13,000 job equivalents. The study also suggests that circular economy may increase net exports by 3–6% (Ellen MacArthur Foundation, 2015b).

For Finland, SITRA (2016) estimates that the potential value of the circular economy could amount to €2-3 billion by 2030[50] through improving circularity in the following sectors: machinery and equipment and forest industries, food waste, real estate, private consumption and second-hand trade and nutrient recycling.

4.2 Environmental impacts

There are several studies available in the literature that have assessed the environmental impacts of the circular economy or resource efficiency. As shown below, some studies have focused on specific processes that fall within the scope of the circular economy (e.g. recycling, reduction of waste), while others have adopted a broader approach.

At the EU level, Cambridge Econometrics & BIO Intelligence Service (2014) assess the impact of resource productivity targets for the EU (see previous section 4.1). The study estimates that improving the EU's resource productivity by 3% would lead to a reduction of 25% of GHG emissions by 2030. A study by EEB (2014) modelled the impacts of improved resource efficiency on GHG emissions reductions, in food waste reduction, avoided water use, avoided fertilizer use and avoided land-use. Depending on the ambition level, EEB estimates that 56.5 Mt[51] to 96.5 Mt[52] of GHG emissions could be avoided by 2025 from reduced food waste and reuse practices in the textiles and furniture sectors. For 2030, the EEB estimates the potential for GHG emission reduction from these sectors to be between 74.6[53] Mt to 115.0 Mt.[54] The study uses models developed by Ökopol (2008) on the impact of different recycling rates[55] on climate

[50] SITRA (2016) uses estimates by Sitra & McKinsey (2015) on resource flows and value creation combined with estimates by Ellen MacArthur Foundation. Among the sources used by Sitra & McKinsey (2015), are data from Eurostat and the National Statistical Authority. Notably, while SITRA and McKinsey do not specify on which Ellen MacArthur studies their estimates are based, the numbers they refer to appear to be based on Ellen MacArthur Foundation (2013a).
[51] 42.1 Mt from food waste and 14.4 Mt from re-use practices in textiles and furniture sectors.
[52] 70.2 Mt from food waste and 26.3 Mt from re-use practices in textiles and furniture sectors.
[53] 56.2 Mt from food waste and 18.4 Mt from re-use practices in textiles and furniture sectors.
[54] 84.3 Mt from food waste and 30.7 Mt from re-use practices in textiles and furniture sectors.
[55] The report uses calculations conducted by Ökopol for the following scenarios: The first (modest) scenario takes the current recycling rate (as of 2005) assuming a constant growth of 1.1% per annum. The second (medium) scenario assumes a 65% recycling rate by 2020 based on an assumption that "the tonnage would

protection and GHG emissions. Ökopol (2008) estimated that by 2020, depending on the scenario, recycling may lead to CO_2eq reductions from 247 to 330 million tonnes. It is to be noted, however, that the predictions are based on research conducted nine years ago, using recycling rates of 2005 as baseline.

EEB (2014) modelling shows potential for water-use savings of 26.1 Ml to 52.2 Ml by 2025 and 34.8 Ml to 60.9 Ml by 2030. The calculation of these figures is based on assumptions regarding the water-use reductions resulting from the re-use of textiles. Textile re-use is also estimated to lead to results in cotton production resulting in reduced fertilizer and pesticide use. The EEB estimates an avoided fertilizer and pesticide use of 0.44 Mt to 0.88 Mt by 2025 and of 0.58 Mt to 1.02 Mt by 2030. The study also foresees positive environmental impacts resulting from avoided land-use due to food waste reduction. The study estimated avoided land use for agriculture amounting to between 28,350 sq km and 47,520 sq km by 2025 and to 38,070 sq km to 56,970 sq km by 2030. These EEB estimates are based on an assumption of a direct link between food-waste reduction and reduction of primary-food production. While making this assumption, the authors acknowledge that such a direct link may be debated.

The Ellen MacArthur Foundation & McKinsey Center for Business and Environment (2015) study, based on economic modelling and information collected through 150 interviews with experts, estimates environmental impacts of the circular economy. The study concludes that in the three sectors studied (see section 4.1), the circular economy may decrease GHG emissions up to 48% by 2030 and up to 83% by 2050. Across the three assessed sectors, the study also shows impacts on primary material consumption. The study estimates that inter alia in car and construction materials, land use and agricultural water use and fertilizer use, primary-material consumption could decrease up to 32% by 2030 and 53 % by 2050.

