PolyCE

Post-Consumer High-tech Recycled Polymers for a Circular Economy

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Disclaimer

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Executive Summary

The concept of Circular Economy (hereafter CE) implies fundamental changes and radical innovations in the economy's current value chains. The CE provides the economic system with alternative material flows, ones that are cyclical and maximize resource sufficiency. Moreover, the implementation of CE may create new business opportunities and generate economic gains. According to estimations of the European Commission and the Ellen MacArthur Foundation adoption of CE would deliver an increase in the GDP between 0.8% and 7% by 2030[1].

A symbiosis of sustainability and business is crucial in achieving success and large scale adoption of the CE concept. Moving towards this form of economy requires disruptive change that effects the whole organization, including its stakeholders (e.g. parts manufacturers, suppliers, service providers and customers). The change is disruptive as it requires innovative ways of working and new solutions to current ways of doing business.

This report investigates different types of business models that generate revenues through the adoption of an alternative approach for value creation, delivery and capture. Based on several case studies from the electronics sector, the report provides metrics criteria in order to classify the business models. The final aim is to contrive a matrix facilitating the classification and characterization of business models deemed as circular. The matrix will serve as the fundament to identify the impacts, drivers and limitations of circular business models in the electronics sector which in turn is the main output of Task 1.2.

[1] http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI(2016)573899_EN.pdf

1 Introduction

The digital revolution has a huge impact on nowadays societies on a global level. Electronic products have changed the way we communicate, work, live and interact with each other. Electronics companies are in constant competition to design, manufacture and deliver higher performing products on the market. As innovative as the technology implemented in their products might be, many of the business models behind modern electronic devices such as smartphones, laptops and home appliances have been stuck in old-fashioned linear production models paired with rapid obsolescence. Linear business models mainly revolve around products with a short lifespan built with non-reparable and/or non-recyclable components. Waste Electrical and Electronic Equipment (hereafter WEEE) streams consist of diverse valuable resources where the majority remains under-recovered, incinerated or landfilled.

The concept of Circular Economy (CE) might serve as a springboard for companies to transform the way they create value and pave a path towards production and consumption patterns that procure long-lasting sustainability. Whereas the practical implementation of the CE concept and circular business models (hereafter CBM) remain on a low scale, the theoretical concept is not a new one. The idea to shift from an end-of-life concept towards a more integrative approach with less waste, less toxic chemicals, more renewable energies and improved design strategies procuring higher value creation has been studied by a large scientific community over the past couple of decades. At the foundation of this strategic shift lies the idea that the flow of materials within an economy must no longer be viewed as a one-way road. Rather, materials are considered as reversible flows, circulating back and forth between production and end-of-first-life, following the example of nature where resources are constantly reused and recycled within a system.
Understanding the value of alternative business models is central for their uptake by any industry. In order to change the classical linear production patterns and push the electronics industry to integrate circular strategies, one should showcase that CE can provide an added economic value. To do so, the company’s business model needs to be assessed on aspects of circularity. CBMs provide a framework for a company to redefine how it creates, delivers and captures value. First, CBMs need to be understood in a broader perspective and deduced to the electronics sector.

The main aim of this report is to analyse the concept of a CBM, list and assess different CBM approaches, summarize current CBM examples embedded in the electronics sector and create a matrix of characteristics to develop a classification that can be of further help for identifying impacts, drivers and limitations of establishing CBMs in the future (plastics) sector.

1.1 Aim and scope of the Deliverable

According to the Work Plan, D1.1 depicts the outcomes of T1.1 and serves as input for the upcoming tasks in Work Package (WP) 1 (see Figure 1).
The overall aim of WP1 is to identify, assess and test business models leading towards CE and verify CBM impact along the whole value chain. Based on a literature review, the goal of D1.1 is to characterise various CE business models, while highlighting their capacity to dematerialise resource demanding production and consumption models while keeping products, thus materials, longer in use.
By the end of WP1 opportunities for an industrial symbiosis between the WEEE value chains and other sectors should be found. The overall aim of the PolyCE project is to increase circularity of plastics in the electronics sector. T1.1 is the first step in fulfilling this goal by laying the theoretical foundation on what characterizes a CBM, particularly looking at examples from the electronics sector.
As a first step an overview of the available literature tackling the different types of CBMs will be provided. In a next step, CBMs are characterized including the corresponding Circular Product Design strategies. Together with past and ongoing research projects, this analysis will provide insights in the current state of the art of CBMs in the electronics sector and will lay the foundation for the upcoming project activities.
Chapter 4 supplements the literature findings by investigating examples of CBMs from the electronics sector. Chapter 5 will develop metrics criteria to enable a classification of CBM types which shall serve as an input for the upcoming WP1 tasks.
Different CBM options with a link to electronics will be characterized including key factors and characteristics. The characterization metrics are aimed to be a starting point for T1.2 where impacts, drivers and limitations of CBMs in the electronics sector will be determined and opportunities identified on how to overcome barriers.

This input is a necessary step towards improving the entire value chain of post-consumer plastics. In WP1, CBMs for the electronics industry will be developed, paying a special focus on the integration of post-consumer recycled plastics (PCR) in the company's' portfolio.

