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Circular by design

Products in the circular economy

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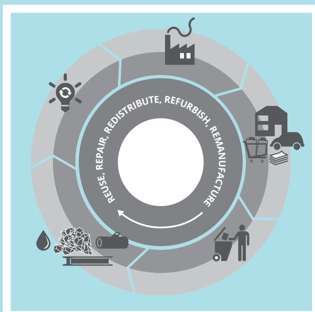

European Environment Agency

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Preamble

This report is the second in a series of EEA reports on the circular economy. The intention with the series is to clarify the circular economy concept, from the perspective of balancing environmental, economic and social considerations, and to highlight knowledge gaps and policy aspects that merit particular attention.

As such, it is a contribution to the framing, implementation and evaluation of circular economy policy at European level, and to capacity building among stakeholders. The report does not attempt to evaluate established policy, as laid down in the European Commission Circular Economy Package (EC, 2015), rather it seeks to inform possible further initiatives as well as the development of related indicators and monitoring.

Building on the concept as presented in the first EEA circular economy report (EEA, 2016a), *Circular economy in Europe: Developing the knowledge base?*, this report highlights the importance of product-related aspects, such as eco-design, innovation incentives, business models and production-consumption trends. The focus is on the systemic drivers of product design and use, and their implications for the governance of the transition to a circular economy.

The report is not intended to fully assess these aspects. The current knowledge base does not allow in-depth analysis of product-related aspects of the circular economy transition.

Abbreviations used in this report

7th EAP	Seventh Environment Action Programme
BoP	Basket of products
EPR	Extended producer responsibility
EU	European Union
IoT	Internet of things
LCA	Life-cycle analysis
LCC	Life-cycle cost
LED	Light-emitting diode
MCI	Material circularity indicator
Nd	Neodymium
PEF	Product environmental footprint
R&D	Research and development
VAT	Value-added tax

Executive summary

This report explores the circular economy from a product perspective, applying a systemic approach and transition theory. Drivers of product design and usage are discussed in the context of emerging consumption trends and business models. For governance to be effective, it has to address the product life-cycle and the societal context determining it. Indicators and assessment tools will be needed to fill the current data and knowledge gaps.

The transition towards a circular economy requires fundamental changes to production and consumption systems, going well beyond resource efficiency and recycling waste. In the concept of the circular economy, preserving the value of products for as long as possible plays a central role, and puts products centre-stage in the transition process. Current actions to stimulate and monitor the transition, however, primarily focus on materials, which is not surprising, as the circular economy vision has evolved as a solution to the waste problem, and current policy and business tools focus on waste or materials.

Designing products in a smarter way, extending their useful lives and changing the role of such products within the system will be crucial to the achievement of a circular economy. Reuse, repair, redistribution, remanufacture and refurbishment have so far received less attention than waste-related issues, and related strategies are less mature. Nonetheless, they potentially offer significant environmental and economic benefits by encouraging, for example, innovations in the design of less environmentally harmful products.

Increasing circularity requires insight into the current drivers of product design, form and function as well as emerging trends that may change these. Linear resource use, based on the cost-efficient production of goods sold to consumers, has become the dominant economic model to cater for societal needs, such as mobility, communication and housing. Drivers include the availability of relatively abundant and cheap natural resources and energy, and technological and organisational innovations, such as assembly lines enabling mass production and automation.

The linear economy may be deeply entrenched, but emerging trends indicate that the role of products in society is changing. The development of additive manufacturing technologies, for example, can stimulate repair of products if spare parts can be supplied on demand. However, it can also be a barrier for recycling if the technology leads to complex mixtures of different materials being integrated into one product. The shift from product-based to service-based business models is another promising development. Well-tailored governance and finance mechanisms, including innovation incentives, will be required to turn these niche activities into mainstream economic models.

The transition to a circular economy requires better knowledge about the links between products, their underlying business model and the societal infrastructure and governance determining their life-cycle. Dedicated monitoring and analysis in order to identify key mechanisms and trends will be crucial in this respect. Generalisations should be avoided though, as there is no one-size-fits-all solution for better designing products for circular use.

1 The challenge of product circularity

Circular material use, including recycling, reuse and refurbishment, aims to reduce the generation of waste as well as our economy's dependence on extraction and imports of raw materials. As such, it has the potential to bring both environmental and economic benefits, and it is increasingly recognised as the resource use mechanism that would allow societal and environmental sustainability. This chapter introduces the policy context and focuses particularly on the role of products in a circular economy.

1.1 Circular economy in the European Union

The European Union (EU) economy is largely linear by design, resulting in avoidable environmental and human health impacts, inefficient use of natural resources and over-dependency on resources from outside Europe. Moving to a circular economy would alleviate these pressures and concerns, and deliver economic, social and environmental benefits.

The EU's Seventh Environment Action Programme (7th EAP) calls for Europe to become a resource-efficient, low-carbon economy. Reducing dependency on fossil fuels, recycling materials and reuse of products are important for the broader goal of reducing the environmental burden of Europe's resource use and staying within planetary limits (EEA, 2015b). Strategies for a circular and low-carbon economy are linked and can support each other through, for example, more efficient use of natural resources. This in turn means that links between resource use and energy, water and biodiversity also will need attention (EEA, 2016b).

The EU's target of reducing greenhouse gas emissions by 80-95 % by 2050 will require fundamental changes not only in energy, food and mobility systems, but also in the way raw materials and manufactured products are produced, traded, used, maintained and fed back into the economy at the end of their life.

In 2015, the European Commission adopted an ambitious Circular Economy Package, which includes legislative proposals on waste and a detailed action plan with measures covering the whole material cycle: from production and consumption to waste management and the market for secondary raw materials. The proposed actions will contribute to 'closing the loop' of product life-cycles through greater recycling and reuse, and bring benefits for both the environment and the economy.

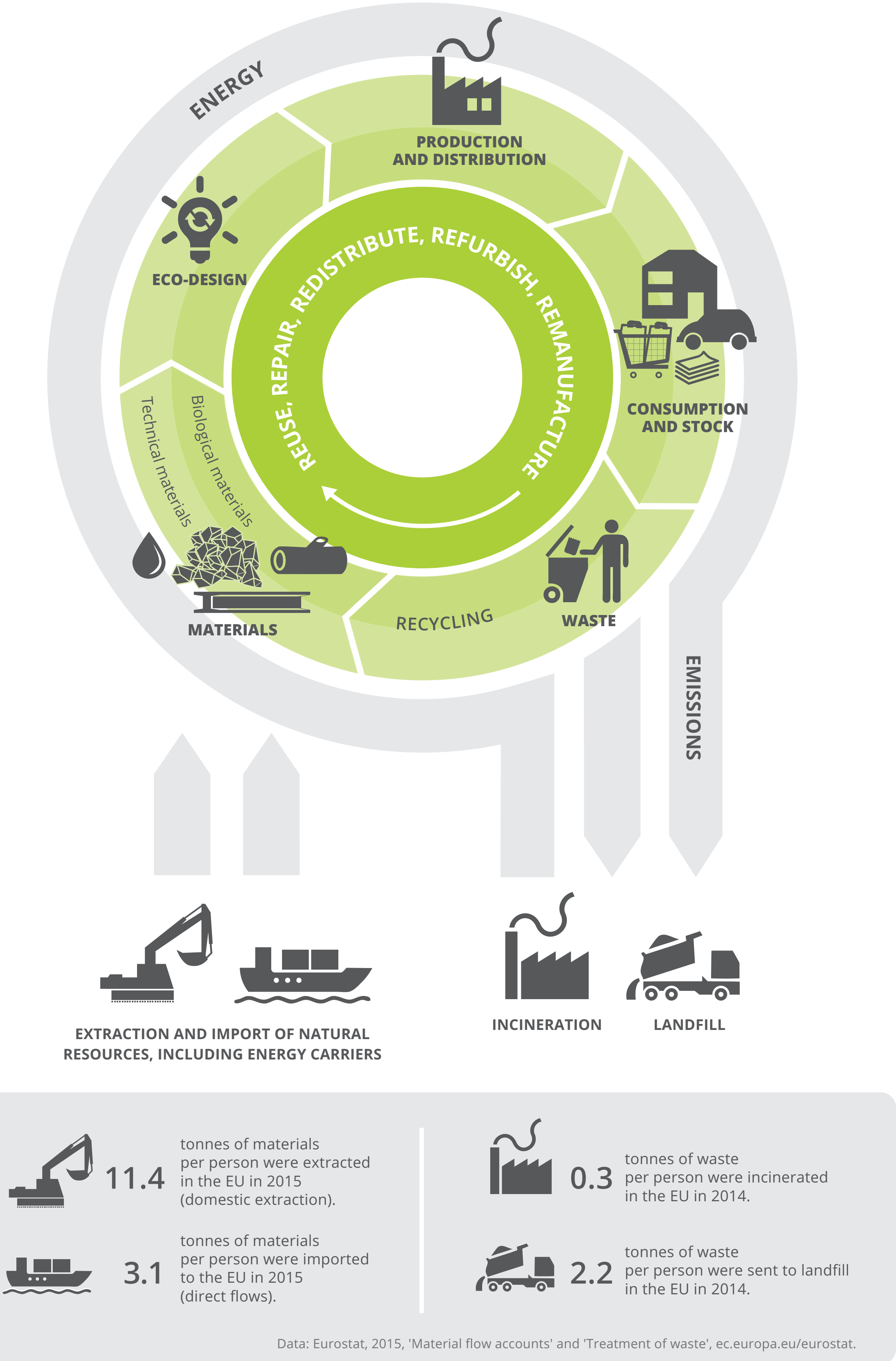
Central to the circular economy concept is the notion that the value of materials and products is kept as high as possible for as long as possible. This helps to minimise the need for the input of new material and energy, thereby reducing environmental pressure linked to the life-cycle of products, from resource extraction, through production and use to end-of-life (Figure 1.1). The benefits of circularity strategies are usually higher for 'inner circle' approaches, such as reuse, repair, redistribution, refurbishment and remanufacturing, than for recycling and energy recovery. This is due to losses during collection and processing, and degradation of material quality during recycling.

1.2 Circular and low-carbon economy — hand in hand

By recirculating products rather than discarding them after use, the circular economy would retain product and material values better than today's linear economy. Through minimising demand for materials and energy, and by minimising the generation of waste, the circular economy could also contribute to a reduction in greenhouse gas emissions.

This contribution, however, is not immediately apparent in the greenhouse gas emissions accounting system, as it covers many more economic sectors than the waste sector (incineration and landfill) alone, and emissions may occur partially outside Europe. Extending the lifetime of a laptop, for example, could save more carbon emissions than replacing it with a more energy-efficient one (Prakash et al., 2016a). It is estimated that a reuse shop in Flanders saves 1.3 tonnes of carbon dioxide equivalent (CO_2eq) per tonne of goods it collects (BKN, 2012). Similarly each 10 % increase in the use of glass cullet rather than virgin material results in 2-3 % energy savings in the

Figure 1.1 **A simplified model of the circular economy for materials and energy**



Source: EEA, 2016a.

flat glass industry (Glass for Europe, 2016). The actual benefits, however, depend on many factors, including the carbon intensity of the assumed energy mix that is used in the reference scenario.

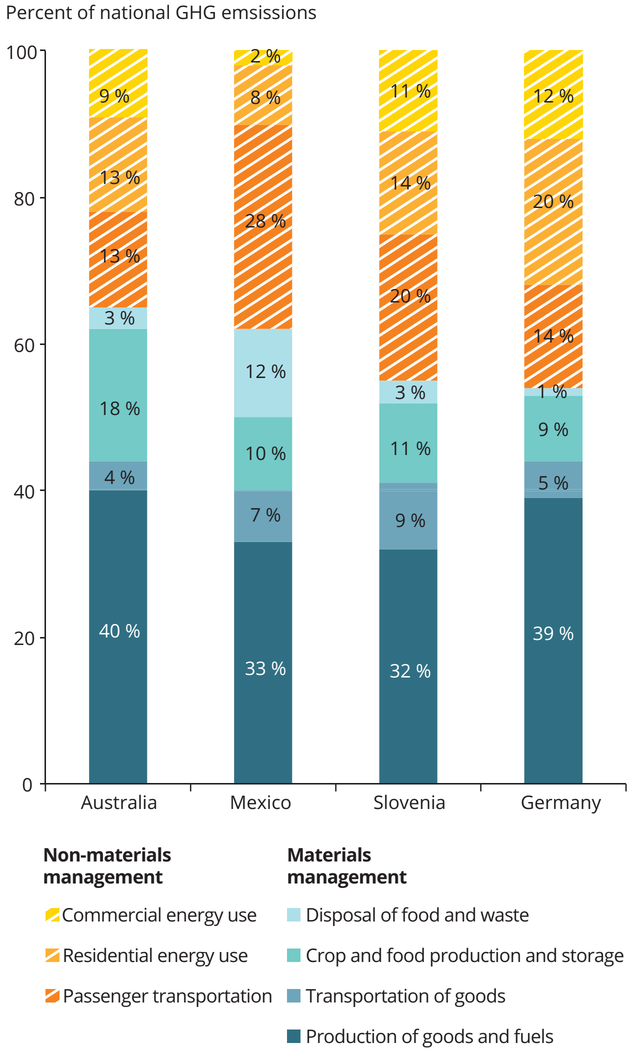
In turn, incentives for a low-carbon economy, such as policies on energy efficiency, renewable energy or emission caps, can trigger or reinforce circular economy solutions. Increased prices for fossil-based energy through carbon emission caps or carbon taxes could, for example, make shared use of cars more economically attractive; enforcing energy efficiency requirements for existing buildings can trigger refurbishment and thus an extension of a building's life.

However, conflicts might arise when, for example, narrow policy focus on energy efficiency in the use phase of products disregards the potential for higher energy savings across the whole life-cycle, or where subsidies for biomass energy production put pressure on the recycling industry's access to bio-based materials.

Although recent EU strategic documents on the low-carbon economy mention the circular economy, resource efficiency and waste recycling, there is potential to better align low-carbon and circular economy policies.

For example, the potential synergies between a circular and low-carbon economy can be illustrated by the role that materials play in the generation of greenhouse gases: from a life-cycle perspective, 55-65 % of greenhouse gas emissions arise from the handling of materials — production, transport and disposal (Figure 1.2). A shift from a linear to a circular economy may therefore contribute significantly to the overall emission reduction target of 85-90 % (EC, 2011).

Figure 1.2 National greenhouse gas (GHG) emissions by systems-based categories in selected countries



Source: OECD, 2012.

1.3 Clean material cycles — a prerequisite for circularity

Clean materials are crucial for maintaining material performance and quality in recycling processes. Material performance and trust in the safety of the materials — in addition to the price — will largely determine whether or not consumers will buy recycled materials and derived products. Keeping material cycles clean is therefore essential for the circular economy, from both a safety and an economic point of view. This is a main area of potential synergy with EU chemicals legislation (for example REACH , EU, 2006) and the strategy for a non-toxic environment stipulated in the 7th EAP.

Traditionally, little consideration has been given to the total environmental and human impact of (mixtures of) chemicals during the life-cycle of the chemical, including production, use, disposal and reuse (Hauschild, 2015). Current regulations focus mainly on restricting the use of hazardous substances in products (e.g. in the open environment or from contact with food) (EU, 2006), primarily by regulation of single substances under thematic legislation. Implementation is checked and enforced through document control and chemical monitoring by the EU Member States.

Despite some successes (e.g. decreased levels of lead and diethylhexyl phthalate (DEHP) in blood), human bio-monitoring data show that people are being exposed to an increasingly complex mix of chemicals (Kortenkamp et al., 2009). In a circular economy, limited ability to track all chemicals will make it even more difficult to control and limit combined exposure. For example, increased recycling and reuse of long-lived products, such as furniture, means that it can takes decades to get rid of legacy pollutants (e.g. brominated flame retardants, BFRs). Also for recycled single use materials, such as paper and board which is chemically cleaned, modelling shows that even after a total stop of using a chemical (e.g. bisphenol A in receipts) it will remain in recycled paper for an estimated 31 years (Pivnenko and Fruergaard, 2016). Studies show that recycled paper even accumulate persistent and hazardous chemicals (Pivnenko et al., 2015).

Preventing chemicals of concern from (re) entering the material stream is therefore crucial. This can be done by improved physical sorting of waste, chemical contaminant removal or phase out the use of problematic groups of chemicals of concern, such as endocrine-disrupting and very persistent chemicals (Bernard and Buonsante, 2017). Modelling shows that improved sorting of recycled paper and board, only decreases the content of BPA in the paper by 19% and DEHP by 3%; chemical removal of BPA by 9% and DEHP by 46%, compared to phasing out the use of hazardous substances which can remove 100% of BPA (takes 31 years) and DEHP (takes 15 years) (Pivnenko and Fruergaard, 2016). Grouping of chemicals with similar properties (e.g. regarding toxicity, physical or chemical similarities or technical use) would be a practical and efficient means to avoid regrettable substitutions.

Another approach is to go upstream and promote alternatives, for example minimising the use of chemicals or using substances that can be considered 'benign by design'. Chemicals and materials that can be biologically or technologically mineralised (degraded) to non-toxic degradation products, would make it possible to produce materials that are effectively 'virgin' again, which is similar to the processes occurring in nature. Products with a high risk of being spread in the environment could be made from biodegradable materials (World Economic Forum et al., 2016). On the other hand, every time a product starts a new cycle, energy and resources are consumed. This is why slowing down the cycles, that is, increasing the longevity of products, should also be considered.

1.4 Focus on products

Products play a key role in the economy, serving society's needs and contributing to people's identity. Designing products better, extending their useful lifetime and changing their role within the system will be crucial for the development of a circular economy.