The impact assessment of the review of waste management legislation has estimated the GHG emissions effect in case of full implementation of proposed EU waste legislation. The impact assessment models the effects of implementing different recycling targets and the landfill diversion targets for municipal biodegradable waste and concludes that they could lead to a reduction of between 424[56] and 655[57] Mt of CO_2eq by 2015 and 2035, respectively (European Commission, 2015b).

A study carried out for the European Commission by Lawton et al. (2013) estimated environmental benefits of materials savings in the food and drink, manufacturing, fabricated metal products and hospitality and food services sectors. The study estimates that improving resource efficiency in the assessed sectors can result in a reduction of 2-4% of total annual GHG emissions in the EU annually. The results are based on individual company case studies, prompting the authors to note that they may not be representative for an average company.

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remain stable as a result of prevention and reduction activities'' (EEB, 2014, p. 32). The third (ambitious) scenario is conducted by EEB (2014, p. 33) based on kg/capita waste generation and "relies on maintenance of similar levels of recycling as the medium [second] scenario, therefore the same conservative estimate is used for GHG emissions avoidance''.

[56] The most moderate GHG emission reductions would take place in case of 65% reuse/recycling target by 2030 for municipal solid waste with the possibility of a 5-year time-derogation for seven member states and 75% recycling/reuse target for packaging waste (European Commission, 2015b).

[57] The highest GHG emissions reductions would take place in case of 70% reuse/recycling final target for municipal solid waste and 80% recycling/reuse target for packaging waste by 2030 (European Commission, 2015b).

At the national level, Wijkman & Skånberg (2015) use an input/output model in order to estimate the effects of the circular economy in terms of reductions of CO_2 emissions in five EU countries. As explained in section 4.1, the researchers consider three steps towards the circular economy and develop scenarios for each step and their overall effects. Depending on the scenario, the steps are estimated to result in reductions of CO_2 emissions between 3% and 50% by 2030. However, combining these three strategies ('steps') could lead to a 66% decrease in CO_2 emissions in Sweden, 68% in Finland, 67% in the Netherlands, 66% in France and 69% in Spain.

Analysis of environmental benefits at the national level has also been provided by the Ellen MacArthur Foundation (2015b) which provides estimates about Denmark (more details are provided in the previous section 4.1). The study finds that circular economy can reduce Denmark's carbon footprint by 3-7%.[58] In addition, the study estimated a 5–50% reduction in virgin resource consumption by 2035.

4.3 Social impacts

While the employment impacts of the circular economy in terms of the number of jobs have been analysed in previous research (see Bastein et al., 2013; Wijkman & Skånberg, 2015; EEB, 2014), assessments of other social and employment impacts appear to be less present the literature. Specifically, there is limited information available on social aspects such as gender, skills, occupational and welfare effects, poverty and inequalities.