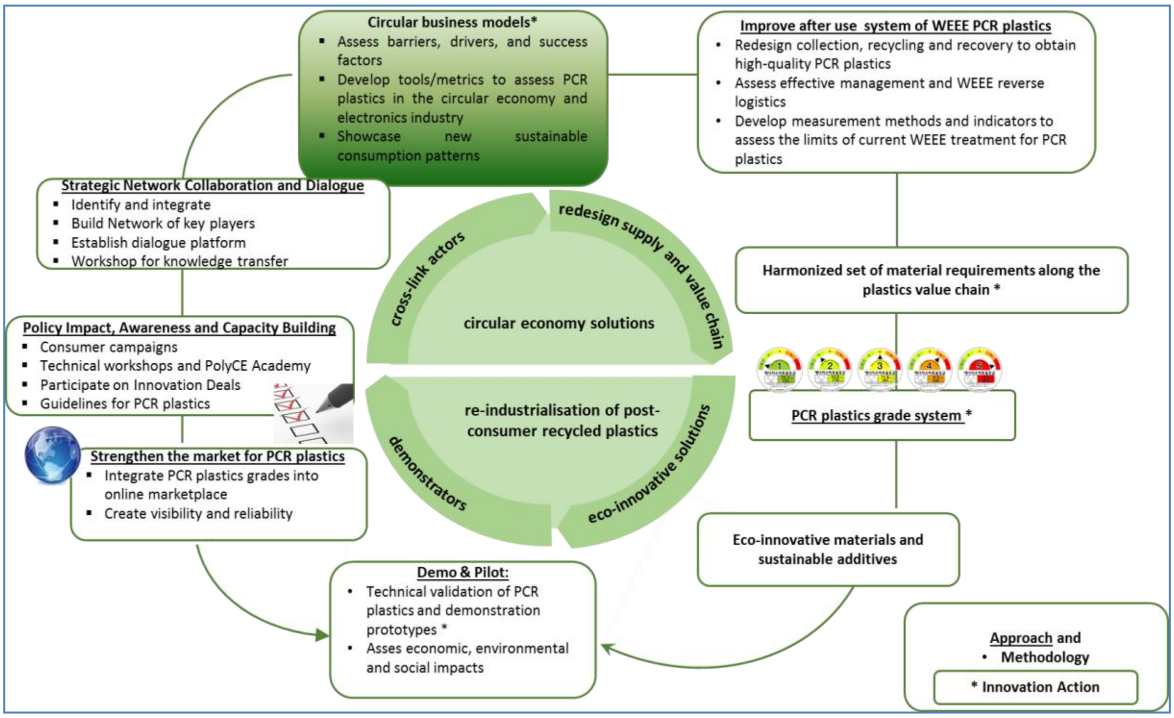

Figure 1: PolyCE Research Aims and Link between the WPs

1.2 Methods

As a first step a literature review was conducted to collect various definitions of the CBM and to gain an overview on the current state of the art. An emphasis was put on available CBM definitions, concepts and design strategies. Table 1 summarizes the type of sources used to collect the information. This review identified key aspects of CBMs, yet remained theoretical in point of view. A number of reports have been found on the topic of how a business can implement measures to become more circular. Since T1.1 has the goal of characterizing different types of CBMs, the first step is to provide the theoretical framework and analyse the different possible forms of CBMs.

Taking into account that the adoption of CE principles in the electronics sector is not widespread, this analysis includes examples from other sectors. Broadening the framework facilitates the identification of more general, but still relevant aspects of CBMs.

Source type	Topic	Source
Past project reports/deliverables	Practical Examples of CBMs from Electronics Sector	REBus project report; ResCoM project report, ZeroWIN project report; Hannemann, Müller, Mischke (2001); ProSUM project report, CloseWEEE project report
Books/scientific articles	Definitions & Concepts of CE and CBM	Korhonen, Ainamo (2003); Osterwalder, Pigneur (2010); B. Mentink (2014); Bakker, Hollander, Hinte, Zljlstra (2014); Lewandowski (2016); Florin, Madden, Sharpe, Benn, Agarwal, Perey, Giurco (2015); Leising (2006); Linder, Williander (2015); Poutiainen (2015); Laubscher, Marinelli (2014); Kashkoush, El Maraghy (2016)
	Design strategies	Lewandowski (2016); Stahel (1994); Bocken, Short, Rana, Evans (2014); Bakker, Hollander, Hinte, Zljlstra (2014); Fitzpatrick, Colin; Hickey, Stewart; Schischke, Karsten; Maher, Paul (2014); Jong, Engelaer, Mendoza (2015)
	Practical Examples of CBMs from Electronics Sector	Bakker, Hollander, Hinte, Zljlstra (2014); Nissen, Schischke, Proske, Ballester, Lang (2017)
Interviews	Definitions & Concepts of CE and CBM	Nissen (2017); Magnin, Hannon (2016)
	Design strategies	Nissen (2017)
	Practical Examples of CBMs from Electronics Sector	Bocken (2017)

Company reports	Definitions & Concepts of CE and CBM	Ellen MacArthur Foundation (2013, 2015)
	Practical Examples of CBMs from Electronics Sector	Hebert (2015)
Student Dissertations	Definitions & Concepts of CE and CBM	Hofmann (2017)
Websites	Definitions & Concepts of CE and CBM	Zero Waste Scotland; Gerholdt (2015)

Table 1: Categorization of literature used

Various authors were screened and key prerequisites for a business model to be defined as circular were identified. The key components of a CBM include the following categories:

- Realisation of resource efficiency
- Realisation of resource circularity
- Collaboration among stakeholders
- Product design aspects

These categories serve as a baseline for the characterization process (see section 5.1). They will be explained in more detail in chapter 2.2.
After identifying the basic principles of CBMs in the broader framework, the literature review was then restricted to examples linking the CBM approach to the electronics sector. This review consisted of deliverables of current and past research projects, websites and examples identified by experts.
In chapter 4, various dematerialisation options applicable to the electronics sector were grouped into CBM types depending on the strategy employed in realizing a circular economy approach. For each of the models portrayed, an example dealing with electronics has been included.
In chapter 5 a characterization matrix was compiled in which the five business model types were matched to the key components of CBMs mentioned above. The matrix can be used to find relationships and differences among complex CBM systems in the electronics sector.

2 Circular Economy and Circular Business Models

2.1 Definitions and literature review

CBMs need to be considered in the wider concept of a CE, a more sustainable approach of producing and consuming goods by which resource depletion, waste generation and environmental pollution is avoided by closing material loops. The report “Jobs for tomorrow: the potential for substituting manpower for energy” (Stahel, Reday-Mulvey 1981) introduced the concept of ‘closed loop economy’ and ‘cradle to cradle’. Various schools of thought have been developed to promote more sustainable business practices, including amongst others the concepts of Industrial Ecology (Frosch, Gallopoulos 1989), Biomimicry (Benyus 2009), Cradle to Cradle (Braungart, McDonough 2009), Thinking in Systems (Meadows 2014) and the Blue Economy (Pauli 2010).
The concept of CE has probably most dominantly been promoted by the Ellen MacArthur Foundation. Since 2010, the foundation intends to foster and accelerate the transition towards CE through education, the development of business strategies and communication through a wide and powerful network of stakeholders (Ellen MacArthur Foundation 2013). At the core of a CE lies the intention to keep all materials at their highest value at all times, thereby preserving natural capital and avoiding diminishing resource stocks.

> *„A circular economy is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times.“ (Ellen MacArthur Foundation).*

Figure 2 illustrates the key message of the CE concept, being that resources are kept in close loops by applying different dematerialisation options, starting with reuse, refurbishment and repair, and as a last stage, recycling. The goal of a CE is to keep the materials within these loops for as long as possible so that the time of final disposal is prolonged (Korhonen, Ainamo 2003).