Most policy attention in the EU has been given to improving material and energy efficiency and on recycling of different types of waste, with initiatives such as the Ecodesign Directive (EC, 2009), product environmental footprints (PEFs) and eco-labelling explicitly targeting product-related aspects. However, reuse, repair, redistribution, remanufacture and refurbishment — the product-related inner circles of the circular economy (Figure 1.1) — have received less attention, and strategies for widespread introduction of these concepts are less mature. Nonetheless, they potentially offer significant environmental benefits through keeping the value of products and materials in the economy.

In EEA's first circular economy report, *Circular economy in Europe: Developing the knowledge base* (EEA, 2016a), large gaps were identified regarding monitoring of progress in developing a circular economy, especially in the area of eco-design. While there are some data and indicators to track material input reductions on a macro-economic scale, consistent information about reuse, repair, redistribution, refurbishment, remanufacture and, more broadly, eco-design is largely lacking.

1.5 Product value in a systems perspective

The central aim of a circular economy is to maintain the function and value of products, components and materials at the highest possible level and to extend the lifespan of such products. Maintaining a product's value for as long as is sensible avoids the use of natural resources and the environmental impacts associated with creating a replacement, and, although recycling captures some of these values, losses are inevitable. However, it has to be kept in mind that this is not necessarily the case for inefficient durable products in which the majority of emissions are caused during their use (e.g. old cars without catalytic converters).

From an economic perspective, a product, for instance a fully functional car, has in most cases a higher economic value than the sum of the separate materials and components from which it is made. From an environmental perspective, an assembled car also has a higher environmental footprint than the sum of its component materials because its assembly has involved the use of additional environmental resources.

Product design determines to a large extent the longevity, reparability, recyclability, proportion of recycled and renewable material in the product, and its suitability for refurbishment or remanufacture. Product design therefore determines the circularity potential of a product.

However, to what extent this potential is actually realised depends on how the product is used and treated in its full life-cycle, or life-cycles in the case of successive applications. The circularity of a product is thus determined not only by the intrinsic product characteristics, but also by the system of which it is a part. For example, the probability that a washing machine that is designed for easy repair is actually repaired will depend not only on the business model being used to market it, but also on the infrastructure and governance context of the country in which the washing machine is sold and used, and the cost of repairing the washing machine compared with the purchase price of a new one. Washing machines that are part of a product-service system, and/or placed on the market in a country with low labour costs and high availability of technically skilled workers, will have a higher degree of circularity than the same machines sold in a country where a repair sector is largely absent.

As another example, the potential of the sharing economy to improve product circularity depends on the actual changes in the use intensity of goods (e.g. by increasing the occupancy rate of a car). This ultimately depends on the actual effects of the business and consumption models used and on the potential rebound effects caused elsewhere in the system.

Promoting and monitoring product circularity thus requires knowledge of the way the system in which the product plays a role behaves (e.g. a car in the transport system). For the implementation of effective business models, policy measures and consumer action, it is essential to identify and understand the systemic links between a product, the business model of which it is a part, and the societal context that determines its life-cycle.

1.6 Scope of the report

This report explores systemic aspects of circularity and examines the constantly changing role of products driven by, for instance, technological developments, product design, or changes in business models and societal preferences. Examples are given for a range of products, including buildings, cars, packaging, electronics and business-to-business products, with an emphasis on the use aspect, including sharing, reuse and repair, rather than the source materials.

Chapter 2 introduces the transitions perspective as an analytical tool to understand the move from a linear to a circular economy.

Chapter 3 stresses the importance of considering the whole value chain and describes a number of selected key trends related to products in society and their impacts on circularity, providing information on business incentives and consumer behaviour that affects the whole product life-cycle.

Chapter 4 discusses the systemic perspective on enabling factors and barriers for product circularity and how they could be strengthened or removed.

Finally, Chapter 5 reflects on the existing knowledge base and the knowledge gaps with regard to products in the circular economy.

2 Transforming production and consumption systems

The transition to a circular economy requires a fundamental change in products and the way they meet societal demand. Products are a tangible part of the socio-technical systems people use to fulfil their needs and wants, for example regarding housing, mobility, energy and food. Understanding the key mechanisms shaping the design, production, use and end-of-life treatment of products in a linear economy is a prerequisite for identifying effective measures that can alter system dynamics and drive the shift to circular material use.

2.1 System dynamics and transition

The persistence of key environmental problems, such as biodiversity loss, climate change and natural resource depletion, poses a systemic challenge. The production-consumption systems and the associated products that meet society's essential needs — such as for energy, food, mobility, water and shelter — account for much of humanity's burden on the environment in terms of resource extraction, waste generation and emissions. Circular material use and smart products design hold a promise of substantially reducing the environmental burden of production and consumption, but it requires fundamental shifts in our resource use patterns.

As the EEA argued in its 5-yearly flagship report, *SOER 2015 — The European environment — State and outlook 2015* (EEA, 2015a), Europe's progress in decoupling environmental pressures from economic growth in recent years has been incremental, with resource efficiency gains having only partially translated into improved ecosystem resilience and human health (EEA, 2015a). Against this backdrop, *SOER 2015* (EEA, 2015b) argued that, if Europe is to achieve the EU's 2050 vision of living well within environmental limits (EU, 2013), it must fundamentally transform its core societal systems of production and consumption, in particular those related to food, energy, mobility and the built environment. This is a long-term and multi-faceted process (EEA, 2015b).

One of the most widely used approaches to analyse socio-technical systems is the multi-level perspective (Geels, 2002). This distinguishes a predominant **regime** of governance systems, challenged by innovative **niche** approaches, and driven by a dynamic **landscape** context (Figure 2.1). Niche developments and innovation are often autonomous responses to large-scale socio-economic, demographic, political and international trends, such as urbanisation and global competition for resources. They can, however, also be stimulated through government intervention, for example via product standards, taxes and subsidies, and funding of research and development. Fundamental change happens where niches gradually disrupt the regime. Such transitions are long-term processes that typically extend over 25-50 years (EEA, 2015a; Grin et al., 2010; Raven et al., 2010).

Reconfiguring societal systems requires innovation across a wide range of sectors — from farming to finance. It includes not only development of new technologies, but also of novel social practices and business models, and changing of consumer behaviour, beliefs and basic values. This will inevitably create tension and produce a mix of societal costs and benefits, falling unevenly on different groups. The creative destruction inherent in entrepreneurial innovation will affect jobs and economic interests, creating conflict and power struggles (Geels, 2014). Other trade-offs that may arise as benefits in one system are offset by harms in another.

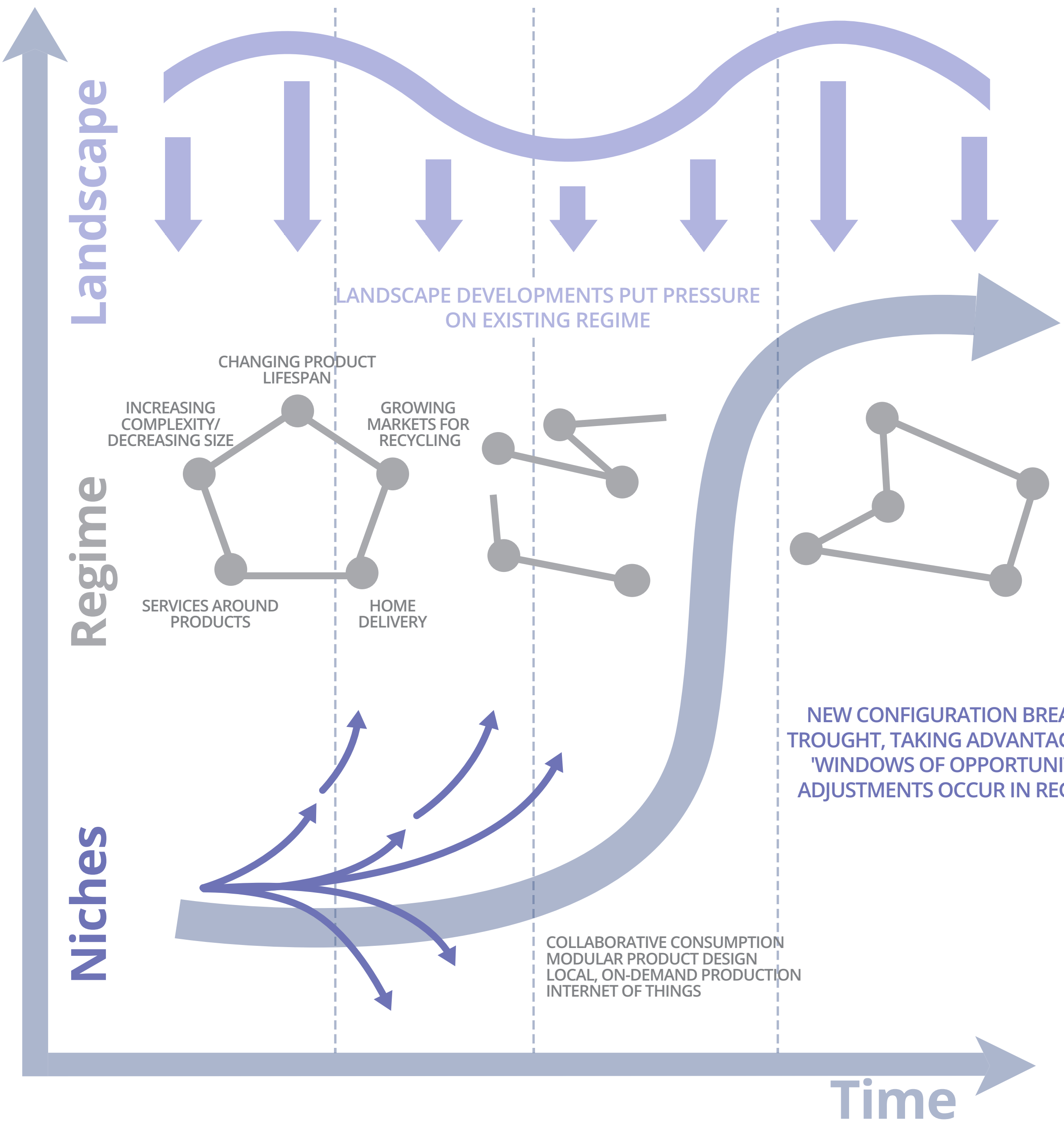
2.2 Moving from a linear to a circular economy and the role of products

Two general aspects of socio-technical systems are relevant for product circularity: (1) the key mechanisms behind the current system are the result of the historical evolution of a complex set of relationships between producers, consumers and policymakers; and (2) the balance of a system is dynamic, implying that it is constantly subjected to internal and external change that might push it towards or away from improved product circularity.

Socio-technical systems are shaped by an array of interrelated factors, including (EEA, 2014):

- economic factors;
- demographic factors;

Figure 2.1 **System transitions in a multi-level system perspective**



Source: Based on Geels, 2002.

- technology and innovation;
- urbanisation and infrastructure;
- social and cultural factors;
- business models and marketing.

The linear model based on the cost-efficient production of goods sold to consumers has become the dominant means of addressing many needs, such as for mobility, communication, housing and food. Some of the drivers propelling this model to dominance include the availability of relatively cheap and abundant natural resources and energy, as well as various technological and social innovations, ranging from engines and electricity, for example, to assembly lines for the mass production of goods.

Table 2.1 provides a non-exhaustive overview of the key mechanisms shaping the role and fate of products in a linear and a circular economy, seen through the lens of three main participants in the system: (1) businesses selling products; (2) consumers buying and using products; and (3) policymakers regulating the production, use and end of life of products. This overview presents a generalised view of a fully linear or fully circular system, neither of which exists today. Nevertheless, it provides insight into the fundamental mechanisms defining products and the societal role of such products required for successfully transitioning towards a circular economy.

Table 2.1 Key mechanisms shaping the role of products in a linear and a circular economy *

Linear system mechanisms	Circular system mechanisms
Business perspective	
Product as value creation source Profit margins are based on the difference between the market price of a product and the production cost. The strategy for increasing profits is to sell more products and keep production costs as low as possible. Technological innovation makes old products obsolete and urges consumers to buy new products. Protection of intellectual property rights, a main source of value, leads to protective design measures, such as creating barriers to repairing a product, rather than sharing product technical information and repair manuals.	*Functionality/performance as a source of value creation* Products are part of an integrated business model focusing on the delivery of a performance or functional service. Competition is mainly based on the creation of added service value of a product, not solely on its sales value. Social/business model innovation allows the creation of extra value by applying technological innovation to solving societal needs. As products are part of a company's assets, cost minimisation drives product longevity, reuse, reparability and remanufacturing.
Economies of scale in global production chains Cost efficiency drives the optimisation of global production chains, minimising the costs of resources, labour and transport.	*Location of production and use tend to be more linked* As the provision of a service is physically linked to the location of the customer, there is an incentive to produce/manage physical products used in a service close to the user.
Steer consumer needs towards product offer Products with short lifespans are preferred as they are cheaper to make and support a market for new products that replace old ones. Maintenance and repair are avoided, as it is more profitable to sell new products than to repair old ones.	*User needs/wants drive the role of a product* Offering the best service means matching the (intangible) needs of the user with a combination of services and products.
Tendency to disregard end-of-life phase There is no economic incentive for product life extension, reuse or remanufacturing as they counteract most linear business models.	*Internal incentive to incorporate end-of-life phase in business model* As products are assets, minimising life-cycle costs is an implicit incentive for a company, inducing a search for the best economic equilibrium between reusing, repairing, remanufacturing and recycling products.
Consumer perspective	
Consumerism follows marketing Consumers want new products that keep pace with fashion and technological advances. Consumers must match their needs with the product offerings available.	*Customer satisfaction is an important driver* In a service relationship with a company, the customer experience feeds back more strongly to the service provider, raising consumers' awareness of their actual needs. In other cases consumers become prosumers who co-create or co-produce the products and services they need.
International opportunities for cost reduction Consumers seek the cheapest version of a product on international markets, enabled by e-commerce.	*Local-first attitude* Accessibility to the service provider is part of the service experience, which leads to proximity as a customer choice criterion.
Ownership is the norm Owning a product is regarded as the normal way to fulfil needs. Over time, previously luxury products become commodity goods due to decreasing production costs. Beyond legal warranty, product repair is considered too expensive compared with buying a new product. Do-it-yourself repair is considered too difficult due to complex and protective product design.	*Accessibility is the norm* Fulfilling needs is driven first and foremost by accessibility of a product and the satisfaction provided by its use. Different consumer segments can access products of their choice through customised services or by sharing products, for instance in peer-to-peer networks. Service agreements provide an incentive for product care for the producer and the user, depending on the agreement.

Table 2.1 Key mechanisms shaping the role of products in a linear and a circular economy * (cont.)

Linear system mechanisms	Circular system mechanisms
Low/no residual value of products End-of-life products (broken or obsolete) are considered a burden, to be disposed of as cheaply as possible — by selling on the second-hand market, storing at home, or through regulated waste disposal systems or illegal incineration or dumping.	*End-of-use incentives incorporated* If products are part of a service, there are incentives to return them to the provider after use, avoiding stocks of obsolete products in households, or illegal dumping.
Policy perspective	
Dependence on existing production system There is a strong link between mass production of goods, and the focus on cutting costs in general, and making the production as efficient as possible, often resulting in lower labour costs and less job creation.	*More focus on facilitating skilled workforce* More localised and service-based activities require a skilled but affordable workforce. Policymakers can facilitate this by shifting taxes from labour to resources.
Global playing field Competition for economic factors on the international market steers national social and environmental policies.	*Less risk for outsourcing jobs* As management of products as local assets is less likely to be outsourced, there is less incentive for a race-to-the-bottom in social and environmental policies.
Balance consumer protection with economic stakes Protection of consumer safety and health is mostly reactive and geared towards protecting existing economic stakes, such as value-added tax (VAT) income.	*Facilitate safe and healthy services with regulation* As safety and consumer health are business incentives for high-quality performance, policies focus on facilitation of these types of services.
Action prompted by health or environmental concerns There is no inherent incentive for regulation of the waste phase of products. Only when waste-related health or environmental concerns arise is regulatory action taken to minimise negative impacts.	*Facilitation of end-of-life management* Extended producer responsibility rules create incentives for companies to internalise end-of-life management. Governments provide basic infrastructure and fiscal measures supporting reverse logistics.

Note: * This table highlights the most relevant process parameters compatible with circular thinking. Environmental effectiveness cannot be evaluated without further investigation.

3 Product trends and their implications

Although the linear economy is deeply entrenched, several emerging trends indicate that the role of products in society is changing. Some can be considered evolutions within a current regime, while others are recent innovations still confined to niches. In this chapter the most relevant trends are described and analysed in terms or their impacts and implications for product circularity.

3.1 Increasingly complex product design and functionality

3.1.1 Trend

Many products (especially electronic devices) are increasingly designed to provide a wide variety of functions, and/or provide better functionality while using less material. This design trend leads to products containing an increasing number of different materials and additives, with smaller amounts of each specific material. In addition, product components are increasingly glued to or even integrated into the product body to achieve smaller form factors. Examples are the inclusion of additives in packaging to improve shelf life; the integration of light-emitting diode (LED) lights or other gadgets into clothing; the introduction of electronic modules for the remote control of appliances such as washing machines; interactive toys for children; or the integration of intelligent electronic control of ventilation, lighting, security, ... etc., into the infrastructure of buildings.

These trends are the result of technological innovation allowing manufacturers to add new features to existing products, or even design new innovative products to meet perceived consumer needs, for example, smart watches. When consumers embrace these product innovations, increasing sales keep the economic engine going, which is especially important in saturated markets within the mainly linear system. As a result of this positive effect on economic growth, product innovation is embraced by policymakers, and even stimulated by means of policies to support innovation.