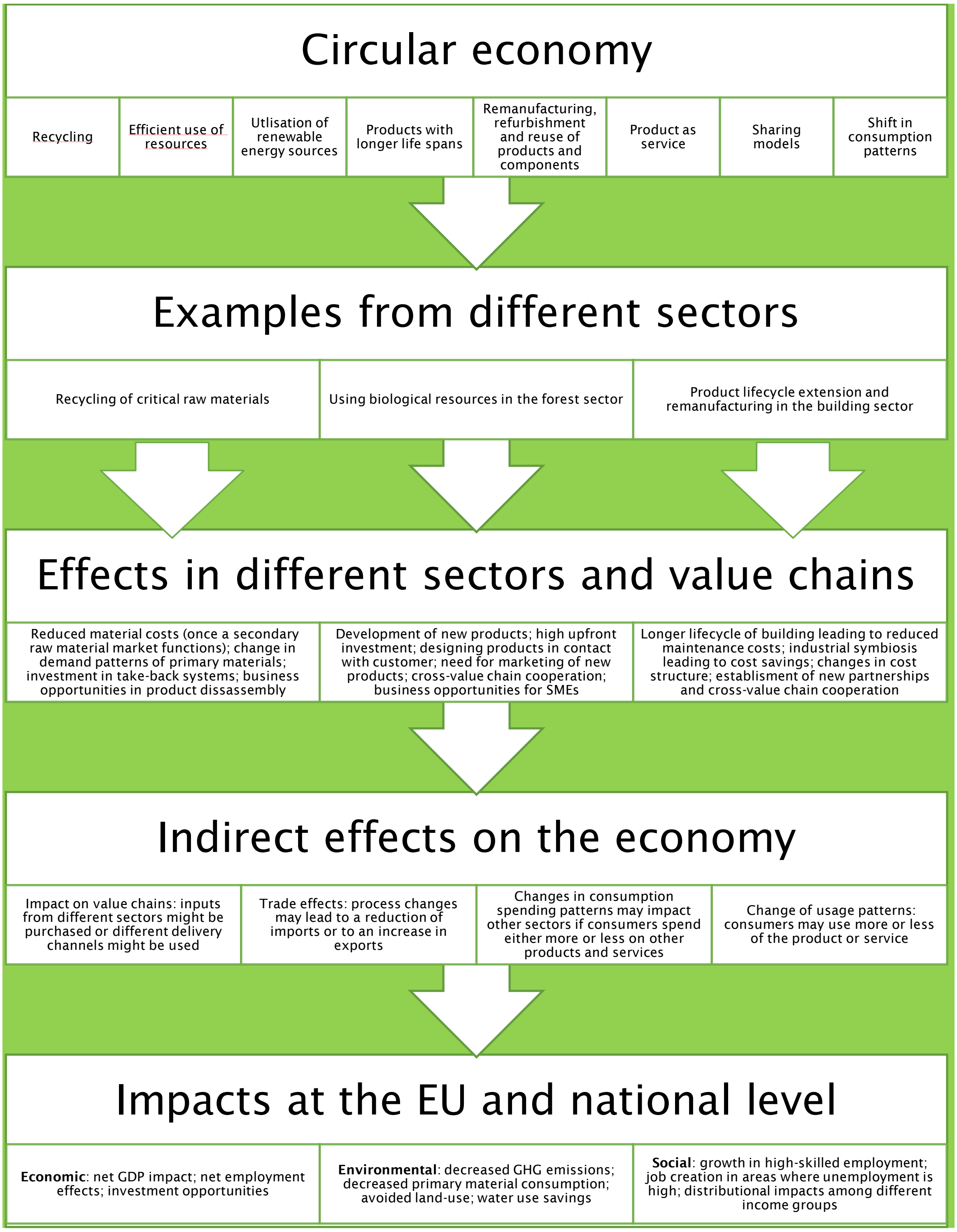
The study by Morgan & Mitchell (2015) is an example of a research effort that goes beyond assessing the potential of the circular economy in terms of the number of jobs and considers additional aspects related to employment. For instance, they estimate that in the UK the circular economy could help offset some job losses that are expected in mid-level skilled positions due to industrial change. Some of their scenarios also foresee a high demand for mid-level skilled employment, which could lead to displacement of mid-level skilled. The study forecasts that the circular economy holds the largest potential to reduce regional unemployment in the areas exhibiting the highest unemployment rates as well as contribute to a reduction in regional unemployment disparities. Some information about distributional impacts is provided by the study by Cambridge Econometrics & BIO Intelligence Service (2014). For example, the study estimates that in the scenario of improving the EU's resource productivity by 2%, the distributional impacts across different income groups would be fairly even.

[58] This reduction is "measured as change in global carbon emissions divided by 'business as usual' Denmark carbon emissions'' (Ellen MacArthur Foundation, 2015b, p. 26).

Table A1 in the Annex I summarises the evidence of the literature assessed in this section 4. Moreover, Figure 1 below provides a visual presentation of the different steps described in the previous sections, from introducing the circular economy processes with their effects on the sectors and value chain to the indirect effects on the economy and the overall economic, environmental and social impacts at the national and EU level. It is important that the different effects on sectors affected by the change are not confused with the overall impacts. Due to the indirect effects on the economy of these processes, the overall impacts can differ significantly from the sum of the direct effects in the affected sectors.