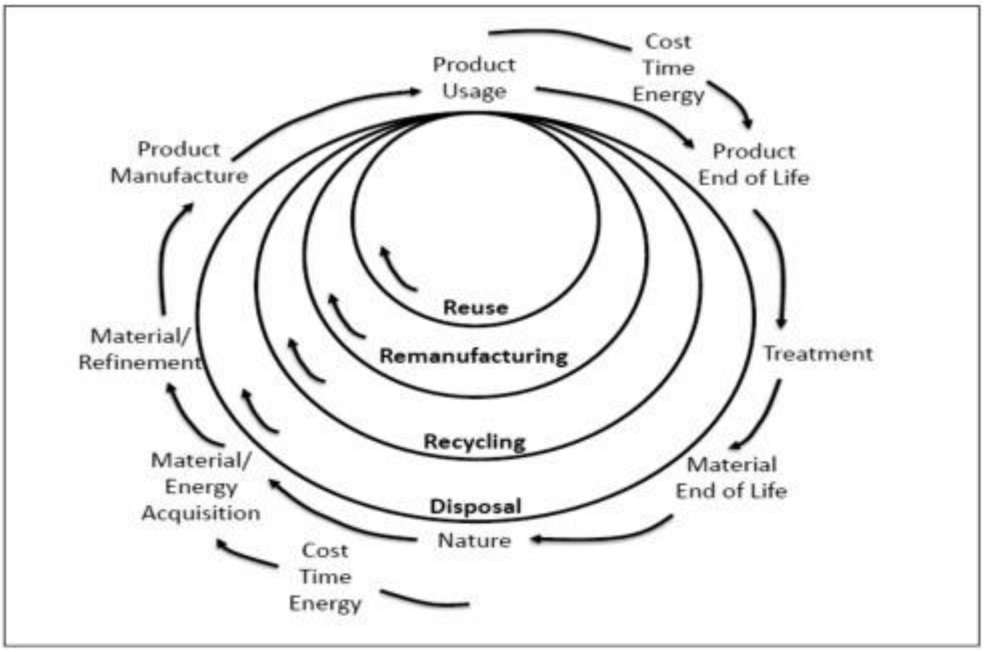

Figure 2: Concept of Circular Economy (Korhonen et.al, 2018)

The concept of dematerialisation complements the CE philosophy paradigm. Dematerialisation is considered a general alternative category of business models, which paves the way away from the resource demanding linear produce-consume-dispose strategy. It includes the inner cycles of Figure 2, but will be extended here towards product service systems. Dematerialisation models might be different in their nature, however, they all have in common that they aim to maintain the inherent value in a product for as long as possible.

Dematerialisation is a key contributor to the CE. It postulates the transition from a product ownership based system to a system where the consumer is more interested in the service that the product provides rather than the direct ownership of the product. According to Stahel (1994), dematerialisation strategies reduce resource inputs (per use-year) in manufacturing and can consist of:

- Extending the service-life of goods through design for long-life use, life-long guarantees, consumer behaviour, repair, refurbishment and remanufacture
- Increasing the intensity of use of goods by offering temporary access to products (e.g. equipment leasing) or selling services rather than products (e.g. copy shop)
- Technological innovations such as LED, microchips, etc.

According to Osterwalder and Pigneur (2010) a „*business model is the rationale of how an organization creates, delivers and captures value*“. Characterising current CBMs thus involves evaluating the choices and strategies adopted by companies to transition to a more circular approach.

Business models are different from business strategies which are plans to create and defend a unique and valuable position in the market. Business models are a set of business choices made to carry out that strategy. Thus, the business strategy dictates which business models may be applicable and the selected business model explains how the strategy shall be executed. Business models are not static but rather dynamic and evolve over time as businesses are under constant pressure to adapt to changing drivers from the business environment (Mentink 2014).

> *"A business model is more generic than a business strategy. Coupling strategy and business model analysis is needed to protect competitive advantage resulting from new business model design*." (David J. Teece 2010)

Therefore the implementation of a CBM may only be possible if the business strategy allows for it or if the company's desire to contribute to a CE is sufficiently strong so as to adapt the business strategy accordingly. Thus the selection of a CBM is a choice to operate within a circular material loop by undertaking various circular strategies. Bakker ~~(~~2014) highlight that the key principle of a CBM is a shift away from linear business models towards a circular economy, where the flow of materials is kept over time. Bakker et al. (2014) highlight the opportunities for businesses to engage in a larger societal change that „*concerns an emphasis shift in the way entrepreneurs and designers develop and exploit goods, thereby reducing materials and energy consumption over time.*"

Mentink (2014) uses a systemic approach of circularity and highlights the importance of the network in which the CBM is embedded. Besides aiming to realize a closed material loop within the business, a CBM should also enable and cooperate with other actors within the system to produce a circular industry. Thus, if a company fabricates products out of recycled materials, but does so in a way that impedes their further recycling, the business thereby has a detrimental effect to the CE as a whole. In fact, the aspect of enabling multiple players to realize a CE together is superior to that of realizing a circular loop within the business itself. The latter, therefor, is not actually a condition for a CBM. To contribute to a CE, businesses must consider closely their product design and the set-up of their supply chain and network of collaborators. (Magnin, Hannon 2016)

In the interview conducted for McKinsey & Company by Josh Rosenfield, senior partner Clarisse Magnin and partner Eric Hannon (2016) state that the traditional linear economy consists of a simple linear value chain – including raw materials extraction, design, production, consumption, and disposal. Even though, over the past couple hundred years, vast efficiency has been squeezed out of the linear supply chain, it still results in an incredible amount of waste. A circular economy aims to resolve a simple fundamental question: How can we capture more of the value that is lost in a traditional linear system? In the circular economy, all actors try to find ways to create loops in that linear supply chain in order to maximally retain value.

The transition to a CE requires new thinking regarding supply chains. A more systems based approach has to be taken, which will require a paradigm shift involving all stakeholders in the value chain (Boons, Lüdeke-Freund 2013; Magnin, Hannon 2016). Supply/ value chains become multi-dimensional with new flows and systems, creating service networks, cycling materials and protecting their value (ready for resale, repair, remanufacturing or recycling). It also implies the re-thinking of reverse supply chains and creating more contacts and opportunities for recovery loops for products and materials. There are very few supply chains that are set up with robust reverse-logistics networks, so one needs to make sure that by whatever circular-economy levers are applied, enough value is generated to overcome the additional challenges and the additional costs associated with implementing those reverse logistics.