3.1.2 Impacts

The multi-functionality of products, one of the main drivers for increasing product complexity, contributes to a lower demand for materials, as a number of the functions for which various products were once needed can now be integrated into a single item. Listening to music, making phone calls, surfing the internet, scanning documents, reading books, taking pictures: these all once required a specific product, but can now they can be achieved using a single smartphone. Similar changes have taken place in kitchen appliances, clothing and even buildings.

At the same time, design requirements such as multi-functionality, mobility and versatility lead to the production of smaller and more robust products, with components often glued together or integrated into the main product structure. This reduces their potential for repair and recycling because the removal of hazardous components prior to recycling becomes problematic. In Switzerland, the amount of non-separable multi-component products in the household waste has increased from 8 percent in 1991 to 12.5 percent in 2012 (Steiger, 2014).

The inability to remove a product's battery, for example, renders the whole product hazardous. In addition, some small electronic devices contain beryllium, a hazardous element that is difficult to separate and remove. As a result, the entire product must be considered hazardous, meaning that 1 kg of material has to be treated or disposed of due to the presence of just 100 g of hazardous content (Lee et al., 2012).

The rising complexity of products and new material mixtures can make products incompatible with existing recycling schemes. Shredding, for example, is a common pre-processing technique for the recycling of electronic goods, but it causes a loss of much of the embodied value within the products. For example, a study of the flow of gold in mobile phones in Germany and the United States reported that only 10 % of the gold is recovered during recycling, with

90 % being lost through uncontrolled dispersion during pre-processing (Elo and Sundin, 2010; Lee et al., 2012).

The potential negative impact of smaller and more complex products on recycling could provide an incentive for a move towards the disassembly of components for reuse or separate recycling (e.g. neodymium-containing magnets inside hard disk drives being removed from the hard disk drives prior to processing (Sprecher et al., 2014)).

3.2 Increasing use of modular design

3.2.1 Trend

In the building sector, modular design is not a new trend (Box 3.1), but in the consumer electronics sector, modular design is being adopted for devices such as phones (Fairphone, 2016), headphones (e.g. Gerrard St., 2016) and watches (e.g. Blocks, 2016). While some niche companies are explicitly exploring modularity in terms of sustainability, other players, such as Google, are adopting a business perspective in which modularity is used to offer mass-customised products (Best, 2016).

3.2.2 Impacts

Modular design is still a very small, niche trend. Nevertheless, if this trend grows, it could extend product lifetimes by enabling the remanufacture and repair of product components. In the business-to-consumer market, the impact of modular design on product circularity depends on the role of modularity in the business model. Modular design might render products more easily repairable, but replacement parts and/or services need to be available to the user or repair service provider. Likewise, by enabling changes in a product to refit it to the changed needs of the user, or to the different needs of the next user, modularity could increase the lifetime of the product's basic structure, but not necessarily its components. Existing smartphone manufacturers, for example, seem to favour incorporating modularity into a traditional business model, enabling them to maximise profits from selling components rather than selling only complete handsets (Best, 2016)(Best, 2016).

Furthermore, modularity enables platform design, which is most commonly employed to reduce manufacturing costs and waste, and to simplify the product development process (Hatcher et al., 2011). In this process, the product is customised only at the end of the production chain, while upstream production is uniform. This approach is quite widely used in the automotive industry, for example by the truck company Scania and the engine manufacturer AGCO Power. If platform design could take into account the possibilities and limitations of recycling systems, modularity could be used to enable separation of components prior to recycling or energy recovery, thereby tackling the negative effect of increasing material complexity on the efficiency of recycling.

3.3 Local production on demand by additive manufacturing

3.3.1 Trend

Additive manufacturing technology, such as 3-D printing, enables highly customised and on-demand production. As a result of manufacturing versatility and decentralised production, supply chains can be local to the end-user markets while the digital design aspect is global.

Today, 3-D printing is mainly a niche innovation in manufacturing for prototyping and the production of highly customised products. It is expected to particularly

Box 3.1 Modular design of buildings

Modular design is widely applied in the construction sector, where buildings are produced in modules at a factory and subsequently assembled on site. Modular construction contributes to circularity in several ways. First, waste is more readily reduced in a controlled environment such as a factory, where practices such as recycling of materials, controlling inventory and protecting building materials are more easily implemented than on an open construction site that is more prone to external disturbance. Modular construction typically involves less transport of materials and staff, contributing to fewer emissions (Kim, 2008). Moreover, modular buildings can be disassembled and the modules relocated or refurbished for reuse, reducing the demand for raw materials and minimising the amount of energy expended in creating a building to meet the new need. The potential reusability of detachable components raises the resale value of building parts that can be replaced, recycled or moved according to need. However, this might be challenging due to the generally long lifetime of buildings, leading to the probability that modules will be outdated by the time they become available for reuse. Finally, modular buildings make the repair or modification of materials or parts possible without destroying buildings' basic structure (Mora, 2007).

influence manufacturing in the aerospace, medical component and machine tool sectors, and to yield additional logistic and macroeconomic benefits by shifting production closer to the consumer (Ellen MacArthur Foundation, 2015). The use of 3-D printing in industry, especially metal printing, is forecast to increase substantially as the technology improves (Laakso, Petri, personal communication, 23 March, 2016). A current challenge for further industrial deployment of 3-D printing is speed, an important cost factor in relation to subtractive manufacturing ([1]). Consumer use of 3-D-printing technology is currently minor compared with its industrial use, and mainly limited to a niche market for printing gadgets. However, the rapid decline in the price of 3-D printers and the ready availability of downloadable design files on the internet will enable wider consumer use (Laakso, Petri, personal communication, 23 March, 2016). Indeed, 3-D printers could be used for printing spare parts in repair cafés, so that consumers could use them to repair products themselves.

3.3.2 Impacts

Additive manufacturing can have different impacts on product circularity depending on the type of products that are made and the context in which they are used. It can lead to increased material efficiency during production, as it is less wasteful than subtractive technologies, and in the product itself, by creating lighter structures. Recyclability can also increase when 3-D-printed products are made from a single material. The main material currently used in 3-D-printing at the consumer level is plastic, rendering mono-material products that are compatible with existing recycling schemes. Plastic filaments made of waste polymers are coming on to the market (Baechler et al., 2013) (Baechler et al., 2013) and work well for homogeneous plastic waste fractions such as polyethylene terephthalate (PET). However, the quality standards placed on feedstock still present challenges for the wider use of 3-D printing using recycled plastics (Garmulewicz et al., 2016). Furthermore, the use of many materials in 3-D-printed products can negatively impact their recyclability.

There are other possible negative impacts related to mass customisation. Markets characterised by highly customised products will not have the advantage of efficient repair or remanufacturing operations. In addition, a focus on mass customisation is counteractive to the shared use of the products involved.

The potential for 3-D printing technology to contribute significantly to the circularity of society may only be revealed in its entirety once it has moved beyond the prototyping stage and the technology has become an end-use solution. In the short term, the biggest contribution to circularity can be expected in the business-to-business context. The possibility of being able to manufacture high-value machinery spare parts on site represents a great benefit, for example in off-shore operations. Some companies, such as Siemens, are using 3-D printing for remanufacturing their own spare parts, printing an outer highly customised layer onto a core component obtained from a used part (Sundin, Erik, personal communication, 9 March, 2016). In general, 3-D printing of spare parts could enable the digitisation of spare-part stocks and the printing of parts on demand. While this is currently possible (e.g. Kazzata, 2016), it has yet to be integrated into common business models. In the business-to-consumer context, however, 3-D printing is currently mainly used to enable online ordering of custom- or self-made gadgets, which leads to more waste of resources than resource savings.

As additive manufacturing technologies enable a more localised value chain, the use of such technologies in the production, repair and remanufacture of products in Europe could create additional benefits, such as lower transport costs and emissions, and more local jobs the supply chain.

3.4 Building services around products

3.4.1 Trend

European industrial companies increasingly rely on services related to a product for income generation. In 2015, only 56 % of income was related to production activities, down from 66 % in 1995 (Witteveen, 2016). Digital technology enables the provision of services related to maintenance, performance management and operations tracking. There are different degrees of product-to-service evolution, ranging from after-sales maintenance contracts to delivery of performance as the basis of a contract. While the product-service system is quite common as a business model in the business-to-business context, for example, leasing of jet engines or copiers, or the maintenance servicing of heavy-duty manufacturing equipment, it is relatively new and immature in the business-to-consumer context, where product-related costs are usually

([1]) Subtractive manufacturing is a process by which 3-D objects are constructed by successively cutting material away from a solid block of material. Additive manufacturing is a process by which digital 3-D design data are used to build up a component in layers by depositing material. The term 3-D printing is increasingly used as a synonym for additive manufacturing.

lower and fashion still trumps functionality. Relevant drivers for the emergence of product-service systems are creating stronger relationships with customers as well as market differentiation and addressing changing consumer behaviour. For example, lighting manufacturers have ventured into product-service offerings to tackle the lower turnover resulting from LED lighting sales due to the longer lifespan of LED components compared with traditional light bulbs. Similarly, in the office furniture sector, service-based models provide more flexibility to provide furniture customised to the specific context of each client, for example flexible workstations and office landscapes. In the mobility sector, car manufacturers are developing customised car-sharing services in response to changing consumer preferences, especially in cities.

3.4.2 Impacts

Using a service-based business model is a powerful way of increasing product circularity if product ownership remains with the producer. In that case, minimising the total life-cycle cost of the product is an economic incentive that can encourage the design of products for longer lifespans, reuse, repair or remanufacture. However, this may still present a higher life-cycle cost if, for example, the labour needed for repair is too expensive. Thus, a product-service system does not automatically lead to more circular design and business.

In addition, products in a product-service system have a higher utilisation rate than the same products in a privately owned context, so fewer products, and thus resources, are needed to provide a similar function to a group of users. However, it should be taken into account that this could lead to faster deterioration of products and a shorter lifetime.

By providing better or cheaper functionality, such services can, however, lead to an increased use of, and thus need for, a product. For example, affordable car sharing can attract consumers that previously made use of public transport.

3.5 Home delivery systems

3.5.1 Trend

The online retail sector is the main driver of growth in European and North American retailing, achieving in Europe growth rates of 18.2 % (in 2015), 15.6 % (2016), and expected increases in 2017 of 14.2 % and 13.8 % in 2018. In contrast, the annual growth rates for all types of retailing (from stores and online) have ranged between an average of 1.5% and 3.5% pa (Center for Retail Research, 2016). Online retail provides an opportunity for adapting production to actual demand and, in this way, saving storage space. Consumers can also take advantage of the opportunity to compare and choose products without having to leave their homes to visit a number of stores.

The rise of e-commerce has had profound effects on the way products are distributed, leading to more centralised storage of goods in large warehouses combined with a finer transport network for delivering parcels to consumers. Distribution markets and systems are rapidly changing as a result of increased e-commerce, with both private and public participants trying to accommodate the rising demand for door-to-door distribution. In the public sector, it is noteworthy that cities are increasingly looking for solutions to tackle transport-related problems (Neirotti et al., 2014), for example by setting up local city depots combined with local distribution of products using eco-friendly means of transport, such as electric vehicles or bicycles (e.g. Citydepot, 2016).

3.5.2 Impacts

Home delivery systems have a direct impact on the amount and nature of packaging materials, which could lead to increased paper, cardboard and plastic packaging waste at the household level. However, when door-to-door delivery of online-ordered products matures as a distribution channel, reusable packaging might become more important for regular deliveries of items such as food.

The evolution of more decentralised distribution systems in retail could help set up reverse logistics, and in this way enable reuse, repair and remanufacture of products, as at-home contact between consumers and retailers provides a stronger incentive for the consumer to hand in appliances rather than having to organise their transport. In many extended producer responsibility (EPR) schemes, the seller of new white goods is obliged to take back old appliances. Some delivery services are already experimenting with taking back waste and reusable goods as part of the service offered when delivering new products — without a one-on-one take-back obligation (Cirkle, 2016).

3.6 Changing product lifespan

3.6.1 Trend

A product's lifespan is usually defined as the period from product acquisition to its disposal by the final owner (Murakami et al., 2010). It is also referred to as a product's domestic lifespan. The period includes any repair, refurbishment or remanufacturing and periods of storage when the product is no longer in use — also called dead storage or hibernation (Bakker et al., 2014).

Since the late 1980s, the domestic lifespan of consumer products has generally decreased (Box 3.2) and there are many possible reasons for this. Products might be replaced for technological reasons, where a product of better quality or functionality is available; for economic reasons, where the cost of repair or upgrading is high compared with that of replacement; and for psychological reasons, shaped by style, fashion or a perceived change in need (EEA, 2014; Prakash et al., 2016a).When producers focus on selling products at high volumes and are not financially rewarded for selling long-lasting products, this automatically leads to shorter lifespans. Some even claim that planned obsolescence is used to drive the market for new products (EESC, 2013). In addition, markets can force manufacturers to change products to keep pace with the competition and with customer preferences, thus adding to the business rationale for an overall shortening of product lifespans (Bakker et al., 2014). On the other hand, certain developments, such as designing buildings that can be easily adapted to changing needs, could extend the lifetime of buildings.

3.6.2 Impacts

A decreasing **domestic** product lifespan has a negative impact on product circularity, as it reduces the incentive for repair or reuse. An increasing **technical** product lifespan has a positive impact on reuse because of the higher residual value of a product after its first use,

Box 3.2 What do we know about the lifespan of consumer electrical and electronic products?

Decreasing domestic lifespan of consumer products

Although reliable data on product lifespan are hard to find, some have become available in recent years, for instance on consumer durables and cars in Japan and for electrical and electronic products in the Netherlands (Murakami et al., 2010; Wang et al., 2013). A summary of the data obtained in the study by Wang et al. (2013) on the evolution of median domestic lifespans in the Netherlands between 2000 and 2006 is shown in Figure 3.1. A study commissioned by the German Federal Environment Agency — to obtain reliable data on the lifespans and duration of use of selected electrical and electronic appliances — analysed data for the period 2004-2014 and found that, in Germany, the average first-use duration of white goods such as washing machines, dryers and refrigerators was 13 years in 2014, a decrease of around one year compared with 2004 (Prakash et al., 2016b).

Drivers for replacing consumer products

The reasons for consumers discarding products and buying new ones depend on the type of product. Disposable income and the price of goods strongly influence purchasing decisions. For example, clothes in Europe have, on average, become relatively cheap over the last two decades, resulting in an increase in clothing purchases per person (EEA, 2014). Reasons for product replacement also include technical failure of the product, or the desire to possess a newer item that has novel or extra functionality and/or aligns with the latest fashion trends, achieving status and identity through the product. In particular, in the case of electronics, incompatibility of older products with the latest software can lead to replacement purchases. Prakash et al. (2016a) have shed some light on the relative importance of these drivers for electrical and electronic devices in Germany. In 2012/13, 30 % of white goods purchased replaced an appliance that was still functioning — the decision to buy a new product was motivated solely by the consumer's desire for an upgrade — while in 2004, this accounted for only 25 % of purchase decisions. Over the same period, the percentage of purchases made to replace a broken product decreased slightly, from 57.6 % to 55.6 %. The percentage of white goods being replaced within just 5 years due to technical defects also increased noticeably: from 3.5 % in 2004 to 8.3 % in 2012/13. These data indicate that, while the technical quality of white goods is the main determinant of their useful lifespan, the importance of consumer preference has increased. It is likely that the focus on the improved energy efficiency of these goods has played a role in this change.

With respect to computer laptops, first-use duration remained fairly constant between 2004 and 2012, averaging 5-6 years, but the reasons for replacing a laptop have changed. In 2004, 70 % of functioning laptops were replaced as a result of technological innovation and consumers' desire for an upgrade, for example as a result of software incompatibility, while only about 7 % of replacements were the result of broken products. In 2012/13, however, consumer preference was responsible for only 25 % of replacement purchases, and more than 25 % of purchases were made because the old product had developed a technical defect (Prakash et al., 2016a).

Figure 3.1 **Lifespan of selected household products and change over time**

PRODUCT CATEGORY (MEDIAN LIFESPAN IN YEARS)	2000	2006	DELTA IN 6 YEARS
Lamps, compact fluorescent (CFL)	7.4	7.7	+ 3 %
Vacuum cleaners	8.1	8.0	– 1 %
Wash dryers ad centrifuges	14.5	14.3	– 1 %
Refrigerators	14.2	14.0	– 1 %
Dishwashers	10.7	10.5	– 2 %
Small IT and accessories	4.6	4.4	– 2 %
Tools	9.8	9.6	– 2 %
Small toys	3.8	3.7	– 3 %
Mobile phones	4.8	4.6	– 3 %
Washing machines	12.1	11.7	– 3 %
Laptop PCs	4.3	4.1	– 5 %
Hot water and coffee	7.0	6.4	– 9 %
Printing and imaging equipment	9.0	8.2	– 11 %
Microwaves	10.9	9.4	– 15 %
Small consumer eletronics and accessories	9.4	7.8	– 20 %

Source: Wang et al., 2013, based on Dutch data.

enabling re-sale and reuse of products. Similarly, the shared use of goods benefits from products with longer technical lifespans.

Nevertheless, the impact of product lifespans should be seen in the context of full product life-cycles. Products that are part of a performance-based service can have shorter lifespans with fewer negative consequences if the product is remanufactured or recycled after the use phase. Improvements in product design, such as energy-saving measures, may also warrant a shorter product lifetime, particularly at times of rapid improvements in energy efficiency. Furthermore, product lifespan can decrease as a result of greater utilisation of sharing schemes compared with the traditional sales model (Kemps et al., 2016). It is thus more relevant to assess the active or functional lifespan of a product than its age.