This is true for several reasons. In the first instance, many process changes will not only affect the directly involved sectors, but they will also have an impact on the complete value chain of the sectors as the new processes might require purchasing from other sectors than the processes they are replacing or the use of different delivery channels. Secondly, the changes can have profound implications for the terms of trade of countries, if the process changes lead to a reduction of imports or to an increase in exports. Thirdly, any changes in consumption spending patterns will have significant impacts on other sectors, if consumers need to balance their books and can either spend more or less on other products and services. Lastly, the changes involved can also lead to consumers using more or less of the product or service (change of usage patterns). All of these changes will have significant economic, environmental and social implications, but we found that these implications have not been discussed in any detail in the literature we found. Therefore, an important aim of the Circular Impacts project will be to summarise and collect the emerging evidence on the macroeconomic impacts to be expected.

Figure 1. Circular economy effects on sectors and impacts



Source: Authors' own elaboration.

5 :: Conclusions and recommendations

Based on an extensive literature review, this paper has provided a reflection on the concept of the circular economy, an overview of the main circular economy processes, their applications in different sectors and their economic, environmental and social impacts.

The breadth of interpretation of the circular economy concept at the academic and policy levels and the wide range of aspects and priorities it encompasses are reflected in the diversity of definitions presented in section 2. While some definitions and interpretations focus on physical and material resource aspects, others go further and discuss a major transformation of the economic system involving various sectors and issues that go beyond material resources and waste. This is also evident in the available studies that adopt different approaches when calculating the impacts, which makes the comparison of results from different sources challenging. The circular economy is a complex concept and it is unlikely that in the short term there can be an international consensus on its meaning. Still, at the EU policy level, there is perhaps a need for more clarity about the areas and sectors that can fall within the scope of the circular economy. This can help avoid confusion as well as support the preparation of focused studies and impact assessments that will provide consistent messages about the potential effects.

Section 3 described different circular processes that can be implemented by businesses. As indicated by the literature, these processes have significant potential to deliver economic, environmental and social benefits. Although the message conveyed in the literature about the net benefits of these processes is generally positive (see for instance Ellen MacArthur Foundation, 2013a; Lavery et al., 2013; Oakdene Hollins, 2011), there are also studies pointing out that their net environmental impacts depend on their careful design and implementation (see Tukker & Tischner, 2006; Intlekofer et al., 2010; Demailly & Novel, 2014). This implies that in order to avoid simplistic messages, there is a need in each case of applying a circular economy process to a sector to carefully consider all the parameters[59] that can play a role in the overall sustainability of the circular process replacing a linear one. The EU-funded project Circular Impacts[60] will follow this case study approach and will aim to assess the net impacts of the circular processes described in section 3 applied in specific sectors and industries.

As shown in section 4.1, several studies have indicated that the circular economy has a strong potential to trigger significant economic benefits and create jobs. However, although some of the available studies mention that there will be 'winners' and 'losers' in this transition (see for example Wijkman & Skånberg, 2015; EEA, 2016; Acsinte & Verbeek, 2015), there is little specific analysis or data on how different sectors will be affected. Since some industries are particularly important for national and local

[59] For example, in the case of product as service processes, these parameters may refer to the optimal replacement pace for each product and how replacement behaviour changes between the circular and the linear model (Intlekofer et al., 2010), while in the case of sharing models they can refer to the quality of shared goods as well as the potential need for increased transport of goods entailing environmental impacts (Demailly & Novel, 2014).

[60] For more information, see: Circular Impacts - Measuring the impacts of the transition to a circular economy (available online at: http://circular-impacts.eu/).

economies, it is important to provide clarity about the expected net impact on employment across different sectors. This would also help policy-makers design well-targeted transitional policy measures to manage the negative impacts in some sectors as well as in national and local economies. There is also a need to understand the indirect effects on the economy (e.g. impacts on the value chain and/or changes in consumption spending patterns) in order to estimate the overall impacts at the EU or national level.

Additionally, although some studies provide information on the employment potential of the circular economy in terms of the number of jobs it might create, much less emphasis has been placed in the literature on other social and employment impacts such as gender, skills, occupational and welfare effects, poverty and inequalities. This indicates that there is a need for more research that would address these aspects and also help policy-makers anticipate effects in different social groups. Another aspect that has not been covered extensively in the literature and would require more research concerns the impact of circular economy practices adopted in the EU on non-EU countries. Given that value chains in many sectors are global and also that important resources, such as critical raw materials, are often imported from third countries, impacts on employment and GDP may also take place outside the EU.