Table 2 summarizes the definitions found in the literature, highlighting key aspects of CBMs which will serve as a framework for characterizing CBMs in the electronics sector for this Deliverable.

Source	Definition	Key aspecs			
		RC	RE	PD	C
Lewandowski (2016)	“(…) pursuing and creating the opportunities for a shift from an “end-of-life” concept to Cradle-to-Cradle, from using unrenewable energy towards using renewable, from using toxic chemicals to their elimination, from much waste to eliminating waste through the superior design of materials, products, systems, and also business models.”			✓	✓
Bakker,Hollander, Hinte, Zljlstra (2014)	“The circular approach contrasts with the traditional linear business model of production of take-make-use dispose and an industrial system largely reliant on fossil fuels, because the aim of the business shifts from generating profits from selling artefacts, to generating profits from the flow of materials and products over time”		✓	✓	
Mentink (2014)	“A circular business model is the rationale of how an organization creates, delivers and captures value with and within closed material loops“ Compared to the definition of the BM, the CBM should be regarded as a subcategory of BMs which fit in an economic system of restorative or closed material loops. This entails that a CBM does not need to close material loops by itself (within its internal system boundaries), but can also be part of a system of BMs which together close a material loop in order to be called circular. CBMs keep materials in the economy and also enable other companies to do so.	✓			✓
Florin, Madden, Sharpe, Benn, Agarwal, Perey, Giurco (2015)	„Circular business models are defined as a subset of sustainable business models and a key distinguishing criterion is that they must be oriented towards consumption, or production and consumption, to promote both efficiency and sufficiency.“		✓		
Leising (2006)	„A circular business model describes the way a business creates, delivers and captures value at every chain in the system with and within closed material loops.“	✓	✓		
Linder, Williander (2015)	„We define a circular business model (CBM) as a business model in which the conceptual logic for value creation is based on utilizing economic value retained in products after use in the production of new offerings.“	✓	✓		

Poutiainen (2015)	„A circular business model describes the rationale of how an organization creates and delivers value to customers and captures value for itself while it simultaneously designs out waste, relies on renewable energy, thinks in systems, and embraces diversity to build organizational resilience.“		✓	✓	✓
(Florian Hofmann 2017)	„A circular business model (CBM) describes the underlying rationale with which a company achieves value production, transmission and recognition while simultaneously minimizing ecological and social costs in order to achieve the goals of strong sustainability. It is essential for a CBM to be embedded in a network of collaborators in order to fully realize closed material, component and product loops."(translated from German)				✓
Zero Waste Scotland	"Circular economy business models keep products and materials in use, by design, for as long as possible to get the maximum value from them."	✓	✓		
Gerholdt (2015)	"…circular economy, a model that focuses on careful management of material flows through product design, reverse logistics, business model innovation and cross-sector collaboration"	✓		✓	✓
Osterwalder, Pigneur (2010)	"A business model describes the rationale of how an organization creates, delivers, and captures value." Circular business models are special in the sense that they look for value creation in places usually of little interest to companies that operate in the traditional linear production paradigm.		✓		

Table 2: Definitions and Key Aspects of Circular Business Models

RC	Resource circularity
RE	Resource efficiency/ Value exploitation
PD	Product Design aspects
C	Collaboration among stakeholders

Table 3: Legend of key aspects

2.2 Characterization framework

The following section provides descriptions of certain criteria which will be used to analyse the CBM types discussed in this report.

2.2.1 Resource efficiency

One of the key criteria when assessing CBMs is the form of resource consumption / how resources are being consumed. In order to meet the demands of a CE materials have to be used more efficiently than in traditional linear business models. Much of the information found in the literature on CBM emphasises that maximum value must be generated. Here, the question of how resource value is captured and how resource consumption is reduced by engaging in a dematerialization model is at core. Improved resource efficiency may be achieved by heightening the utilization per product or by restoring new value to a product after one use phase. In this aspect CBMs contrast strongly with traditional linear consumption models where products are disposed of after one use cycle..

2.2.2 Resource circularity

At the core of any CBM lies a strategy envisaging to keep products as well as their respective components and materials in a closed loop for as long as possible. and measures are undertaken to safeguard the high value of materials, either through maintenance, repair or exchange of broken parts
It could imply the following:

- providing an infrastructure for post-use collection to enable repair/ refurbishment and/or harvest of valuable parts for reuse, and/or
- contributing to a closed material recycling system.

2.2.3 Collaboration of stakeholders

Another key aspect of CBMs is the extent to which companies engage within a network of actors. A company’s CBM does not need to be circular in itself, but can also be part of a larger network that collectively closes resource loops or enables other actors to become circular as well. Electronic devices contain various valuable materials mainly sourced outside of Europe. Through collaboration, the actors along the value chain can establish resource resilience and minimise the supply risk - within and outside of the organisation. The CBMs will be characterised based on how the collaboration between parts and product manufacturers, service providers and consumers is performed.

2.2.4 Product Design

Product design plays a crucial role. The way an electronic product is designed, including the choice of materials, fasteners and connectors, replaceability of components and availability of spare parts influences the capacity to sustain longer use. It also has significant impact on the possibility of disassembly, i.e. the degree to which materials can be isolated at EOL. Facilitated disassembly is relevant in order to efficiently recycle and back-loop materials into the economic system. The integration of CE product design as a part of the business model of the company helps minimise the risk of product obsolescence.

2.3 Circular Design Strategies

Stahel (1994), Bocken et al. (2014) and Lewandowski (2016) have determined two design strategies to change linear resource consumption: Design to slow down resource loops and design to close resource loops.

2.3.1 Design to slow down resource loops

According to Bocken et al. (2014) slowing down the resource loops seeks to avoid the vast resource consumption associated with new virgin-material production as well as to avoid the waste generation. The reuse of products leads to an extension of their use phase. The feasibility of reuse can be increased by designing long-life products and by introducing service loops. The latter includes repair, reconditioning, technical upgrading, or a combination of these. These design practices lead to a deceleration of the flow of materials from production to recycling (Stahel 1994).

Design for Durability, Design for Maintenance and Repair, Design for Upgradeability and Adaptability as well as Design for Standardization and Compatibility are several strategies that allow **slowing down** resource loops.

Design for Durability is a strategy in which products are specifically designed to have a **longer lifespan** (above the average durability compared to products from the same product group). This design strategy produces a high-quality product, which is robust against failure. A repair service provided by the manufacturing company might also be part of the business strategy. In theory this is a very simple design concept, however, the practical measures to be undertaken to produce a long life product are complex and require detailed technical knowledge as well as intensive testing procedures.