3.7 Collaborative consumption

3.7.1 *Trend*

Collaborative consumption, or the shared use of products by consumers, either peer to peer or mediated through a company, is a niche development that is increasingly becoming an important aspect of consumer behaviour. A survey conducted by consumer associations in four EU Member States (Belgium, Italy, Portugal and Spain) revealed that participation in these kinds of activities is quite high, reaching 72 % of those interviewed ([2]) (OCU et al., 2016). From the most recent estimates, the United Kingdom has emerged as the 'capital' of the sharing economy, accounting for 1 in 10 of the world's companies in this new digitally enabled sector, more than Europe's next three most prolific hubs — France, Germany and Spain — combined. There are 23 million collaborative consumers in the United Kingdom, and some estimates put the proportion at up to 64 % of the population (Stokes et al., 2014). More data on collaborative consumption can be found in a survey by the European Commission, the Flash Eurobarometer (EC, 2016e).

Research has identified economic incentives such as earning more through collaborative consumption than in the traditional market place, cost consciousness (Dubois, 2015; Hamari et al., 2015), and time, space and effort saving as reasons for joining collaborative business models. Growing environmental awareness (Gansky, 2012) and an increasingly critical view of overconsumption (Coyle, 2012; Leismann et al., 2013; Belk, 2014) are among the environmentally motivated reasons for participation in the collaborative economy. Trust, reputation, (Botsman and Rogers, 2010; Lamberton and Rose, 2012; Tussyadiah, 2015; Schor and Fitzmaurice, 2015), the desire to belong to a community (Belk, 2010) and authenticity are also among the reasons for these new forms of consumption.

Within the great diversity of collaborative consumption initiatives and businesses, two main models, with fundamentally different characteristics, can be identified: the corporate model and the community-based model. Examples of the corporate model include Uber and Airbnb: these are online platforms that have expanded to the international level in just a few years, and are backed by investment capital. The community-based model includes a large number of local, small-scale initiatives that have emerged from grassroots organisations and operate independently from each other across the world, spanning a wide variety of areas, such as urban gardening and sharing of toys, tools, or clothes (Gsell et al., 2015).

3.7.2 *Impacts*

In the public debate, collaborative consumption — more commonly known as the sharing economy — is seen as a contributor to a circular economy. The assumption is that shared use of assets leads to an increasing utilisation of existing products and consequently to a lower demand for new products. A market study on car sharing in Europe, for example, predicts that car sales will be 182 000 units lower (or 1.3 % of projected total car sales) due to car sharing in 2021 (Boston Consulting Group, 2016). There is, however, a lack of scientific research into the actual impacts of such business models in Europe on the environment or on product circularity (Schor, 2014). In principle, each business model that is categorised under the collaborative consumption umbrella should be scrutinised for its contribution to the more efficient use of the products concerned. In addition, the issue of rebound effects is of great importance in evaluating the environmental impacts of collaborative consumption. For example, the availability of cheap accommodation offered by a platform such as Couchsurfing enables more people to travel abroad instead of taking a vacation at or closer to their own home, leading to an increase in emissions from transport. Determining such rebound effects is not an easy task (Fremstad, 2015). Box 3.3 provides an example to illustrate the need for a nuanced and fact-based approach towards the impact of collaborative consumption on circularity.

Sound evidence on the impacts of collaborative consumption on jobs, taxes, prices and other economic and social aspects is emerging slowly. A number of challenges have been identified, including in the areas of regulatory obligations, consumer rights, liability insurance and the status of workers. In addition, many of the national rules on taxation and social protection do not easily apply to collaborative consumption activities. The European Commission has therefore published some good practices and guidance on how existing EU rules already apply to the collaborative economy (EC, 2016c, 2016a).

([2]) When all four countries were analysed collectively.

Box 3.3 Does collaborative consumption contribute to a circular economy?

There is no straightforward 'yes' or 'no' answer to this question. This example illustrates some of the difficulties in assessing the actual environmental impact of collaborative consumption.

A study on car sharing in the United States concluded that one car-sharing vehicle replaces 9-13 vehicles among car-sharing members because they sell their vehicles or postpone purchasing one. Overall, car-sharing users reported that they walked, cycled and carpooled more, leading to decreased monthly household transport costs (Transportation Sustainability Research Centre, 2015). Another study, however, reported that this change in lifestyle does not always occur, and that the overall effect of car sharing on car use depends on the proportion of users abandoning car ownership rather than public transport (Martin and Shaheen, 2011).

3.8 Markets for recycling

3.8.1 Trend

Since the early 2000's, markets for recyclables such as metal, glass, and paper and cardboard have grown considerably, with turnover between 2004 and 2008 almost doubling (EEA, 2011). For most recyclables, the main driver is export beyond the EU (Eurostat, 2014). This trend is largely policy driven by introducing obligations to recycle increasing percentages of waste while discouraging disposal to landfill. It is embedded in the linear regime, as recycling does not interfere with the dominant business model, based on increasing sales of products. A recycling industry already exists in many countries. The development of the EU Action Plan for the Circular Economy, and the societal debate in the context of its development, have shown a strong focus on the further development of recycling markets as the main policy priority.

3.8.2 Impacts

The strong policy — and consequently business — focus on developing and growing markets for recyclables could be a key driver of greater recycling, besides the use of recycling targets. In the absence of

Box 3.4 The impact of extended producer responsibility on product circularity

As defined by the Organisation for Economic Co-operation and Development (OECD), EPR is 'an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life-cycle'. In practice, EPR implies that producers take responsibility for collecting or taking back used goods and for sorting and treating them for eventual recycling. Such a responsibility may be merely financial, or may also be organisational. The policy first appeared in the early 1980s in a few EU Member States, especially for packaging waste, and has since spread around the EU and beyond. The underlying rationale is that EPR should foster the internalisation of environmental externalities and should provide an incentive for producers to take into account environmental considerations throughout a product's life, from design to end of-life.

So far, EPR has been proven to be effective in the collection of waste and its subsequent recycling. There is no clear evidence, however, of a strong positive impact on the eco-design of products (Monier et al., 2014). While some schemes, especially in the packaging sector, include lower fees for eco-designed products, mainly reflecting recyclability, only a few EPR regulations contain targets or indicators regarding waste prevention, reuse, repair or remanufacture. This primary focus on recycling in EPR implementation schemes has created a blindspot regarding design for reuse, repair and remanufacture.

Most EPR schemes are organised as collectives in which the cost-saving investment in an improved product design is shared among producers. At the same time, the end-of-life costs for collection and processing of wastes are often insufficient to justify any investment in innovations for reuse, repair or remanufacture. This is reflected in the use of EU research and development (R&D) funds. Based on information from the EU R&D database, Cordis, roughly 5 % of all EU projects related to product design deal with eco-design. Designs for remanufacture or repair are considered in only 1 % and 2 %, respectively, of product design-related projects, while 8 % of those projects focused on recycling. As the subject of design for circularity first appeared in the scientific literature as recently as the late 1990s, it remains difficult at present to note any clear changes.

similar incentives for repair, reuse and remanufacture, however, these inner circles (Figure 1.1) will not also benefit from growing recycling markets. Clear targets for recycling, for example, greatly encourage EPR schemes to organise a cost-efficient collection system fully geared to recycling, but do little to stimulate other product circularity options as part of the waste management chain (Box 3.4).

3.9 Internet of things

3.9.1 Trend

There are more devices connected with one another through the internet today than there are humans in the worldwide population, and the number of devices is expected to grow to more than 40 billion by 2020 (Ellen MacArthur Foundation, 2016). The rise of the internet of things (IoT) enables products to be tracked for location, status and quality, and to be remotely controlled in unprecedented ways. For example, this interconnectedness of devices allows the efficiency of product use to be monitored, and facilitates the predictive maintenance of products in ways that were previously inconceivable. Currently, the IoT is still a niche, mainly applied by industry for enhanced logistics and smart buildings for energy efficiency and comfort. In the near future, the increasing availability of data on the location, status and quality of products will enable economy-wide product flow and stock management, creating opportunities for improved collection, remanufacturing and recycling systems. The current use of embedded data among recyclers and remanufacturers remains limited primarily because the filtering of relevant data from all the product data available is not yet readily (Sundin, 2016). Furthermore, making product data available to third parties is a concern for the design and manufacturing industry, and this confidentiality issue could be a barrier to wider use of the IoT in the recycling industry.

To connect products to the internet, specific hardware needs to be integrated. The IoT trend thus contributes to increasing product complexity, as a wider range of elements, mainly metals, will be incorporated in products such as electronics, cars (Kemps et al., 2016) and buildings. In addition, the IoT and the wider trend of increasing use of electronics is leading to an increase in electricity consumption.

3.9.2 Impacts

The IoT can affect the circularity of society in several ways. Material recycling can be significantly improved when products themselves 'know' what materials they contain, who manufactured them, and other information that facilitates their reuse and the recycling of their components and materials. More knowledge-intensive products make it possible to optimise the use of resources, especially energy, during the product life-cycle and allow 'predictive maintenance', whereby the product itself can detect and communicate potential operation failures. Traceability in logistics enables optimal stock utilisation, thus reducing material waste and transport costs (IMS2020, 2010).

The IoT for circularity is currently utilised by companies that have moved from manufacturing to a product-service model, including leasing, and maintenance and remanufacturing of their own products, such as Philips (lighting) (Balkenende, Ruud, personal communication, 2 March, 2016), Siemens (engines) and Toyota (forklift trucks) (Sundin et al., 2009). Asset tracking — determining the location of an asset — is a significant enabler of collaborative consumption models such as car sharing (e.g. Car2Go and Zipcar), which increases the use of a given product. In addition, manufacturers can use the information generated by the product during its life-cycle to further improve its design (Ellen MacArthur Foundation, 2016). However, the improved interconnectedness of products also has a potential downside for product circularity, as the incorporation of sensors and other electronic elements in products contributes to their complexity — thereby reducing their reuse and recycling potential.

3.10 Implications for circularity

Taken together, the observed trends provide a mixed picture when it comes to the prospects for product circularity. Most of them have aspects that can either enhance or hamper circular resource use.

The trends towards modular design and collaborative consumption appear on balance positive, as they hold a promise of increased reparability and prolonged use of products. The shift to product-based services is also predominantly favourable, as durable and less resource intensive solutions become more profitable in this model. In contrast, the trend towards increasingly complex products is likely to counteract circularity, as it complicates recycling, repair and reuse. The remaining trends are all very ambiguous in this respect and much will depend on the actual implementation of related technologies, business models and consumer behaviours.

A summary of the potential impacts of the discussed trends on product circularity is provided in Table 3.1. This first analysis is by no means exhaustive, rather a first attempt to prompt thinking, criticism and, in due course, improvements in the method. It reflects a preliminary, somewhat superficial, expert opinion. More in-depth analyses of triggers and barriers related to the circular economy are available in Van der Veen and Wilts, (forthcoming); InnovFin Advisory and EID Advisory Services 2015; Rizos et al., 2015.

Table 3.1 Indicative impacts of product trends on material circularity

Trend	Positive aspects	Negative aspects	On balance
Increasingly complex product design and functionality	May lead to lower total demand for materials due to multi-functionality	Reduces potential for reuse and recycling (heterogeneous materials, complex disassembly)	Probably negative
Increasing use of modular design	Can extend product lifetime through easier remanufacture and repair		Probably positive
Local production on demand by additive manufacturing	Enables increased material efficiency compared to subtractive production	Customisation of products may hamper shared use May hamper recyclability (multi-material products)	Unclear
Building services around products	May increase efficiency of product and material use (frequency of use, longevity, repair)		Probably positive
Home delivery systems	Reverse logistics enable reuse, repair and remanufacture of products	May lead to an increase in household waste (packaging materials)	Unclear
Changing product lifespan	Increasing technical product lifespan of some products	Decreasing useful product lifespan of others	Unclear
Collaborative consumption	Enables more frequent/efficient use of individual products use		Probably positive
Markets for recycling	Provide support to recycling business models	Reduce incentives for reuse	Unclear
Internet of things	Allows for better information on product composition improves material recycling	Leads possibly to more complex products	Unclear

4 Enablers

Identifying effective levers that enable products to contribute to the transition to a circular economy requires analysis of the complex and non-linear relationships between many economic system drivers. This chapter focuses on three aspects: (1) shifting from product-based to service-based business models; (2) making additive manufacturing and the IoT work for product circularity; and (3) aligning policy instruments throughout a product's life-cycle.

4.1 Shifting to service-based business models

As argued in Section 3.5, product-service systems can boost the shared use, reuse, repair and remanufacture of products. However, transitioning towards a service-based business model is no easy task for manufacturers, as they face a variety of lock-ins to established product sales models.

- While product-service systems are quite common in a business-to-business context, service-based business models still need to break through to markets for consumer goods, where fashion and changing preferences are still important drivers.

- A service-based model leads to important changes in the nature of cash flows, resulting in up-front investment requirements for the producer, balance sheet extensions and the need to consider the residual value of assets (Witteveen, 2016). The financing mechanisms of the linear economy are not adapted to such a model.

- Manufacturers risk cannibalising their own product sales, and consequently the profits of their production plants (Zils et al., 2016).

- Manufacturers need a system for collecting products at the end of a service agreement, otherwise reuse, repair or remanufacture are not feasible. Moreover, uncertainty about the timing at which products in a service will reach the end of their technical or useful life presents a challenge for production planning and logistics.

- Many different institutional aspects can hinder the adoption of a product-service system, including incompatibility with current procurement rules, taxation rules and infrastructural barriers.

As discussed in Chapter 2, governments can help product-service systems to overcome these barriers to market entry and become established by creating niches where new practices can be developed and improved. In doing so, the conditions for realising the effective potential of product-service systems must be taken into account (Figure 4.1).

4.1.1 Exploiting reinforcing trends

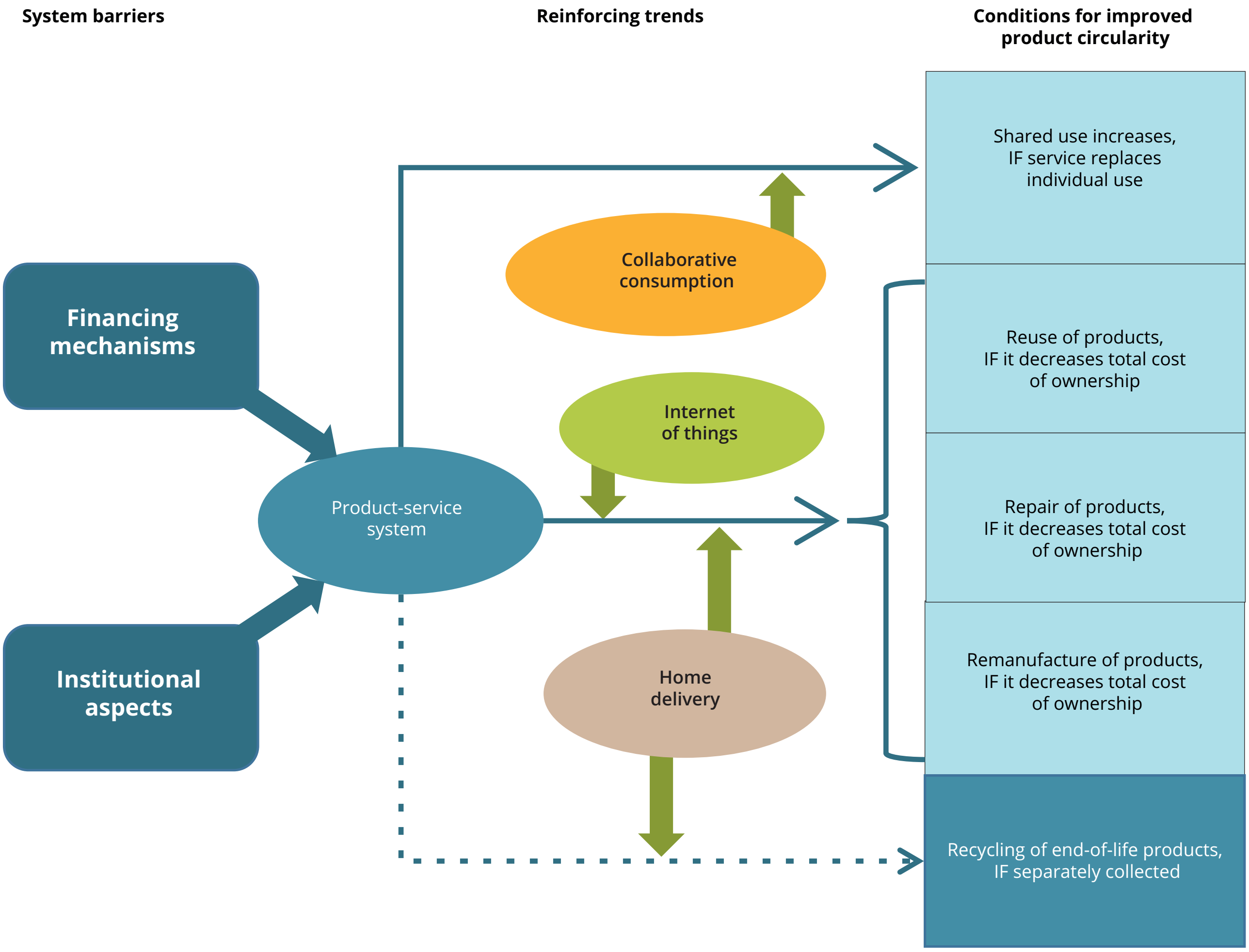
The rise of collaborative consumption indicates an increasing consumer preference for having access to a product rather than owning it. Developments in the IoT field provide solutions to the technical challenge of monitoring the location, status and quality of the assets in use in the product-service system. The growth in home delivery linked to online retail provides opportunities for organising reverse logistics, enabling manufacturers to collect their assets during or at the end of a service contract.

4.1.2 Tackling system barriers

The need for financing mechanisms adapted to service-based business models is a major system barrier for the growth of product-service systems (Box 4.1). It is encouraging that several banks and other financial institutions are actively analysing these issues and exploring solutions (InnovFin Advisory and EID Advisory Services, 2015).