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Annexes

Annex 1. Tabular summary of the literature

Table A 1. Literature on impacts at the EU and national levels assessed in the study

Source	Scope	Methodological aspects	Impacts
Ellen MacArthur Foundation & McKinsey Center for Business and Environment (2015)	Sectors: Mobility, food systems, and built environment sectors in the EU	Economic modelling and information from 150 interviews. Consideration of several aspects such as material reuse, renewable energy, nutrient flows, management of both materials of biological origin and technical materials and optimisation of performance/efficiency of products.	**Economic**: Growth in resource productivity by 3% by 2030, translating to total annual benefits of €1.8 trillion leading to a GDP increase of 7%. **Environmental**: Decrease of GHG emissions up to 48% by 2030 and up to 83% by 2050. Also in several sectors primary material consumption could decrease up to 32% by 2030 and 53 % by 2050.
Ellen MacArthur Foundation & SYSTEMIQ (2017)	Sectors: Mobility, food, and built environment in the EU	Investment opportunities are quantified on the basis of investment metrics that are identified through a combination of desk-based research and expert interviews.	**Economic**: Investment opportunity of €320 billion by 2025
Wijkman & Skånberg (2015)	Five EU countries: Finland, Sweden, the Netherlands, Spain and France	Input/output model. Three strategies ('steps') are considered: i) enhancing energy efficiency, ii) increasing the percentage of renewable energy in the energy mix and iii) improving material.	**Economic**: 75,000 jobs (Finland), 100,000 (Sweden), 200,000 (the Netherlands), 400,000 (Spain) and 500,000 in (France). Need for an additional level of annual investment in the range of 3% of GDP until 2030. **Environmental**: Combing the three strategies could lead to around 66% decrease in CO_2 emissions in Sweden, 68% in Finland, 67% in the Netherlands, 66% in France and 69% in Spain.

Morgan & Mitchell (2015)	Job creation potential in the UK Interpretation of circular economy as : reuse, closed looped recycling, open loop recycling, biorefining, repair and remanufacturing and servitisation	Development of different scenarios about the potential expansion of the circular economy up to 2030.	**Economic**: 520,000 new jobs and net employment growth of around 100,000 jobs (ambitious scenario) **Social**: Offset of job losses in mid-level skilled positions and generally high demand for mid-level skilled employment due to the circular economy. Potential to reduce regional unemployment in the areas exhibiting the highest unemployment rates as well as contribute to a reduction in regional unemployment disparities.
Bastein et al. (2013)	Impacts of circular economy in the Netherlands.	First assess the impact of improving circularity in the metal and electrical sectors and using biomass waste streams and then scaled up these findings in order to estimate the overall economic impact on the Dutch economy.	**Economic**: Potential to create added value of €7.3 billion per year, creation of around 54,000 jobs.
SITRA (2016)	Impacts of circular economy in Finland. Sectors: machinery and equipment and forest industries, food waste, real estate, private consumption and second hand trade and nutrient recycling.	Uses estimates by Sitra & McKinsey (2015) on resource flows and value creation combined with estimates by Ellen MacArthur Foundation (2013a). Among the sources used by Sitra & McKinsey (2015) is data from Eurostat and the National Statistical Authority.	**Economic**: Value potential of the circular economy could amount to €2-3 billion by 2030.
EEB (2014)	Impacts of improved resource efficiency on GHG emission reductions in food waste reduction, avoided water use, avoided fertilizer use and avoided land use in the EU. Impacts of improved resource efficiency on	Different scenarios around potential EU targets. Calculations on economic impacts are based on assumptions regarding the number of jobs that are created per thousand tonnes of reused textile and furniture material.	**Economic**: Depending on the level of ambition in the targets, around 635,000-750,000 additional jobs could be created by 2025 and 710,000-870,000 by 2030. **Environmental**: 56.5-96.5 Mt of GHG emissions could be avoided by 2025 and 74.6 Mt-115.0 Mt by 2030.