Design for Maintenance and Repair is a strategy in which products are specifically designed to enable **lifespan extension.** This design strategy focuses on keeping the product out of EOL as long as possible by avoiding failure. Measures include preventative measures (maintenance) or restorative measures (repair). Bakker et al. (2014) argue that, in principle, every product is repairable. However, since repair is labour intensive, thus expensive, it is not commonly performed. "**Ease of Maintenance and Repair**" is a further aspect of the Design for Maintenance and Repair. Not only should repair be made possible, but also economically feasible. Jong et al. (2015) identified the essential elements of Design for Maintenance and Repair, including easy access, the handling and interchangeability of parts, a simple fault diagnostic, technical safety of repair, quick access to diagnostic and lubrication points, reduction in a number of electronical connections and simplicity in final adjustment.

Life extension can be achieved through product upgrade. **Design for Upgradability and Adaptability** is an important aspect for the environmental performance of a product. Besides easy maintenance and repair, designing a product that allows upgrades and updates over a longer period of time enables the users to prolong the use life when newer software or hardware versions appear. For instance, a smartphone can be upgraded through a software update or by a new part, which is compatible with the previous component. An example for Design for Upgradability and Adaptability is Fairphone 2. Instead of introducing a new smartphone generation to the market, Fairphone introduced a new higher performing camera module, which can replace the older one, thus upgrading the smartphone.

The last design strategy relevant for a more circular approach is **Design for Standardization and Compatibility.** Nowadays most products are made of multiple parts and components and they are surrounded by additional or similar products in the market. In order to extend the life of a product it is important that the interfaces are compatible with each other so that broken components from one product can be exchanged with repaired components from another product without hindering the whole functionality.

2.3.2 Design to close resource loops

The key idea behind the concept of closed resource loop is the continuous flow of resources in the technological cycle, avoiding the generation of any “waste” resources. After use materials are recycled into secondary raw materials, where the material properties are comparable to those of virgin materials (Bocken et al. 2014).
Material quality needs to be maintained to enable closed resource loops. This can be achieved by performing an upcycling process to maintain the quality and enable the recyclates to go as a reverse flow to a product similar to the original one. There is a clear difference to downcycling which delays end of life (hereafter EOL) taking into account properties degradation. By allowing material and component isolation, **Design for Dis- and Re-assembly** is an important prerequisite for high-quality recycling and upcycling of the materials.

3 Pilot Projects on Circularity in Electronics

The following section will summarize past and ongoing research projects that target CE specifically in relation to the electronics sector, as this is the key approach for the PolyCE project. During the literature research many projects could be identified that suggest a shift away from linear production-consumption-disposal patterns towards CE. Guidance on how to develop a business towards a CBM could also be found, however only a few tackled electronic products or businesses related to the electronics sector.

3.1 Rebus

The REBus project reduced resource consumption by demonstrating the commercial case for business model change, through a series of real world pilot projects. Samsung developed a national product “upgrade” leasing offer to UK customers, to improve recovery of its own products and better meet market needs for new technology. This lead was followed by competitors, such as Apple.
Argos, a UK digital retailer, launched a UK-wide gadget trade-in offer to help customers get value for their used smartphones and tablets. Argos approach aimed at facilitating collection and subsequent recycling. It offers in-store facilities, and take-back on white goods and packaging for home delivery. However, the company has also been looking for opportunities to develop efficient business models to engage into greater circular economy thinking. In 2015, Argos launched its Gadget Trade-in service online and across nearly 800 UK stores. The scheme initially includes mobile phones and tablets, but could be extended to include cameras and laptops in the future. The incentivized return model enables customers to trade in their old mobile phone or tablet in exchange for an Argos gift card, which can be spent on anything in store.
The new service includes a range of business, environmental and customer benefits, such as:

- Old electronics will have data securely erased, the product refurbished and re-sold;
- Adding value to the current Argos business model;
- Demonstrating an innovative approach to business;
- Responding to customer demand for sustainable solutions for unwanted gadgets; and
- Scalability, commercial potential and credibility, which all add critical value to the Argos brand.

The Rebus project is of interest for the PolyCE project as it involved adapting the role of the retailer as well as the second user of the refurbished products. The project triggered the rethinking of a supply chain and a great integration of stakeholders by changing the perception of customers for end of life products to valuable products even when the products were no longer wanted by the first user. Furthermore, the change towards CBM did not involve the re-design of products and neither the involvement of integration of manufacturers, but was initiated by a retailer organisation engaged into closed economy thinking. (REBus 2017)

3.2 ZeroWIN

The EU funded research project is based on the concept of industrial symbiosis by developing a structured and innovative production model for resource use, optimization and waste prevention amongst various sectors, including the electronics sector. For the electronics sector a major focus was put on the so-called D4R (Design for Recycling, Repair, Refurbishment and Reuse) of high-tech products and a life cycle assessment was conducted to demonstrate the environmental benefits achievable through adoption of D4R. (ZeroWIN 2014)

Within the ZeroWIN project, a laptop was developed that integrates the D4R concept. It showed that D4R leads to considerable reduction in greenhouse gas emissions compared to the environmental performance of a standard laptop (see section 3.5.). Adopting a design strategy allowing broken parts of a laptop to be replaced ensures an 87% reuse or recycling potential as well as a 65% reduction of fresh water consumption. (ZeroWIN 2010) The technical specifications adopted in the laptop prototype will be elaborated more closely in chapter 3.5.
Key guiding principles from the ZeroWin project, which are interesting for the PolyCE project goals, is the notion that reused and recycled materials are seen as closed-loop resources avoiding disposal. Furthermore, resource efficiency can be maximized by ensuring the highest and best use of materials. Some of the key principles in the ZeroWin project aim at preventing pollution and reducing waste, the use of non-toxic chemicals and selling products or services that are not wasteful or harmful to the environment.

3.3 CloseWEEE

The CloseWEEE project, funded by the Horizon 2020 program of the European Union, aims to close the loops and provide circular economy solutions for valuable materials from waste of electric and electronic equipment (WEEE). The project's scope is on materials, which are under-recovered or where effective sorting and recycling technologies have not been developed. The project focus is placed on secondary raw materials and aims at improving the separation and recovery of the following target materials:

- PC/ABS and ABS plastics used as standard casing material in modern consumer electronics
- Antimony trioxide (Sb2O3), which is used as flame retardant synergist in plastics containing brominated flame retardants.
- Critical materials present in Li-ion-batteries, containing significant amounts of Lithium and Copper, but also of Cobalt and graphite.