An example of a policy measure with the potential to tackle institutional barriers related to product-service systems is the German state of Baden-Württemberg's promotion of car-sharing parking spaces (which are marked and cannot be used by private cars). Since 2015, a change in the state's building regulations has allowed the owners of buildings to pay a fee, defined by individual municipalities, to the municipality if

Figure 4.1 Enabling product circularity with product-service systems



the required installation of car parking spaces is not possible, or would be possible only with great difficulty. The municipality is then required, within a certain time frame, to use the money to provide car-sharing parking spaces (among other options) (Ministerium für Verkehr Baden-Württemberg, 2015b). Prior to this, municipalities were not able to divert the fee to pay for car-sharing parking spaces (Ministerium für Verkehr Baden-Württemberg, 2015a). In addition to this policy change in building regulations, Baden-Württemberg generally permits the rededication of streets or spaces used for traffic into marked car-sharing parking spaces. A good example of this regulation in operation can be seen in the city of Freiburg.

Box 4.1 Challenges and solutions related to the financial aspects of product-service systems

Transitioning from a product sales model to a service-based model creates a number of financial challenges that require new ways of doing business ([3]).

- Product-service systems require more emphasis on and management of cash flows. Access to finance is a key challenge.
- Contracts are important in financing service-based models. Legally binding contracts are also essential components in ensuring access to finance, as they provide greater security to financing institutions.
- The creditworthiness of consumers becomes important, as pay-per-use models may attract less creditworthy consumers.
- Value creation in second-hand markets must be better understood, as this may increase the financial viability of service-based business models.

One key solution to improving access to finance for circular businesses is to partner with banks willing to take on risks and provide services, such as factoring or reverse factoring. Factoring entails a company selling its account receivables to financial institutions or financiers advancing a sum of money to providers to reduce client risk and pressure from cash flows. In turn, financial institutions receive revenues from periodic payments made by the customer base. Reverse factoring implies that financial institutions pay a large sum of money to suppliers upstream of service providers to cover costs for inputs and materials, further reducing cash flow impacts. Meanwhile, service providers repay financial institutions in instalments with low financing costs.

4.1.3 Conditions required for product-service systems to contribute to product circularity

When businesses take advantage of emerging trends that enable the introduction of product-service systems, financial agents provide solutions to financial barriers, and policymakers address institutional barriers, the leverage allowing product-service systems to grow and contribute to product circularity will increase substantially. Multi-stakeholder experimentation initiatives, such as Green Deals in the Netherlands, in which all types of barriers can be addressed simultaneously by relevant participants, provide an essential mechanism to maximise the success rate of introducing systemic change.

However, as indicated in Section 3.5, a particular product-service system does not automatically lead to improved product circularity, but depends on the actual replacement of individual use by shared use, as opposed to solely attracting new consumers, and also on the implementation of reuse, repair and remanufacture in business operations. Scrutinising the effects of product-service systems on these two factors must be a key part of monitoring the contribution of service-based business models to increased product circularity. Policy initiatives supporting innovation for circular business models should include clear criteria for achieving real product circularity.

4.2 Making additive manufacturing and the internet of things work for product circularity

The analysis of trends such as additive manufacturing technologies and the IoT reveal that emerging innovations can have both positive and negative impacts on product circularity. Research, innovation, implementation and policy related to such technological changes largely evolve independently from changes in the circular economy arena. While it can be argued that there is growing interest in the potential of 3-D printing and connecting devices to the internet for the circular economy (Accenture, 2014; Ellen MacArthur Foundation, 2016; Witteveen, 2016), real integration of research and innovation in these areas is not yet happening. At the same time, there is scant consideration of the possible negative consequences of these technologies for recycling, repair or remanufacture.

([3]) Based on a review of recent reports on finance in the circular economy (Sonerud, 2014; ING Economics Department, 2015; InnovFin Advisory and EID Advisory Services, 2015; FinanCE Working Group, 2016).

Circularity opportunities and threats could be integrated in research visions and roadmaps on the IoT and additive manufacturing, both to stimulate the triggering effect of those technologies and to avoid negative side effects. At the level of the value chain, information regarding product recycling, reuse and remanufacture should be effectively transmitted to product designers, and the flow of information from processors involved at the product's end-of-life stage to product designers needs to be reinforced. Looking forward, IoT platforms that enable product tracking throughout supply chains can provide a basis from which to create policy and economic (tax) incentives related to how products are designed, utilised and managed along supply chains and across use cycles. Such policy and economic incentives could eventually be implemented in real time. Smart waste management systems, for example incentivising waste separation by households through a reward system, could become standard practice.

4.3 Aligning policy instruments throughout a product's life-cycle

The systemic nature of the transition towards a circular economy implies that policy measures targeting the waste phase, while necessary, are insufficient to achieve circular products. In this context, two elements are essential: (1) the focus of the policy should encompass more than just waste management; and (2) policy actions throughout the product's life-cycle need to be aligned to avoid negative side-effects and lock-in situations.

Initially, waste-related policies were introduced to tackle environmental and health problems related to landfill. Over time, the policy focus shifted towards stimulating recycling as an environmentally and economically sound way of managing waste. Product policies initially focused on the energy efficiency of products and the labelling of products with lower environmental impacts. With the policy focus now being on the transition towards a circular economy in which the value of products is maintained for as long as possible, a new phase in policymaking has been initiated. However, the change that is needed now is a widening, rather than a shift, of the policy focus. Stimulating markets for recycling is an important part of the transition, but the inner circles of circularity (Figure 1.1) should be equally stimulated. At the EU level, durability, reparability, upgradeability, and design for disassembly and ease of reuse and recycling will play a bigger role when setting eco-design requirements according to the Ecodesign Directive (EC, 2016b). Specific examples of existing policy initiatives that go beyond the waste phase are discussed in Box 4.2.

Box 4.2 Examples of policy initiatives targeting product circularity beyond waste management

France: enforcing the availability of spare parts

Article L111-3 of the French Consumption Law (Code de la consommation, Version consolidée au 22 mars 2015, Art. L111-3), which came into effect in December 2014, requires that customers be informed about the availability of a product's spare parts. The information needs to contain either a specific period or the end date of availability, and must be delivered by the manufacturer or importer to the vendor and by the vendor to the buyer. In addition, the law specifies that the information must be visible prior to purchase and confirmed in writing after a purchase is made. If need be, the spare parts for a product have to be supplied by the manufacturer to vendors or repair enterprises within two months. This law applies to all products that are placed on the French market since 2015 (JRC-SUSPROC, 2015).

Flanders: reuse enabled by job creation

In Flanders an extensive reuse network was set up by subsidising reuse shops. Subsidies depend on the amount (kilograms) of product sold for reuse and are proportional to the number of inhabitants of the area in which the reuse shop is located. In combination with subsidies for workers undertaking repairs in these shops, this led in 2015 to a reuse rate of more than 5 kilograms per inhabitant through these reuse networks.

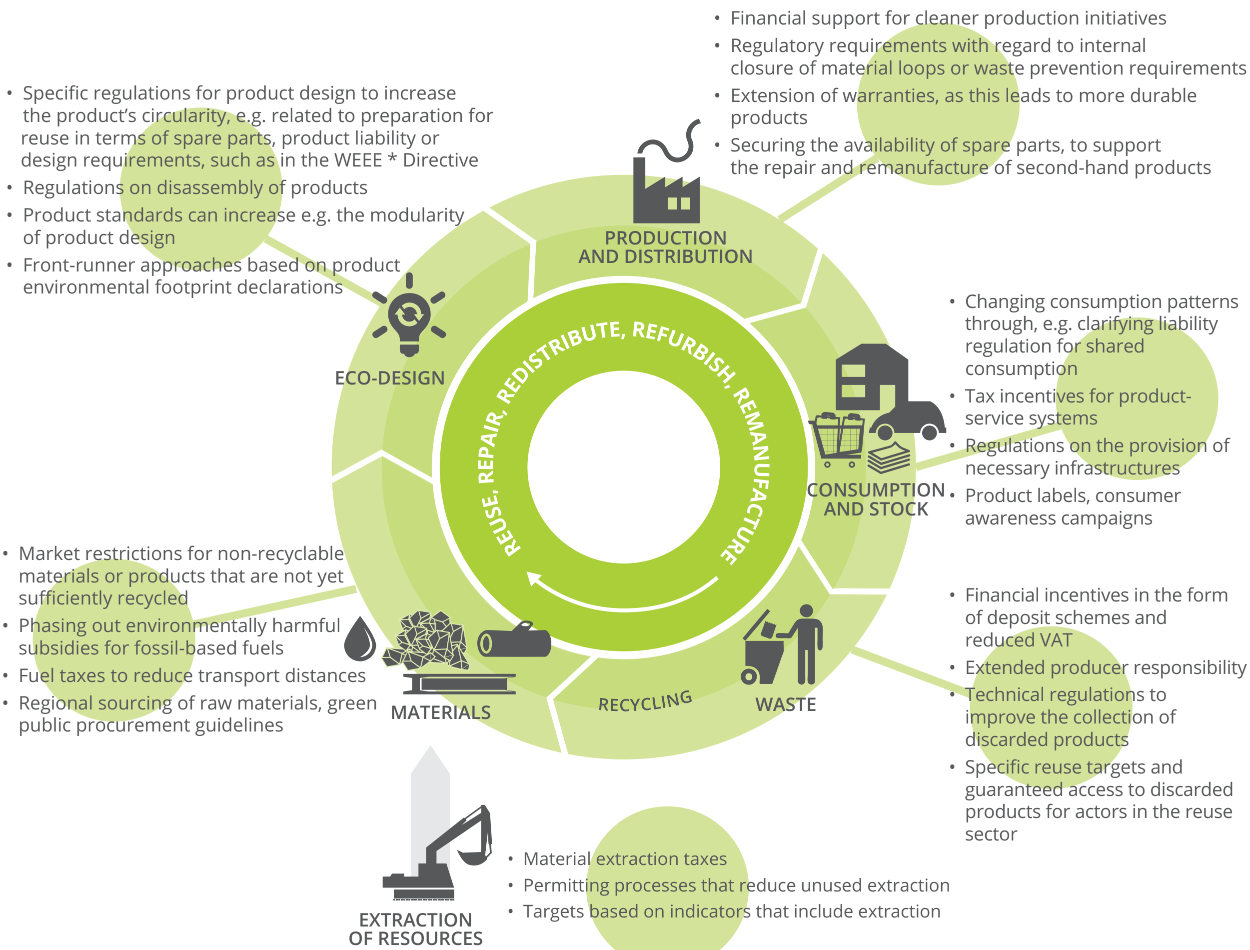
Sweden and Belgium: stimulating repair through tax reforms

Since January 2017 Sweden has been giving tax breaks on repairs. The value-added tax (VAT) on repairs to bicycles, clothes and shoes has been decreased from 25 % to 12 %. In addition, the Swedish government allows customers to claim back half of the labour cost of repairs of electrical appliances from income tax (Orange, 2016; Margolis, 2017). The idea behind this is that lowering taxes on these activities will boost the demand for repair services that are easily substituted by do-it-yourself work and therefore tend to be under-used. In Belgium a reduced VAT rate of 6 % (down from 21 %) for minor repair services was introduced as part of an EU pilot programme in 2000, and was made permanent from 2011 onwards.

In general, a wide range of possible policy instruments to improve product circularity can be applied throughout a product's life-cycle (Figure 4.2). It will be essential, however, to ensure the alignment of policy measures throughout the life-cycle, not only to avoid conflicting incentives for businesses and consumers, but also to capitalise on synergies resulting from concerted action aimed at different product circularity strategies. For example, the collection rate of end-of-life products from consumers could be increased if collection initiatives not only make use of recycling as an argument for consumers to hand in their old products, but also include the opportunity to reuse or repair. Another issue that should be tackled is the aspect of liability when the repair of a product is undertaken through an informal sharing economy approach (such as repair cafés).

Streamlining policy measures is, however, a significant challenge, not only because different policy actors are responsible for different stages in a product's life-cycle, but also because it is difficult to predict all the possible impacts of a policy before it is implemented. This highlights the need to use a systemic monitoring framework allowing the identification of systemic impacts of policy action, and appropriate adaptations.

Figure 4.2 Overview of potential policy instruments affecting product circularity throughout the product life-cycle



Note: * WEEE: Waste Electrical and Electronic Equipment.

5 Reflections

While the circular economy has become a prominent guiding vision for businesses as well as policymakers, there remains much uncertainty about the pathways to achieving such an appealing future, in which production and consumption patterns allow Europeans to live well within the limits of the planet.

The transition to a circular economy can be compared to trying to sail across the ocean to another continent. A clear idea of the desired destination — the vision of how the circular economy should look — and a navigation plan will not suffice. One needs to understand the effects of actions at the steering wheel on the boat's behaviour (regime trends), to know how the wind blows and what the currents are (landscape trends), and to appreciate how all this affects the boat's behaviour. By monitoring key parameters, such as wind speed and location, the effect of steering the boat can be evaluated and corrections made. Along the way, specific events (niche innovations) can reinforce the boat's course, or can drive the boat off course entirely, depending on their strength.

Taking a systemic perspective can help navigate a transition to a circular economy. Learning to identify and observe key mechanisms, as well as landscape, regime and niche trends relevant to product circularity, is a key asset in developing the knowledge base on the circular economy. It enables the design of more appropriate ways to monitor the transition, and to take action that has a higher probability of leading to change in the right direction.

The following overarching points can be made:

- As the system consists of many mechanisms affecting many different, there is a need to align measures to improve product circularity.
- The potential of specific niche innovations, such as additive manufacturing or collaborative consumption, to contribute to increased product circularity cannot be generalised or taken for granted. The eventual impact of such innovations will depend on the adoption pathway followed.
- As there is no way to predict the specific impact of changing a business model or adopting a particular policy up-front without avoiding unintended side effects, a reflective and iterative approach is key for any action taken to stimulate the circularity of products.
- The monitoring required for assessing the impacts of measures taken, and for observing the transition of the system in general, must also take a systemic perspective. Quantitative indicators need to be complemented by qualitative assessments, and put in the context of the system being monitored.

As for availability of data and knowledge on the area of circularity, the following challenges exist:

- Appropriate data on product stocks and flows throughout the economy are generally missing. Available data are mostly about materials, which is insufficient to capture the evolution of the inner circles of the circular economy (Figure 1.1). Moreover, data are structured according to the logic of the linear economy, which is a barrier to assigning stocks and flows of products, and their related monetary flows and environmental impacts, to different circular strategies.
- More empirical research into the environmental and economic impacts of key trends, such as collaborative consumption, is urgently needed. A recent review of academic literature identified a gap in research on the environmental impacts of collaborative consumption models (Cheng, 2016).
- There is an equally urgent need to better understand the behaviour and discourse of participants within the system. Perspectives from social sciences, for example discourse analysis and behavioural economics, need to be incorporated in the knowledge base. For example, a recent niche-regime analysis of the different discourses used by various participants on collaborative consumption (Martin, 2016) shows that the original framing of the sharing economy in the public discourse as a more sustainable form of consumption gave way to a framing as a purely economic opportunity. If this continues, the further development of sharing economy platforms will probably not incorporate a sustainability agenda.

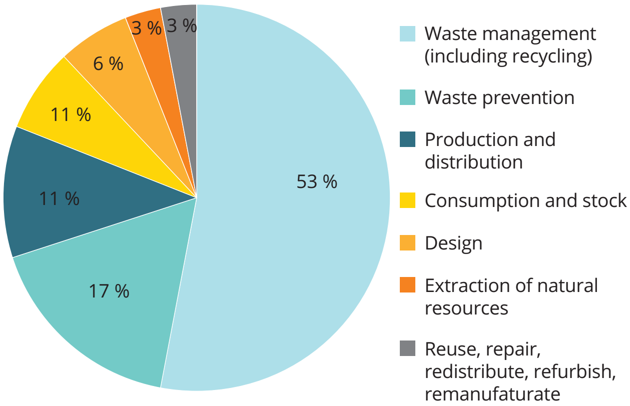
EEA and ETC-WMGE have reflected on some of the main challenges inherent to measuring and assessing progress with products in a circular economy, not least that quantitative data are largely missing for many aspects of products. These reflections are described in some detail in Annex 1 and can hopefully provide a starting point for discussions on where to go in the coming years on measuring progress towards product circularity.

Apart from the lack of appropriate data and knowledge, accomplishing a transition to a circular economy will not be straightforward — it is a complex and challenging process and there is no clear idea of what to expect along the way. Guidance for the different stakeholders involved is also required, as shown in the recent report *More from less: Material resource efficiency in Europe* (EEA, 2016b). Policy approaches to closing material loops in EU Member States are expanding beyond the end-of-life phase (Figure 5.1) but in a moderate way. About half of the responses to the survey question 'What is the policy approach towards closing material loops in the economy/circular economy?' were still related to waste management, and, furthermore, within this category most policy approaches were focused on recycling.

Trying to find out what can stimulate the different stakeholders in the transition to a circular economy will be one of the elements of the knowledge base that must be expanded. For example, changing consumer behaviour is crucial for the circular economy, but identifying effective policy levers to stimulate changes in consumer behaviour is a difficult task. For example, the proposal to reduce VAT rates for repair services in Sweden is intended to encourage consumers to choose repair of their products over throwing them away and buying new ones. Monitoring the actual impact of this policy measure will provide much needed insight into its effectiveness.

The analyses presented in this report are far from complete and are only the next step in the transition towards a circular economy. The knowledge base needs to be further developed and action must be taken at different levels. The EEA aims to contribute to this development in cooperation with its relevant partners and networks, including Eionet — the European Environment Information and Observation Network.