	job creation on recycling, furniture re-use, textile re-use in the EU.	The calculation of water-use savings is based on assumptions regarding the water-use reductions resulting in re-use of textiles. Estimates about avoided land use for agriculture are based on an assumption of a direct link between food-waste reduction and reduction of primary food production.	Potential for water-use savings of 26.1-52.2 Ml by 2025 and 34.8-60.9 Ml by 2030. Avoided fertilizer and pesticide use of 0.44 Mt-0.88 Mt by 2025 and 0.58 Mt-1.02 Mt by 2030. Avoided land use for agriculture to amount to 28,350-47,520 sq km by 2025 and 38,070 sq km-56,970 sq km by 2030.
Ökopol (2008)	Impact of recycling rates in CO_2eq emissions in the EU	Build different scenarios i) Modest: current recycling rate (as of 2005) assuming a constant growth of 1.1% per annum; ii) Medium: assumes a 65% recycling rate by 2020; iii) Ambitious scenario based on kg/capita waste generation and "relies on maintenance of similar levels of recycling as the medium scenario''.	**Environmental**: CO_2eq reductions of 247 to 330 million tonnes.
Friends of the Earth (2010)	Impact of recycling on employment in the EU	Applies co-efficients for jobs per thousand tonnes of recycled material in the UK to EU recycling data in order to calculate the potential	**Economic**: EU recycling target of 70% could create 563,000 net new jobs. This figure Includes 'direct' new jobs but also 'indirect' and 'induced' employment.
European Commission (2015b)	Impact of full implementation of proposed EU waste legislation on GHG emissions and jobs	Models the effects of implementing different recycling targets of municipal solid waste, targets for packaging waste and the landfill diversion targets.	**Economic:** Depending on the scenario, full implementation of proposed EU waste legislation could create between 136,000 to 178,000 full-time jobs by 2025. **Environmental**: Reduction of 424–617 million tonnes of carbon dioxide equivalent over 2015–2035.

Lawton et al. (2013)	Environmental benefits of materials savings in the EU Sectors: food and drink, manufacturing, fabricated metal products, hospitality and food services sectors.	The results are based on individual company case studies and thus may not be representative for an average company.	**Environmental**: Potential to reduce annual GHG emissions by 2-4%
Ellen MacArthur Foundation (2015b)	Benefits of circular economy for Denmark. Sectors: food & beverage, construction & real estate, machinery, plastic packaging and hospitals).	Combination of data from the National Statistical Authority with expert opinion and judgment to evaluate impacts in a quantitative or semi-quantitative manner. The estimate of the carbon footprint is carried out by assessing the change of carbon emissions divided by 'business as usual' emissions.	**Economic:** GDP growth of 0.8–1.4%, creation of additional 7,000–13,000 job equivalents, increase of net exports by 3–6 %. **Environmental**: Potential to reduce Denmark's carbon footprint by 3-7%. Potential to also reduce virgin resource consumption by 5–50% by 2035.
Cambridge Econometrics & BIO Intelligence Service (2014)	Impact of different EU resource productivity targets. Material types: food, animal feed, forestry, construction minerals, industrial minerals, ferrous ores and non-ferrous ores.	Use of a macro-econometric model. Resource productivity is defined as the unit of GDP produced with one unit of raw material consumption.	**Economic**: 2% increase in EU's resource productivity could create 2 million additional jobs in 2030. 2-2.5% increase in EU's resource productivity could have a small but positive net impact on EU's GDP. Any further improvement could lead to net costs to GDP. **Environmental**: 3% increase in EU's resource productivity could lead to a reduction of 25% of GHG emissions by 2030. **Social**: 2% increase in EU's resource productivity would lead to even distributional impacts across different income groups.

Annex 2. List of experts interviewed

Name	Position	Organisation	Date
Klaus Jacob	Research Director	Environmental Policy Research Centre (FFU)	16/01/2017
Hans Stegeman	Chief Economist	Rabobank	17/01/2017
Nina Leth-Espensen	Senior Adviser	Danish Industry Association	18/01/2017
Sylvain Chevassus	Policy Officer Europe-International	French Ministry for Environment, Energy and the Sea	25/01/2017
Kambiz Mohkam	Policy Advisor - Macroeconomic modeling	French Ministry for Environment, Energy and the Sea	25/01/2017
Michal Kubicki	Policy Officer for Sustainable Industrial Policy	DG GROW, European Commission	26/01/2017

List of project partners

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