To provide circular economy solutions, CloseWEEE sets the following objectives:

- Develop and implement robust and cost efficient recovery technologies
- Give recycled materials a new life in added-value applications
- Provide efficient tools for the localization and separation of hazardous and valuable materials.

Within the project different sorting and recovery technologies have been developed and tested to produce high-quality post-consumer recycled PC-ABS and ABS plastics. CloseWEEE develops and tests sorting and recycling technologies to obtain high-quality ABS and PC-ABS from WEEE, previously under-recovered materials. The technologies include advanced sensor-based sorting of the legally restricted Bromine-rich from Bromine-free plastics and further separation into pure polymer fractions. The aspiration is to produce high-quality compound containing at least 30% recycled content and apply it in new electronic applications similar to the original one. In addition to closing the loop for some high-grade plastics from WEEE, the project addressed the recovery of

Antimony from the Bromine-rich plastics fraction using the solvent-based recovery process CreaSolv® and recovery of Cobalt, Copper, Lithium and Graphite out of End-of-life Li-Ion batteries. (CloseWEEE 2017)
Disassembling of electronic devices is facilitated through the development of an online Recycler Information Center by iFixit in cooperation with the D.R.Z – Dismantling and Recycling-Centre and Fraunhofer IZM. Sound disassembly guides were provided to assist workers on the disassembly line to dismantle electronic devices rapidly and effectively.

3.4 ProSUM

ProSUM, Latin for 'I am useful', created an Information Network that allowed partners to provide and use data by the creation of an inventory of waste streams with a high potential to serve as a source of critical raw materials (CRMs). The two-year research project was funded by the Horizon 2020 research and innovation programme. ProSUM developed the First Urban Mine Knowledge Data Platform, a centralized database with data and information on market flows, stocks and treatment of waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELVs), batteries and mining wastes (Chancerel et al. 2017).
The ProSUM Urban Mine Knowledge Data Platform provides the foundation for improving the EU position on future raw material supply. ProSUM provides data aiming at improving the management of WEEE and enhancing the resource efficiency of collection, treatment and recycling.
The project addresses circularity at its last stage, once electronic products end up in EOL by calculating how many precious materials could in theory be recovered if the urban mine would be available. One result was that the calculated primary Cobalt consumption could in theory be covered by the Cobalt inherent in the EU battery stock if the urban mine would be made available immediately (Chancerel et al. 2017).
Data was carefully screened and discussed with experts to see where better data was required. This led to the identification of the need for additional standards and datasets and harmonised methodologies for characterising the CRM content of these waste streams (ProSUM Deliverable 3.6). The desire to contribute to a circular economy in Europe and counteract an uncertain supply of raw materials triggered the ProSUM project. Urban Mining allows the recovery of raw materials from spent products such as waste flows which is increasing each year.

3.5 The Iameco laptop

The Iameco laptop was developed as part of the above mentioned Project "ZeroWin". The prototype laptop was developed to overcome the limited ability that small and medium sized enterprises (SMEs) have within the electronics sector to influence material consideration of electronic assemblies necessary in their products. Since design and materials used in the components are dictated by global suppliers, SMEs are most often not able to produce individual parts. This is also partly due to the limited production and financial capabilities of most SMEs.

Fitzpatrick et al. (2014) see the biggest opportunity in contributing to circular design strategy in prolonging the use phase of an electronic product. Design features linked to achieving this goal are for instance alternative casing, choosing durable components, using single screw types for easy disassembly and easy access to crucial components such as processor of memory.

Figure 3: The iameco Laptop

Another important decision when it comes to adopting circular design strategy is the question of EOL routes. Offering a service where products are easily returned minimalizes the unfavourable route of informal e-waste management. Coupled with a refurbishment strategy this ensures a prolongation of resource loops. (ibid)

The design for lifecycle strategies identified before have been adopted in the Iameco laptop, a prototype to demonstrate circular design. The design strategy not only integrates the Ease of Disassembly strategy, but also mindful material selection using hardwood instead of plastics for the casing. Another important design feature is the application of standardized types of screws for ease of accessibility of individual components. Key parts of the laptop such as display and motherboard are easily repairable. [1]

3.6 Gold recycling from WEEE

The 2001 EU-funded research project "Environmentally friendly gold recycling in the electronics industry" [translated from original German title] conducted by Hannemann et al. (2001) aimed to develop environmentally friendly recovery methods of isolated gold factions from waste electronics products, which are applicable and commercially feasible for small and medium-size businesses. An urgent need for research on new recovery methods was recognized in light of lacking precision and environmental/ human toxicity precautions in conventional gold recovery methods.

Additionally, opportunities for industrial symbiosis, e.g. the secondary use of chemical baths, were investigated.

The research project resulted in the identification of two feasible chemical recovery methods involving different combinations of selected oxidants and complexing agents. The optimal operating conditions were described and the technical as well as practical, financial, and environmental advantages of each method elaborated upon. Both methods produce far lower human health and environmental hazards in comparison to the conventional method, which employs toxic cyanide. The developed methods can not only be used for gold recovery but also for structuring gold layers and cleaning gold-contaminated equipment.

[1] Fitzpatrick C, Hickey S, Schischke K, Maher P, Sustainable Life Cycle Engineering of an Integrated Desktop PC; A SME Perspective, Journal of Cleaner Production (2014),

The limitations faced with the implementation of these more sustainable gold recovery methods include mostly financial as well as technical restraints. Whereas the chemical recovery process is most effective when particle size is small, the operational costs, however, increase with diminishing particle size. Further limitations of the developed methods include long process durations and the fact that the processes are not controllable to the extent that full gold recovery may be guaranteed. The developed methods are not economically viable for the processing of materials where the gold component is not accessible without pre-treatment and where the gold coating exceeds a thickness of 3 µm.

The key drivers for this project ranged from legislative to financial, technical and environmental aspects. The particular interest in the recovery of precious metals and, more specifically, of gold, grew due to the high market value of the material(s) and the favourable properties of gold for the demands of electronic technology.

4 Circular Business Models within the Electronics Sector

The next section will introduce five different types of dematerialization models that have been categorized to cover alternative business model types. Each model will be characterized based on the key characteristics identified in Section 2.2. In the upcoming tasks of WP1 this knowledge will be used to identify drivers, barriers and limitations of CBMs in the electronics sector. Each CBM type is followed by an example relevant for the electronics sector.