Figure 5.1 Distribution of responses on policy approaches to closing material loops in the economy/circular economy across different life-cycle stages



Source: EEA, 2016b.

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Annex 1 Assessing progress

Changing product characteristics and product design will need to play a central role if Europe is to bring about a circular economy in the coming decades. Assessing progress in this regard though poses several fundamental measurement challenges For example, how can society assess and measure progress at the product level, given that statistical and other data are largely missing particularly in the way products are produced, used and discarded? And how can one measure and assess if this circularity leads to lower environmental impacts and more sustainability, which is the ultimate goal of a circular economy? Furthermore, to what extent can progress be assessed using quantitative data and indicators as against qualitative approaches that, for example, bring niche product innovations to the attention of society thereby spurring their greater use in the economy.

Almost all available indicators for measuring progress towards the circular economy are macro-level in their focus and largely concern material flows and waste. Such indicators give insight into material flows in the economy as a whole, but are unable to capture the mechanisms behind these flows. Life-cycle approaches offer promising possibilities at the product group level but remain far from operational. Additional information is needed, for example, on trends in product design and product handling to minimise environmental impacts when aiming to achieve circular use.

In 2016 the EEA published a set of policy questions that could help to assess progress towards a circular economy from a materials perspective (EEA, 2016a). In this framework, policy questions on eco-design mostly address the intrinsic circularity properties of products, while others address how products are embedded in the system, for example regarding business strategies shifting towards circular concepts (Table A1.1). An attempt to identify suitable indicators to answer these policy questions revealed that indicators on eco-design and product circularity in a broader sense are currently lacking (EEA, 2016a).

The policy questions in Table A1.1 take the perspective of policymakers or influencers. There are, however, many other stakeholders. There is no one size-fits-all indicator framework for product circularity; it depends on perspective and the respective participant's ability to take action. The following participants could benefit from assessment tools to support their decision-making.

- Policymakers or influencers, such as government authorities and non-governmental organisations need information on material flow parameters and levers for action and uptake of circular practices.
- Companies that manufacture and/or place products or services on the market need insight into consumer demand and the characteristics of the value chain to decide on product design, technology, business, financing and distribution models and procurement strategies.
- Consumers, both collectively and individually, need information to choose products or services on the basis of circularity and its associated benefits, and, conversely, to inform product design.

Table A1.1 Policy questions related to the circular economy from a materials perspective

Eco-design	Are products designed to last longer?
	Are products designed for disassembly?
	Are recycled materials included in product design?
	Are materials designed to be recycled, avoiding pollution from recycling loops?
Production	Is Europe using fewer materials in production?
	Is Europe using a lower volume and number of environmentally hazardous substances in production?
	Is Europe generating less waste in production?
	Are business strategies shifting towards circular concepts such as remanufacture and service-based offers?

A1.1 Monitoring product circularity from a systemic perspective.

Knowledge of a product's technical properties needs to be complemented with information on the system in which the product circulates, such as:

- the business or consumption model that determines the life-cycle of the product;
- the societal and governance enablers/constraints that determine the life-cycle of the product;
- the macro-scale result of all similar product life-cycles in a certain region.

This is illustrated in Figure A1.1.

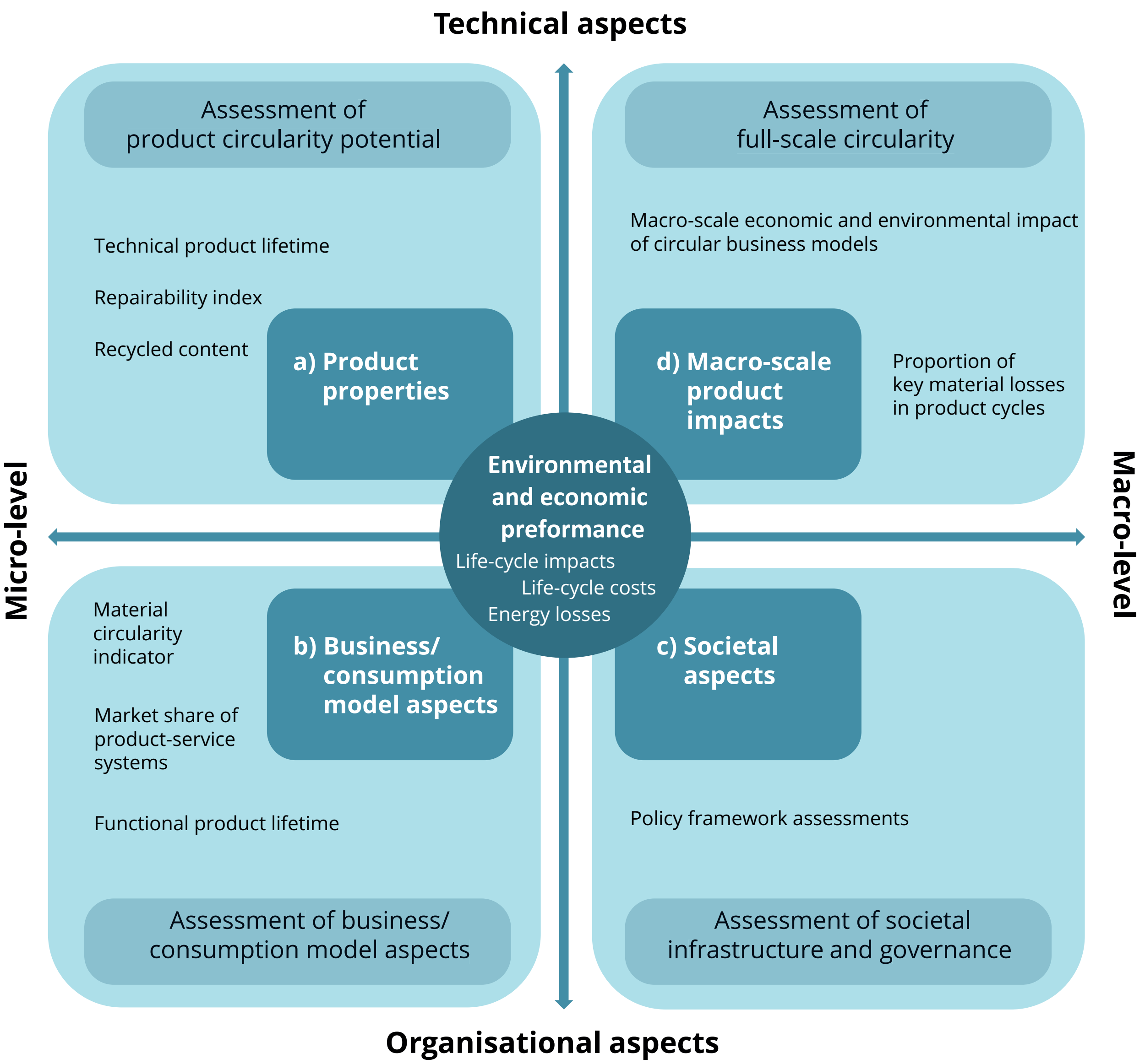
In the following paragraphs we elaborate further on the questions in Table A1.1, adding various aspects that could be monitored.

A1.1.1 Product properties

Questions on product properties raised in the 2016 Circular Economy report (EEA, 2016a) included whether they are designed to last longer, can be disassembled, contain recycled materials and can be recycled themselves (non-toxic materials).

In addition, it is relevant to analyse whether the product is designed to be easily repaired and to cause

Figure A1.1 Conceptual framework for evaluating product circularity from a systemic perspective



minimal environmental pressures. All of these aspects could be considered for dedicated monitoring and information gathering.

A1.1.2 Business/consumption model aspects

Whereas the design of a product determines its circularity potential, it is the business and/or consumption model that determines if this potential is fully realised over its complete life-cycle. The service that is offered in connection with a product — repair, take-back, remanufacturing, shared use, etc. — is as important as the product itself.

Relevant information in this respect already mentioned in the 2016 Circular Economy report (EEA, 2016a) concerns the lifespan (actual use) of the product, the uptake of circular business models and the shift in consumption to less environmentally harmful products and services.

In addition, information on the number of product-service systems would be relevant, as would information on transport, take-back, repair and utilisation rates of products.

Such information illustrates how products are actually used; comparing the circular and environmental performance of different business models can inform the design of a product.

A1.1.3 Societal aspects

Relevant societal aspects include regulation of products, waste, labour, etc., as well as existing infrastructure for distribution, collection, reuse, recycling, etc. These macro-scale factors determine to a high degree the potential for circular material use and can be captured in measurable parameters.

A1.1.4 Macro-scale product impacts

The aggregated impact of the use of a product over time is especially relevant for assessing priority production and consumption domains, and for putting micro-level measures into a wider perspective. The higher the macro-scale impact, the more can be gained from increased circularity. Environmental benefits of material use efficiency gains could be offset by shorter use cycles, for example where lighter packaging material is used. Relevant parameters are the proportion of recycled material and overall material loss, and loss of European production. In addition, it could be investigated whether or not European consumption is resulting in the use of fewer materials along the product life-cycle (material footprint).

A1.1.5 Monitoring the environmental performance of greater circularity and the economic impacts

The concept of product circularity addresses the degree to which materials (and their value) can be preserved while products circulate in the economic system. To monitor the sustainability of improved circularity, the environmental and economic impacts related to the products and the system in which they occur need to be assessed as well. For example, replacing a throw-away product with a product-service system can lead to an increase in transport emissions due to the reverse logistics necessary to bring the product back to the producer. In that case, the environmental performance of the circular product-service system will only be better than the linear throw-away system as long as the extra transport emissions are offset by decreased emissions at the end-of-life stage of the product and by the replacement of primary materials and new products.

One question related to monitoring environmental performance could be: Is the environmental impact caused by material consumption decreasing? Box A1.1 gives an example of monitoring environmental performance and the economic impacts of more circularity.

A1.2 Assessment of a product's circularity potential

A1.2.1 Technical lifetime of a product

Although a very relevant parameter, the durability of a product and its actual lifetime is hard to assess in an objective way. It depends not only on technical properties, but also on fashion and various societal aspects (e.g. wealth, and historical and cultural background) and the way it is used. Clothing may, for example, be discarded before it is worn out, or IT equipment may be made obsolete by new technological developments. A distinction should be made between the technical lifetime, which is part of the intrinsic properties of the product, and the functional lifetime, which is determined by the conditions that are created around it.

Apart from some very specific products, such as light bulbs, it is hard to get reliable data for comparing the

Box A1.1 Monitoring the environmental performance of more circularity and the economic impacts

Agfa Graphics, a company that produces offset printing plates for the graphics industry, has made extensive use of life-cycle analysis (LCA) in developing its business strategy ([4]). Starting with an LCA of their initial product, the company identified that reusing or recycling the aluminium printing plates would generate significant environmental savings. This insight has stimulated the company and its partners in the value chain to undertake innovation projects to set up the technology for recycling the printing plate waste into new printing plates, and to develop a fitting business model and logistics system. While the new circular business model has been successfully tested with real customers of Agfa Graphics, the costs of setting up a separate aluminium production line appeared to be too high relative to the volume needed for the printing plate application. Moreover, additional LCA calculations showed that the leasing model is only beneficial compared with the classic model within a certain distance from the recycling plant. As a result, Agfa now leases the printing plates as a service to customers within a limited distance, but sends the used printing plates to an aluminium recycler where it can be recycled into other high-value applications, such as car doors.

technical lifetimes of similar products, although this could be useful for consumers. If there were legislative requirements for stating the technical lifetime of products, determined under standardised conditions, this would increase the transparency and availability of data, and empower consumers to contribute to a circular economy. It could also provide a basis for policymakers to establish product criteria, such as minimum guaranteed lifetime. Producers of products that last longer would also benefit from more transparency on technical lifetimes, as it would give them a competitive advantage.

A1.2.2 Reparability

The iFixit index is an example of an indicator that rates the reparability of new smartphones and tablets to a standard protocol (iFixit, 2016). By gathering the indices for different companies/models through time, trends in reparability can be assessed, overall or per brand. For example, Figure A1.2 shows that the average reparability score for new electronic tablets has decreased since tablets first appeared on the market in 2010. This makes this indicator useful for policymakers, product designers and consumers. The indicator is calculated for each new model of tablet, laptop and smartphone of the main brands on the market, but its use is limited to raising awareness among the community of iFixit users.

The iFixit example can serve as inspiration for the development of similar scoring standards for a wider range of products and for other product circularity aspects such as reusability, remanufacturing ability or recyclability.

A1.2.3 Recycled content

The proportion of recycled material in new products indicates the actual rate of closed-loop recycling, and is useful for informing consumer choice and green procurement. This indicator requires clear definitions of what is considered recycled, how far one goes or can go down the supply chain (traceability), and possibly a regulation for producers to disclose this information. As yet, there are no such standards or regulations, so the use of this indicator is currently very limited.

Box A1.2 gives an overview of the Joint Research Centre's (JRC) work on the development of product indicators.

Figure A1.2 Average iFixit reparability scores for electronic tablets

Source: iFixit, 2016.

([4]) http://www.mo.be/nieuws/planet-was-ons-motief-maar-het-resultaat-kwam-vooral-profit-en-people-ten-goede.

Box A1.2 The Basket of Products indicators — EU Consumer Footprint indicator

The European Commission is developing an assessment framework to monitor the evolution of the overall environmental impact associated with EU consumption, as a policy tool supporting the transition to a resource-efficient and circular economy. This assessment framework is built on a consumption-based perspective in which environmental impacts along the product's life-cycle (raw material extraction, production, use phase, reuse/recycling and disposal) are allocated to the country where the final consumer is located.

The EU Consumer Footprint is the measurement of the environmental impacts based on the LCA (EC, 2013) of products (or services) purchased and used in one year by an EU citizen. The EU Consumer Footprint is based on the results of LCAs of representative consumed products (and services where relevant). Consumer consumption is split into key consumption areas, and for each area a basket of products (BoP) is developed, based on representative products. For each of the five BoPs (food, housing, mobility, household goods and electric/electronic appliances), a baseline scenario is defined, taking the consumption of an average EU citizen as reference. The Consumer Footprint synthesises the LCA of products used in one year by an average European and covers goods of the five key consumption areas. For this purpose up to 70 LCAs are conducted, accounting for 15 different impact categories (e.g. climate change, acidification, eutrophication, ecotoxicity, resource use-related impacts, etc.) calculated using the models recommended by the European Commission.

The baseline models allow the identification of environmental hotspots along the product life-cycle and within the consumption sector of each specific BoP. The results of the hotspot analysis are used as a basis for the selection of actions (covering both consumption pattern and behavioural changes or implementation of eco-solutions) that can help to reduce the environmental burden of EU consumption, including actions relevant in the context of the circular economy (e.g. closing the loop of materials). For each of the actions a scenario is developed by acting on the baseline model and simulating the changes provided by the action. The LCA results of each scenario are compared with the results of the baseline to identify potential benefits or drawbacks arising from the implementation of the solution tested. The complete set of BoPs will be available from the end of 2017, together with a set of preliminary scenarios in each area of consumption.

The Consumer Footprint indicators aim to have a twofold use for institutions by both monitoring EU consumers' shift towards more sustainable consumption patterns (time and geographical dimension) and supporting the development of better consumption-focused policies. The tool is designed to support policymaking and monitoring of policy impacts, as it aims to:

- **measure** the overall environmental impacts of the private consumption of an average European citizen in one year;
- **identify** which products and consumption areas create the highest environmental burden;
- **enable the identification of differences in impacts** due to pro-environmental behaviour (e.g. the purchase of an eco-labelled product versus a standard one or changes in how the same product is used, such as personal use of a car versus carpooling)
- **measure and compare the performance of policies** contributing to sustainable consumption with regards to overall environmental savings achieved.

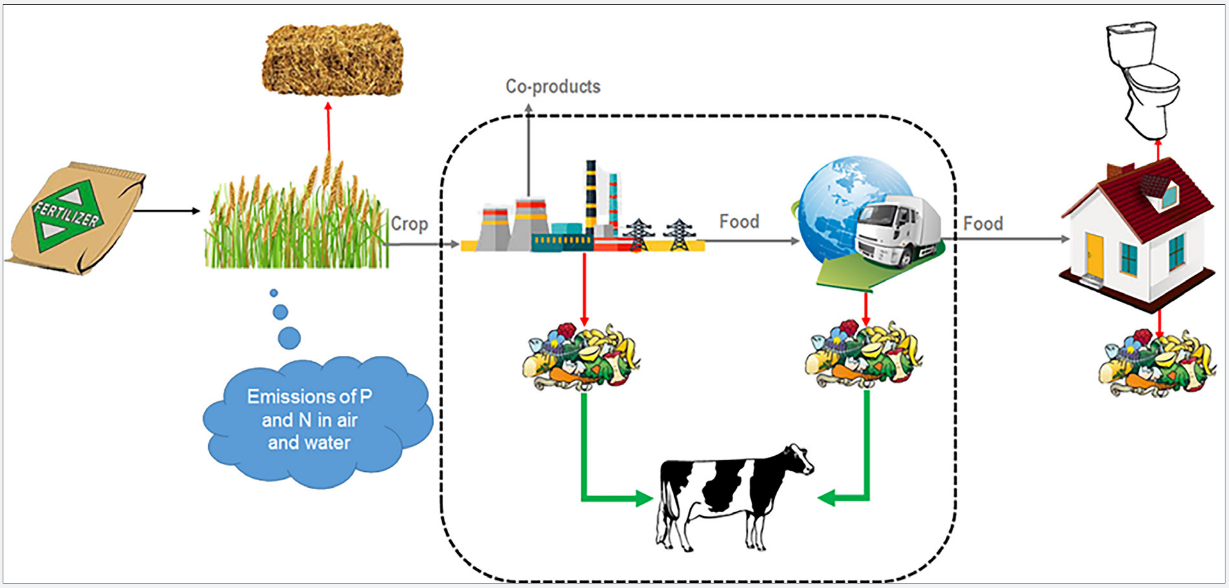
To illustrate the methodology used for calculating the EU Consumer Footprint indicator, an example from the BoP food, namely the implementation of measures to reuse food waste, is provided.

This scenario aims to assess the effects of introducing recovery of nutrients across the whole life-cycle of food products. The analysis is focused on one specific product (i.e. bread consumed in one year by a European citizen), and represents an example of the potential benefits achievable by closing the loop for nutrients. In this scenario, it is assumed that 100 % of waste produced at the processing and retail stages of bread is used as feed for animals (Figure A1.3). Assumed food losses are 5 % at the processing stage (0.05 kg for each kg of bread produced) and 2 % at retailing.

The use of LCA helps assess the potential benefits of using food waste as feed from several environmental perspectives (Figure A1.4) The greatest reduction in impact is on freshwater ecotoxicity (– 20.4 %), followed by land use (– 7.3 %). This result is consistent with what emerges from the hotspot analysis of the baseline, in which the impact of feed production mainly affected the freshwater ecotoxicity and land use categories (due to emissions of heavy metals to soil and water). As expected, the life-cycle stage that shows the greatest reduction in environmental burden is the processing phase, because in this phase a greater amount of waste is produced than in the retail phase.

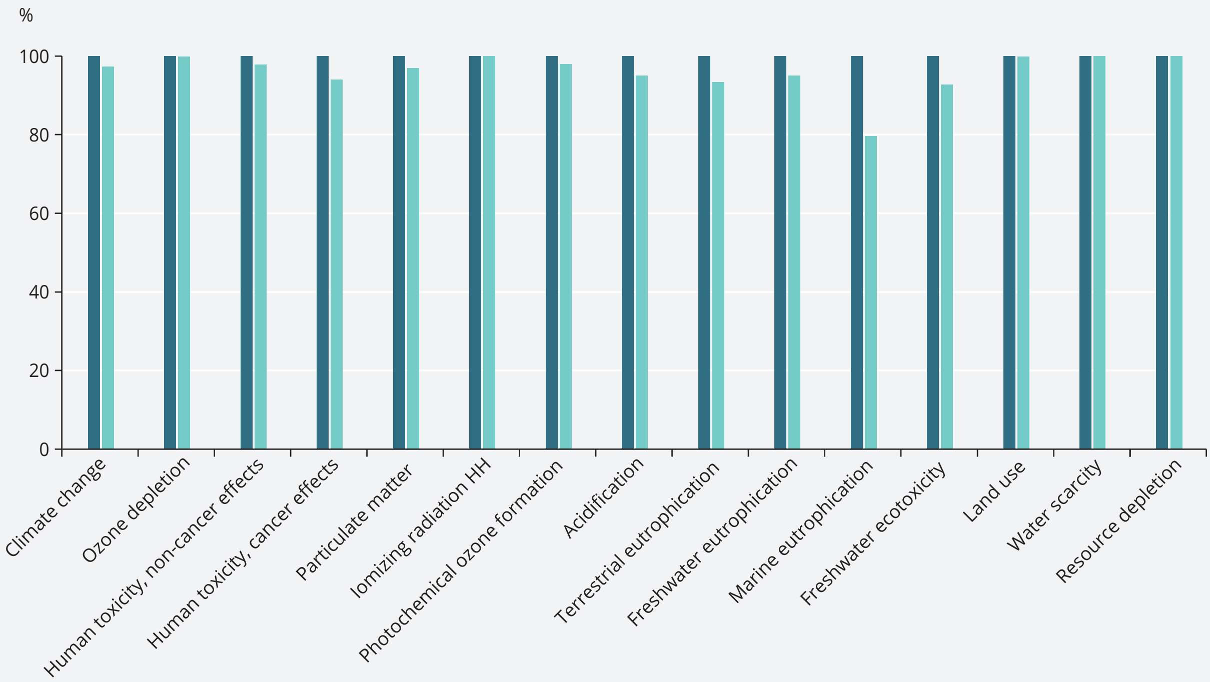
Box A1.2 The Basket of Products indicators — EU Consumer Footprint indicator (cont.)

Figure A1.3 Scenarios of food waste to feed



Note: The red arrows represent the output flows (as by-products or waste) from the food supply chain production system. The green arrows represent the reuse of these waste streams as input to other systems (e.g. animal breeding).

Figure A1.4 Expected reduction of impacts



A1.3 Assessment of business model or consumption model aspects.

A1.3.1 Material Circularity Indicator

There is a general lack of assessment tools for evaluating how well a specific business model accommodates circularity. The Ellen MacArthur Foundation has made the first attempt at addressing this issue by developing the Material Circularity Indicator (MCI) (Ellen MacArthur Foundation and Granta Design, 2015). This is designed to be used by companies to assess the degree of circularity of products or of the entire business, based on four principles:

1. using feedstock from reused or recycled sources;

2. reusing components or recycling materials after the use of the product;

3. keeping products in use for longer, for example by reuse or redistribution;

4. making more intensive use of products, for example through service or performance models.

The MCI is an index that ranges from 0 to 1. Any product that is manufactured using only virgin feedstock and ends up in landfill is considered a fully linear product and scores 0. Conversely, any product that contains no virgin feedstock, is completely collected for recycling or component reuse, and where the recycling efficiency is 100 %, scores 1. The indicator addresses crucial issues for product circularity, looking not only at the intrinsic properties of a product, but also at how the business model contributes to actual reuse, recycling, a longer lifespan and more intensive use of the product. A shortcoming of the MCI is that the different circularity aspects are included in the indicator using a rather pragmatic and empirical approach, with an equal weighting of shared use, reuse and repair in determining circularity.

Although developed primarily for companies, this indicator may also be interesting for policymakers. For instance, if standardised and applied by several companies, it could be used for benchmarking businesses on their circularity and assessing how a group of companies within a certain sector or region is making progress. For the MCI to become a true circularity indicator, however, more research is needed to enable trade-offs between different product circularity strategies. As the indicator was only developed in 2015, its uptake and use are still limited.

A1.3.2 Functional lifetime of products

Data on the average functional lifetime of products are not readily available, as they are confidential and not systematically gathered by independent organisations or public bodies. However, for several product types they can be derived from market data. For example, the useful lifetime of smartphones is related to the timeframe during which software updates are supported for a given handset. The Apple iPhone's useful lifetime has increased from 3 years for the first model to 5 years for the fourth-generation model (Statista, 2016). Another option for assessing functional lifetime might be to use the availability of spare parts as a proxy for functional lifetime.

A1.3.3 The proportion of product-service systems in a specific market

Assessing the adoption rate of product-service systems would provide an insight into the dispersion of business models that enable product circularity. While there is currently no systematically obtained information on the business models used to deliver and use products, useful information could be derived by analysing the financial or sustainability reporting documents for different sectors. The proportion of product-service systems in a sector could be a proxy for exploring the adoption of such business models. Other sources could be consumer surveys on the adoption of specific services. In the future, as the IoT becomes more widespread, more information about the use of products will become available from the products themselves.

A1.4 Assessment of societal infrastructure and governance

How well governance is geared to product circularity can be assessed through qualitative analysis of existing policies.

- What aspects of product circularity are stimulated or hampered by policy instruments?

- What is the size of the market that is affected by these policy instruments?

- What groups are targeted by the policy instrument?

These questions could be enhanced by additional factors, such as strong/weak implementation of the policy, new/established policy.

A1.4.1 Aspects of product circularity stimulated or hampered by policy instruments

A screening of how policy instruments address the different phases in the product life-cycle may provide insight into progress towards circularity, and can reveal synergies and inconsistencies in policy frameworks. For instance, requirements for increasing the separate collection rate of waste for recycling may be at odds with specifications in public procurement schemes that do not require any particular recycled content or even forbid the use of recyclates.

A1.4.2 Design and production

Policies that lay down criteria for placing products on the market can strongly influence product design. The degree to which these criteria address product circularity could be considered an indicator of how effectively these policies are being used to promote product circularity. Relevant issues to cover include recyclability, recycled content, requirements for easy dismantling and repair, minimum guaranteed lifetime, maximum environmental impact generated over the life-cycle and requirements for transparency within the value chain.

Another instrument that can be used is EPR. Most EPR schemes are limited to requirements on the collection and treatment of waste. The degree to which the schemes address the way products are designed and business models are organised may be an indication that a shift is taking place in policymaking.

Economic instruments that influence the design of products are another example, such as taxes on specific products or differentiated VAT rates.

A1.4.3 Transport, distribution and spatial development

An environment that fosters local production or tries to shorten the value chain could contribute to greater transparency, shorter transport distances and the provision of repair services, creating more opportunities for product circularity. Relevant questions when evaluating policy frameworks could include:

- Are there any policy measures in place favouring local production and local reuse or recycling services to shorten the transport distance between production, consumption and reuse/recycling?
- Are there policy measures in place engaging the distribution sector in stimulating local reuse and repair?
- Do spatial development strategies consider the optimisation of material flows within a specific region?

A1.4.4 Use and consumption

New business and consumption models are emerging. Some may create opportunities for product circularity, while others may throw up new barriers and lock-ins. From a monitoring perspective, it is relevant to assess to what extent policymakers proactively anticipate new developments and steer them towards product circularity, for example by favouring the shared use of products, replacing products with services or increasing access to repair/refurbishment services.

- Are there any policies that support a favourable cultural environment for collaborative consumption and product-service systems?
- Are policies in place to regulate new business and consumption models in line with consumer protection, workers' rights and tax regulations?

A1.4.5 Reuse, remanufacturing and recycling

This is the more classic domain of advanced waste management policies. The degree to which policy measures in this domain are gearing up for product circularity can be measured from the answers to the following questions:

- Are any policy measures in place favouring the separate collection of waste for reuse and/or recycling?
- Are there any instruments that support remanufacturing?
- Are there any instruments in place for stimulating the market for recyclates?
- Are there any standards on reuse/recycling or reusables/recyclates?

In addition to assessing the presence of policies stimulating the different aspects discussed above, it is equally relevant to assess existing policies for creating possible barriers to improving product circularity, for example, subsidy mechanisms that counteract companies' product circularity measures or public procurement rules that are not adapted to circular business models.

A1.4.6 Size of the market that is affected by specific policy instruments

It is also relevant to look at the size of the market that is affected by specific policy measures. For instance:

- What quantity of the products placed on the market is affected by a product requirement?
- What amount of waste is affected by these measures, compared with the total amount of waste generated?
- What is the level of green taxation?
- How many businesses and employees are affected by a specific measure?

The higher these numbers, the more likely it is that the policy instruments will have an effect on changing the environment.

A1.4.7 What groups are addressed by policy instruments?

Policies are aimed at changing the behaviour of actors in society. It may be helpful to differentiate between different groups on the basis of how receptive or prepared they are to change their behaviour towards increased circularity. Everett M. Rogers developed a theory on the diffusion of innovations, making a distinction between innovators, early adopters, early majorities, late majorities and laggards (Rogers, 2003). As the transition to a circular economy is all about innovation, it may be helpful to analyse how policy instruments try to address these different groups. For instance, public procurement schemes can be designed in such a way that they incentivise the innovators and early adopters to come up with new products or new business models that are more circular. Legislative minimum requirements on recycled content imposed on all products placed on the market will be aimed more at the late majorities and laggards (Figure A1.5), as one would expect that the early adopters would be well beyond these requirements. Policy instruments aimed at front runners (Figure A1.6) may be up-scaled for the late majorities and laggards (e.g. by turning an incentive into an obligation).

The more policy frameworks consist of a mix of instruments that address these different groups, the more likely it is that they will be successful in bringing about a system change.

Table A1.2 gives an overview of policy measures in the building sector, specifically aimed at front runners or the large majority.

Table A1.2 Examples of policy measures in the building sector, addressing different aspects of product circularity

	Incentives specifically aimed at front runners	Basic requirements aimed at all participants
Design and production	Specifications for buildings built by public authorities (Green Public Procurement, GPP) imposing a low environmental footprint, taking into account both the use phase of the building and the environmental impact occurring throughout the life-cycle	Prohibitions on the use of specific hazardous substances in construction materials
	Tax cuts for buildings that are constructed for a low life-cycle cost	Requirements on laying down material passports for buildings
	New financing models for buildings that incentivise building owners to invest in circular buildings	Taxes on primary materials for building materials
	Environmental labelling for circularity	Requirements on minimum recycled content for specific construction works
Transport, distribution and spatial development	Requirements for redeveloping sites owned by public authorities in such a way that the built environment fulfils strict requirements on circularity	Higher taxes on transport fuels or on kilometres driven to make transport over larger distances more expensive
	Requirements on the use of locally available reusable building elements or recycled building materials in public works to limit the need for transport	
Use and consumption	Financial incentives for owners of larger buildings (e.g. offices, schools) to share spaces with neighbouring organisations to limit the need for buildings and space	Requirements on the use of shared energy networks for heating a building in specific areas
Reuse, refurbishment and recycling	Subsidies for buildings that are designed for disassembly so that buildings can be dismantled into reusable building elements	Minimum requirements for the separate collection of construction and demolition waste when demolishing a building
		Taxes on landfilling and incinerating recyclable construction and demolition waste
		Lower VAT rates for the refurbishment of buildings

Figure A1.5 Policy measures primarily addressing the large majority of enterprises

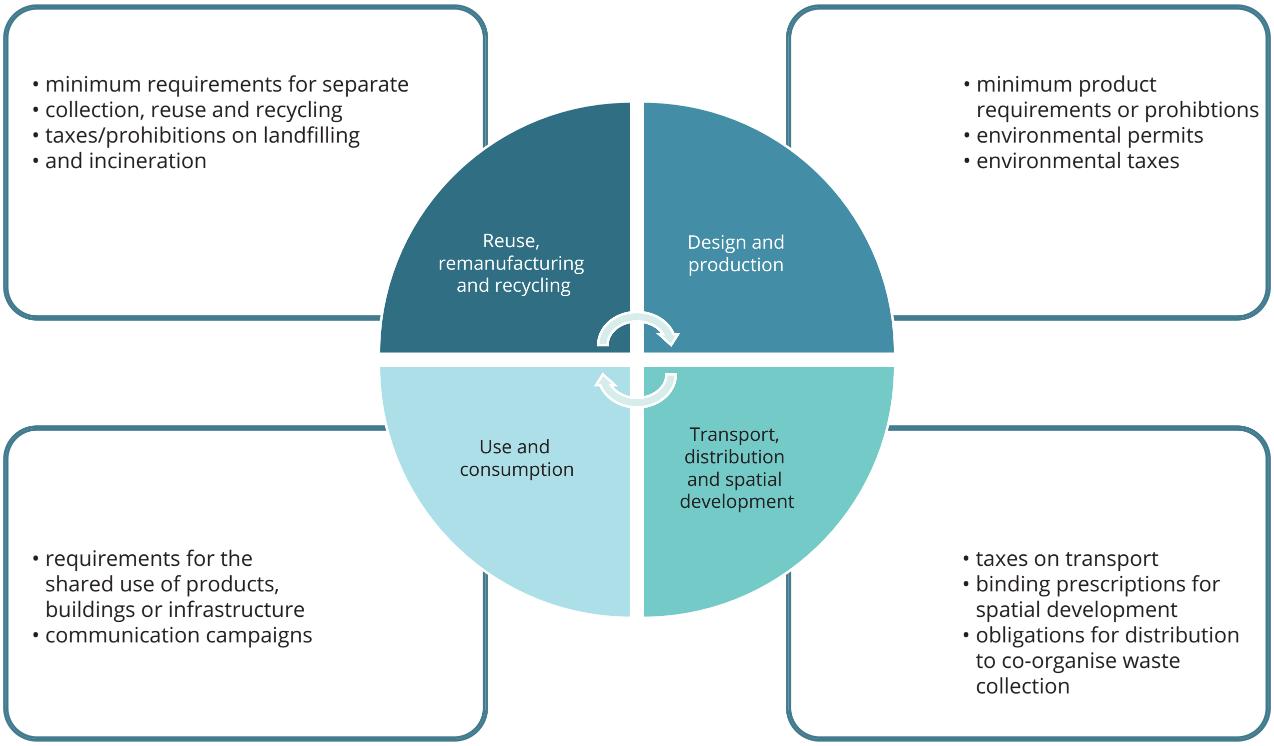
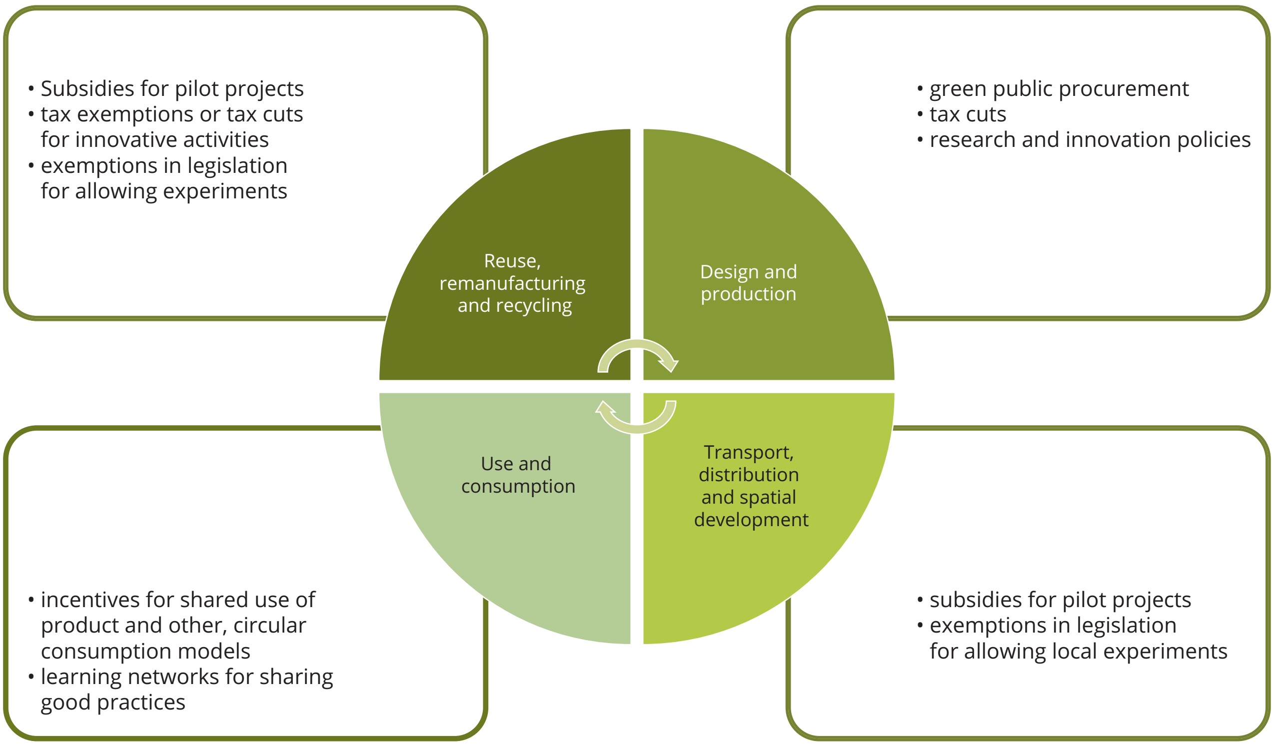


Figure A1.6 Policy measures primarily addressing front runners



A1.5 Assessment of full-scale circularity

To obtain a macro-scale view of the impact of certain product groups on the scale at which they are used — geographically and/or over time — indicators or assessment tools are required that aggregate the stocks and flows of products throughout the economy. This information can draw attention to specific problems that arise not so much from the way that products have been designed, but more from the scale on which they are used over time. This information can be used to trigger certain changes in the product design process that, although small, have a significant effect because of the scale of use.