4.1 The Long Life Model

The Long Life Model describes the production and sales of high-quality long-lasting products, which retain extensive value after use by the consumer so that reuse or refurbishment is likely. (Bakker et al. 2014) Strictly speaking, it is not a CBM as such, since resource loops are not necessarily integrated in the Long Life Model. However, it does address the important aspect mentioned by (Korhonen, Ainamo 2003) that materials in a CE should be kept at the highest possible value for as long as possible. The high value of the product results both from the sophistication of the implemented technology, as well as from the positive marketing image (Bakker et al. 2014).

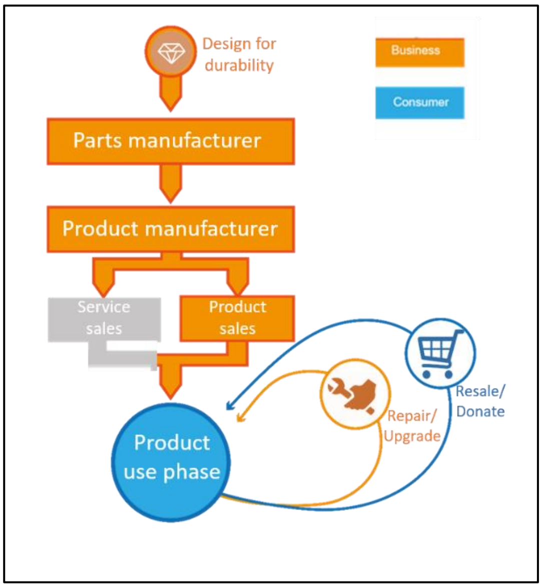

Figure 4: The Long Life Model (modified from Ellen MacArthur)

In these long life business models the primary revenue stream consists of the customers' initial purchase of the product, through which they retain full ownership (blue). Additionally, repair services or other post-purchase services are usually offered to keep the high quality product in good condition (orange). After the first use phase, the product will most likely be used in a second life either through re-sale or donation due to its high value and good brand reputation. By engaging in a Long Life Model, the designers make use of the raw materials in a way that procures the maintenance or functionality for as long as possible. The formation of waste streams is extended into the future, thus the goal of a CE to expand the product value chain and life cycle while retaining the highest possible value is met (Korhonen, Ainamo 2003). The resource efficiency is realized through the longevity of the product and resource circularity may be enhanced by maintenance services and/or the likelihood of reuse of the good. (Bakker et al. 2014) The customer motivation lies in the guarantee of high quality as well as the brand appeal. Examples include high-quality cars or washing machines.

4.1.1 Case Study: Miele

The Miele "WKG 120 WS" (from here on called Miele WKG) released in 2014 is a much appraised high quality laundry machine. At a purchase price of about € 1200, it ranks amongst top-end machines though still being considerably cheaper than the most costly machines on the market, which amount up to € 3000. (ResCoM 2016) The cheapest machines available in the consumer market on the other hand cost less than a third of the price of the Miele WKG. The high initial investment, however, is justified by the extensive functional value of the machine. The main benefits include long use life (2 years warranty, optional 10 year warranty with service certificate), high energy efficiency (A+++) and innovative detergent dosage technology (TwinDos and CapDosing) (Miele 2017). In addition to the initial payment for the machine itself, Miele continues to receive revenue flow throughout the consumer's use phase of the Miele WKG, seeing as the dosage systems TwinDos and CapDosing require brand-specific cartridges. Furthermore, Miele offers vast service such as machine care and maintenance, private consulting, as well as extension of warranty (Bakker et al. 2014).

4.2 The Modularity Model

The Modularity Model describes the production and sales of products which are designed to enable exchangeability of the components of a device and high-level material separation without destruction (Laubscher, Marinelli 2014). Modular devices are defined as containing modules which are structurally independent elements or sub-assemblies with clearly defined interfaces (Kashkoush, El Maraghy 2016).

In the Modularity Model, the potential for a longer product lifetime is increased by encouraged repair via replacement of faulty components. While the consumer initially purchases the complete device, the acquisition of spare parts may follow throughout the use phase (see Figure 5) adding further revenue streams to the retailer. The product is designed and produced by the business, while the customer is enabled to exchange or certain modules by himself (blue). In some instances, the exchange of components may not only serve to regain functionality, but also to upgrade or adapt the device's functions according to the personal needs of the consumer. One premise is that components are standardized so that exchanging individual modules becomes a viable option. The longevity of the device resulting from the possibility, practicality and economic feasibility of repair/ exchange as well as the possibility of customization and upgradeability are attractive aspects for the consumer. However, besides the positive environmental effect of saving resources by not needing to replace the entire product, easy replacement of certain components might also lead to a rebound effect, in a way that consumers upgrade their device more frequently than if a device does not offer such a feature. Examples of the modularity model include modular smartphones and other modular devices.

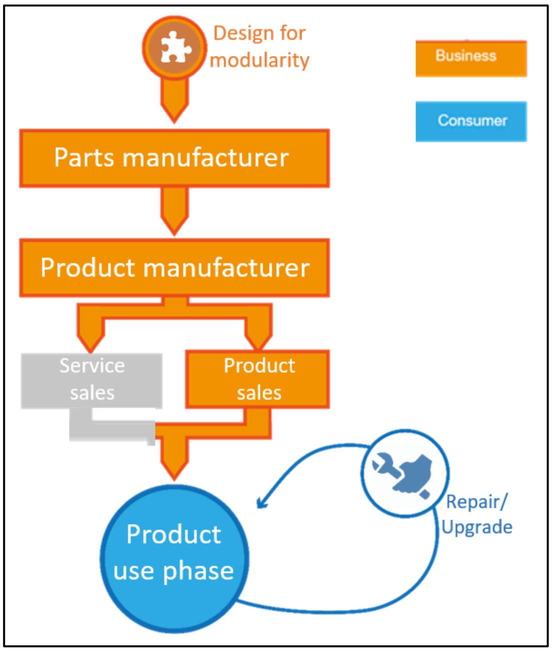

Figure 5: The Modularity Model (modified from Ellen Mac Arthur)

4.2.1 Case Study: Fairphone 2

The Fairphone 2 is a first of its kind: a smartphone designed for maximal exchangeability of its components. Contrary to the Fairphone 1 which merely offered easy removal of the battery and a mono-material back cover, the Fairphone 2 realizes far more extensive modularity, enabling the exchangeability of several key components when repair is needed or higher performing components are desired. The modules of the Fairphone 2 are the display, the battery, the protective back cover, the core module with the processor and memory, a rear camera module, the loudspeakers module with microphone and USB port, and a receiver module with headset connector, noise-cancelling microphone and front-facing camera. (Nissen et al. 2017) All of these modules can comfortably be purchased separately on Fairphone's online platform. All in all, Fairphone aims to make Do-it-yourself or third party repairs much easier (Hebert 2015). This high repair potential results in the extension of the product lifetime. A use phase scenario calculated by Nissen et al. (2017) suggested a lifetime extension from 3 to 5 years.