A1.5.1 Macro-scale impacts of circular business models

Useful data at the macro-scale can be derived by using macro-economic data, such as (environmental) economic accounting based on input-output tables (Eurostat, 2008), or by aggregating micro-scale data derived from individual or groups of business cases. The first approach has the advantage of data availability. However, as the data are structured according to classic linear categories of supply chains and sectors, it is hard to assess the magnitude of specific circular strategies, such as product reuse, at the country level.

The bottom-up approach is less accurate as a result of the assumptions that have to be made on the representativeness of individual business cases for a whole sector. Moreover, while the effects of economic displacement and rebound effects are reflected in the macro-level data, they cannot be disaggregated from the overall picture. Nevertheless, if research efforts lead to a better understanding of the direct and indirect economic and environmental effects of specific circular business model categories, this knowledge can be used together with market data on the adoption of these models to monitor aggregated macro-scale impacts. Using both approaches in a concerted way would, however, provide the most comprehensive assessment of macro-scale economic and environmental impacts of circular business models.

A1.5.2 Proportion of key material losses in product cycles

Material flow analysis is a methodology increasingly used to map the flows and stocks of individual materials through a well-defined geographical region. Although flows and stocks of products can be a part of the analysis to obtain material flows and stocks, a product flow analysis is most often not possible due to the lack of (publicly available) data at a product level. Nevertheless, results from such studies can be used to obtain insights on key product flows in terms of opportunities for increasing circularity and decreasing material losses. For example, a study of the stocks and flows of neodymium (Nd) — a rare earth metal used in permanent magnets in a wide variety of products — in Denmark revealed that the most relevant product (in terms of quantities) for recycling would be wind turbines, which had a stock of more than 530 metric tons of Nd, compared with 403 tons in all home appliances combined (Habib et al., 2014).

Based on a more pragmatic approach to material flow analysis, methodologies are currently being developed to assess leakage of key materials from a material cycle (OVAM, 2015). The methodology starts with mapping the product categories in which specific resources are used and then estimates how well these resources are being preserved within the cycle. The methodology shows which products are responsible for major losses in a material cycle, given average product lifespans and collection, reuse and recycling rates. This bigger picture provides feedback on which product groups deserve more attention from policymakers, for instance when establishing eco-design criteria, and product designers, for example when thinking about using the right material for the right application, striving for greater circularity.

A1.6 Environmental and economic performance

As product circularity improvements do not automatically lead to increased environmental or economic performance, it is important to include environmental LCA and economic costing methodologies in the monitoring framework.

A1.6.1 Environmental impact assessment

LCA is a methodology for calculating environmental impacts linked to emissions to water, air and soil during the production, use and end-of-life management of a product, which also takes into account resource depletion and land use. It is possible to aggregate and weight different impact categories (midpoints) into a single score. Existing approaches are ReCiPe (weighting according to an expert panel), ILCD (equal weighting and different weighting approaches under development within the PEF pilot phase) and the distance-to-target methods (e.g. LIME or the ecological scarcity method) (Frischknecht and Büsser Knöpfel, 2013). These assessments provide insights on what part of the life-cycle contributes most to the environmental impact of a product, and allow a comparison of different products providing a similar 'functional unit of use' (e.g. 1 kg of product, or one unit of product). Consumer products, such as coffee machines, can be assessed, as can buildings or larger infrastructure. For identifying hotspots it is crucial to rely on midpoint indicators and to use different weighting methods for sensitivity analysis and decision-making (Kägi et al., 2016).

Although not specifically designed for it, an LCA can provide insights on the relative importance of the technical properties of a product, including its material content, in determining environmental impacts. For instance, although policymakers pay much attention to limiting the energy consumption of buildings during their use phase, in modern low-energy buildings the largest part of a building's total environmental impact over its life-cycle, including its contribution to greenhouse gas emissions, relates to the materials used in its construction (OVAM, 2013). This emphasises the importance of lowering the impact of materials used, for instance by using reusable or recyclable building materials and building elements. Box A1.3 shows how LCA can act as a trigger for developing a circular business case.

LCA is a well-established methodology, building on a strong scientific basis and making use of extensive databases, including on average emission rates of different materials and processes. The accuracy of the results depends on the availability of data on the specific life-cycle of the product being investigated. When using an LCA for determining the environmental impacts of improved product circularity, the methodology must be adapted to assess the impacts over different life-cycles instead of the linear concept of from cradle to grave. This means that extra care needs to be taken in establishing the system boundaries, as these may seriously affect the outcome of an LCA. The environmental impacts and benefits of the use of reused or recycled materials must be considered. Fewer data are available on the impacts of recycled materials than for the impacts of primary materials.

Exergy analysis is a thermodynamic approach used for analysing and improving the efficiency of chemical and thermal processes. Exergetic efficiency gives a good indication of how efficiently materials or energy sources are used (Box A1.4). It has been extended to LCA and sustainability evaluations of industrial products and processes. Figure A1.7 illustrates that the cumulative exergy extracted from the natural environment for the manufacture of a vacuum cleaner from recycled plastics is much lower than that for one made of virgin plastics.

Box A1.3 Using LCA to identify circular business opportunities — a company case

Nearly New Office Facilities (NNOF) delivers state-of-the-art office furniture by reusing, refurbishing and remanufacturing the customer's old furniture ([5]). The business emerged after an environmental impact assessment of the parent company — an office furniture mover — identified throwing away customers' old furniture as a significant hotspot for CO_2 emissions. The NNOF business offer is both cheaper and more environmentally beneficial than the standard model of buying new furniture. IN addition, the company has invested in an independent LCA model for its products that calculates the emissions savings for each customer.

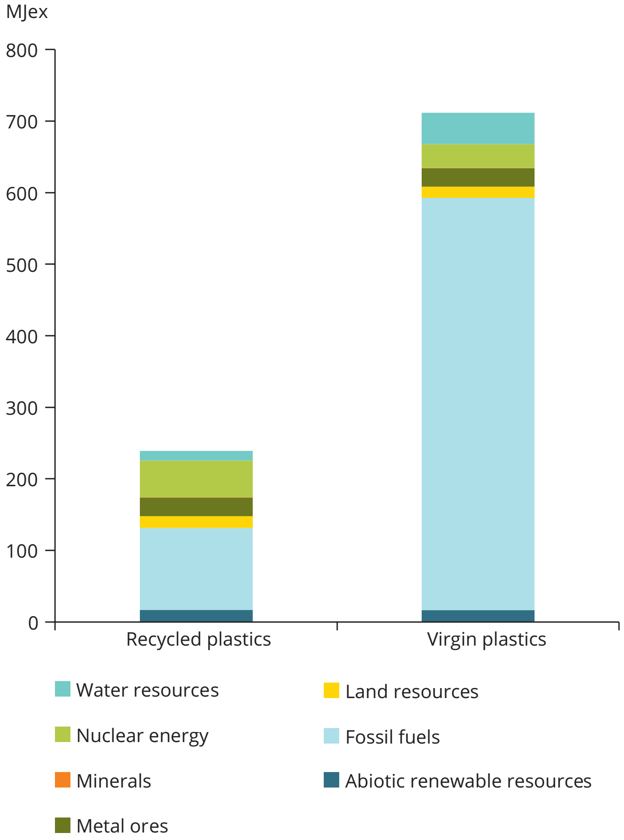
Box A1.4 Exergy

Exergy is defined as the maximum amount of labour that can be obtained from a material or energy source when it is brought into balance with its environment. It reflects the quality of the material or energy source. Contrary to energy, exergy can be lost. This loss is an indication of the loss of quality during processes.

Every material contains a certain amount of chemical energy. When this material is incinerated, chemical energy is transformed into heat. Heat is always emitted in the transformation of energy forms, which means that exergy is destroyed as heat contains a smaller fraction of useful energy than the chemical energy content of the material. In other words, the exergy of the material is reduced due to the heat loss. The advantage of an exergy analysis is that mass and energy can be expressed in a single unit.

([5]) http://www.nnof.be/minder-afval-minder-grondstoffen-minder-co2.

Figure A1.7 Cumulative exergy extracted from the natural environment of a vacuum cleaner made of recycled and non-recycled plastics



As a type of resource footprint, an exergy indicator gives product designers and policymakers more insight into the potential benefits of incorporating more recycled materials in products. As an assessment method, it provides a different perspective from that obtained through LCA, but, unlike LCA, it does not include all environmental impact categories.

Exergy analyses can also be used to calculate a recyclability benefit index (Debavaye et al., 2014). Expressed as a percentage, this indicator measures the advantages (in terms of exergy) of recycling a waste product rather than sending it to a landfill. This index can be used by both industry and policymakers for prioritising measures for separate collection and recycling and better design, when comparing the recycling step in the waste hierarchy to the lowest step of landfill waste. The indicator is still in an experimental phase — one element that needs to be clarified is the concept of recyclability, which is yet to be clearly defined and standardised.

A1.6.2 Economic performance

The life-cycle cost (LCC) is the cost throughout the life-cycle of a product — from purchase, through use and maintenance to its disposal. LCC analysis is useful to compare the real financial costs of products rather than focusing solely on the purchase price. This is particularly important for products that have long lifetimes, such as buildings, and for products that consume energy and/or water or materials during the use phase. An LCC analysis can be used as an indirect indicator for product circularity, as it may reveal long-term savings made by using components that last longer and need less maintenance. For consumers, LCC analyses can deliver useful information on which to base procurement decisions because they provides a better estimate of the costs that are likely to occur in future. It makes both consumers and product providers more aware of the likely behaviour of a product through time and maintenance, encouraging them to take into account design for disassembly, adaptability and upgradeability.

At this stage, LCC analyses are being experimented with and used in the context of green public procurement, but they are not yet widely used in the context of product circularity.

Table A1.3 gives an overview of the different elements that can be assessed for measuring progress towards products circularity, their current status and possible next steps.

A1.7 Towards a systemic monitoring framework

As has been shown in the previous chapters, there is still a lot of work to be done in developing good indicators and gathering the necessary data to feed them. This will require multi-stakeholder collaboration and considerable efforts to improve data availability. The following overarching strategies can be considered.

A1.7.1 Make use of existing indirect data

As a result of digitisation, a lot of data are gathered for a wide range of different purposes. Some of these data can be used to provide information on the indicators that are needed for product circularity. For instance, sales data of electrical appliances and data gathered by websites that sell reusable goods may give an indication of the average lifetime of a product. Data on transport of goods can give information on the average distance that goods travel, thereby providing

Table A1.3 Overview of elements that can be assessed for measuring progress towards product circularity

	Example assessment	Current status	Possible next steps
Product properties	Technical lifetime of a product	Lack of standardisation for determination of technical lifetime; limited data availability	Development of standardised assessment method; disclosure of expected technical lifetime by producers
	Reparability	Method and data available for three IT product types	Expand to other product types, building on the iFixit methodology
	Recycled content	Lack of standardisation and traceability to determine what is considered recycled	More research on applicability and acceptability of recycled content as a useful indicator
Business/consumption model	MCI	Methodology that integrates product characteristics and circular strategies available in an easy-to-use format	Encourage use of the indicator among businesses; use for benchmarking; expand the methodology by including trade-offs between circular strategies
	Functional lifetime of a product	Lack of standardisation for determination of functional lifetime; limited direct data availability	Develop ways to derive functional lifetime from indirect data (e.g. duration of product support in market; duration of availability of spare parts)
	Proportion of product-service systems	No clear assessment tools available yet	Assess occurrence of relevant terms in financial or sustainability reporting of companies; add relevant questions to consumer/producer surveys (e.g. Eurobarometer)
Society	Policy framework	There is no consistent assessment of existing policy frameworks in the context of circular economy	Develop a list of criteria/questions for screening European and national policies; analyse and report results allowing countries to benchmark and learn about best practices
Macro-scale product impacts	Macro-scale impact of circular business models	Top-down: input-output modelling is a well-established methodology, but designed for describing a linear economy (research ongoing for application in circular context) Bottom-up: aggregation is feasible, but requires many assumptions and thus is less accurate	Further monitor and invest in research that improves usability of macro-economic tools in the context of circular economy; gather insights from running projects related to assessing macro-scale impacts of circular strategies
	Proportion of key material losses in product cycles	Methodologies are available, but data availability is generally limited, and results often do not communicate product-level information	Build on existing and developing material assessment frameworks (e.g. Raw Materials Scoreboard, material system analysis) to develop integrated product-level analyses
Environmental and economic impacts	Life-cycle impacts	Well-established methodologies exist; research under way for factoring in impacts and benefits of recycled materials	Integrate environmental life-cycle impact assessments with circularity assessments to identify trade-offs between product circularity and environmental performance
	Exergy losses	Methodologies exist, but are not often used because of concept complexity	Further investigate applicability and acceptability of the assessment
	LCC	Lack of standardisation, mainly used for durable goods	Integrate life-cycle costing with product circularity assessments to identify hot-spots and trade-offs

information on the proportion of the life-cycle impact of products that results from transport. Sharing services for goods, such as cars, are often driven by internet platforms keeping track of how intensively goods are used by different persons, giving an idea of how efficiently consumers' needs are fulfilled. The algorithms and technologies for extracting information from these big data sources will further increase, opening up new opportunities to gain information on how materials are managed.

A1.7.2 Cooperation between private, governmental and non-governmental organisations

Data are gathered by a large number of organisations, both private and public. For reasons of efficiency, it may be helpful to join forces to share the costs of gathering and interpreting these data. For instance, public authorities wanting to know more about the recycled content of products, may have common interests with the waste treatment sector looking for new markets for recyclates. They could set up public-private partnerships for organising direct data collection.

A1.7.3 Set up new schemes for providing access to data on a voluntary or mandatory basis

Not all data that are needed for circularity indicators can be derived from existing data sets. In some cases, there will be a need for new data schemes. Public authorities can play a role in setting up new schemes that require certain data to be collected. For instance material passports for buildings can provide information on the recycled content and reusability/recyclability of building materials and building elements used, providing useful information to both the building sector and public authorities seeking information on materials management.

A1.7.4 Technology for data generation and data mining

The potential for more tracking and tracing with a relatively low administrative burden has increased, and will further increase in the coming years, as a result of the development of sensors and data-processing systems. For instance, the development of the so called 'smart city' (the concept of digital technologies being embedded into city infrastructure to improve management of energy, traffic, water, waste and other relevant flows) will open up a range of new opportunities for tracking and tracing flows throughout the city, making it possible to gather real-time data on, for example, waste generation and collection. The algorithms and technologies for extracting information from these big data sources will further increase, opening up new opportunities to gain information on how materials are managed.

A1.7.5 Transparency

Transparency throughout the life-cycle will help in getting access to data that are necessary for feeding circularity indicators. Just as emissions have become a natural thing that companies are required to report on, more data on how materials flow throughout the chain can help in getting, for example, a better view of what is actually recycled and what gets lost.

A1.7.6 Standardisation

There is a need for greater standardisation of data collected in relation to waste. For instance, international standards for determining the recycled content of products would help achieve comparable data.

A1.7.7 Develop insights that enable integration of different assessment methodologies into truly systemic tools

While the monitoring framework presented covers all relevant aspects related to product circularity in a systemic context, assessment tools are most often specifically related to one of the different quadrants (Figures 5.3 and 5.4). The integration of (insights derived from) tools from different quadrants will be the next step towards a fully systemic approach towards product circularity. For example, more insights are needed on how business models contribute to the circular economy: what kind of product-service system or what kind of sharing system actually leads to less material consumption and less material loss? Or, another question relating to the systemic nature: how do businesses respond to or anticipate new legislation or economic instruments? Do policies achieve what they intended? Combinations of assessments from the different quadrants will be required to provide robust answers.

European Environment Agency

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