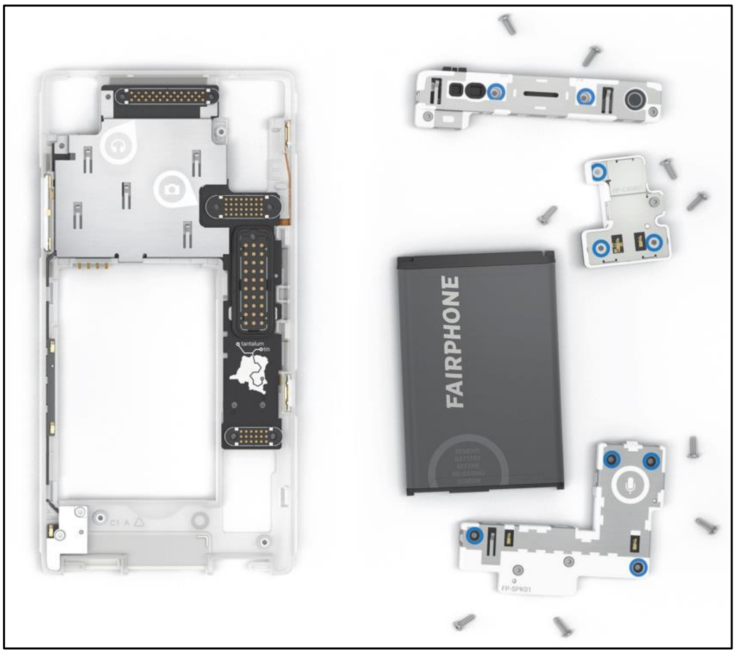

Figure 6: Modules of the Fairphone 2 (IZM)

4.3 The Re-value Model

The Re-Value Model describes businesses which extend the lifespan of products or materials by giving them new value either as the same or an alternative product after the first use phase. This can be done via redistribution, refurbishment or recycling. (Laubscher, Marinelli 2014) This business model represents a more circular approach, seeing as further value exploitation occurs than in the place of disposal (see Figure 7).

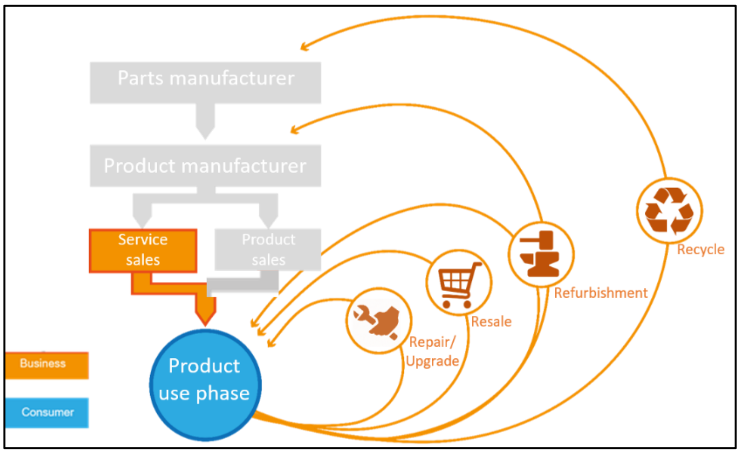

Figure 7: The Re-Value Model (modified from Ellen Mac Arthur)

The revenue streams for the business may originate from the purchase of secondary products or from solicited fees for a repair service (Bakker et al. 2014). A remarkable consequence of the implementation of such business models is the encouragement of the transmission of information, for example relating to the implemented technology of a device or the chemical properties of materials. In order to increase the percentage of recoverable parts, compatibility of parts and standardization are key product design aspects.

A higher ratio of product reuse could save more resources (materials, energy, labour, etc.) and can reduce the environmental impact of electronics per usage cycle.

One obstacle in establishing a re-value CBM approach revolves around insufficient collection infrastructure of “waste” products/materials and low customer acceptance of second hand goods or insufficient knowledge thereof. Examples include second hand shops, re-pair services, sales of refurbished electronics devices or plastics recycling companies.

4.3.1 Case study: Loewe

Loewe Technology GmbH is a German producer of communication technology who remains one of the few manufacturers still producing in Europe. Loewe develops and manufactures high quality home entertainment. The company has engaged in sustainable production approaches to transition into a more circular production model for many years. This includes building long lasting devices, modular technology for ease of repair, high quality materials, regular software updates as well as devices with low energy consumption. [1]

Loewe took part in the ResCoM Project as a case study to transition even further into closed loop product systems. The television market is characterized on the one hand by a fast innovation pace where new TV devices are designed and produced every few months and a long use phase with an average 8-12 years before the products reach eventually EOL. Remanufacturing of old TVs is therefore unlikely, so LOEWE looked for a different pathway for closing material loops.

Current remanufacturing activities are being outsourced to retailers collecting failed devices and replace malfunctioning components with new ones. (ResCoM 2014) Nevertheless, keeping a high stock of spare parts for a long period of time is financially costly for any company. One improvement option identified throughout the ResCoM project was to integrate condition monitoring system into future devices to collect information on e.g. use patterns and failure mechanisms. The data collected is used for better spare parts planning and control over maintenance and repair. Making product failure information available together with integration of a reverse logistics system may be used to design closed-loop product systems and products integrating the spirit of CE. (ResCoM 2014)

[1] http://www.rescoms.eu/case-studies/loewe

4.4 The Access Model

The Access Model describes businesses which, instead of selling a product, offer a rental or leasing service for the temporary use of a product. Contrary to traditional business models, the ownership of the products remains in the company's hands (see Figure 8) as customers return the product at the end of the allotted time slot, i.e. after completion of use. (Laubscher, Marinelli 2014) It is thus also often referred to pay-per-use business model. Access business models contribute to the maximization of utilization per product. In decoupling product possession towards product access, a transition to a "sharing economy" is induced. The products and the therein implied materials are used more efficiently and in a circular fashion, going through multiple reuse loops. Figure 8 demonstrates that the company offering the products are in control of the maintenance since products are returned after each rental or incentives for maintaining a good product condition is included in the business model concept.

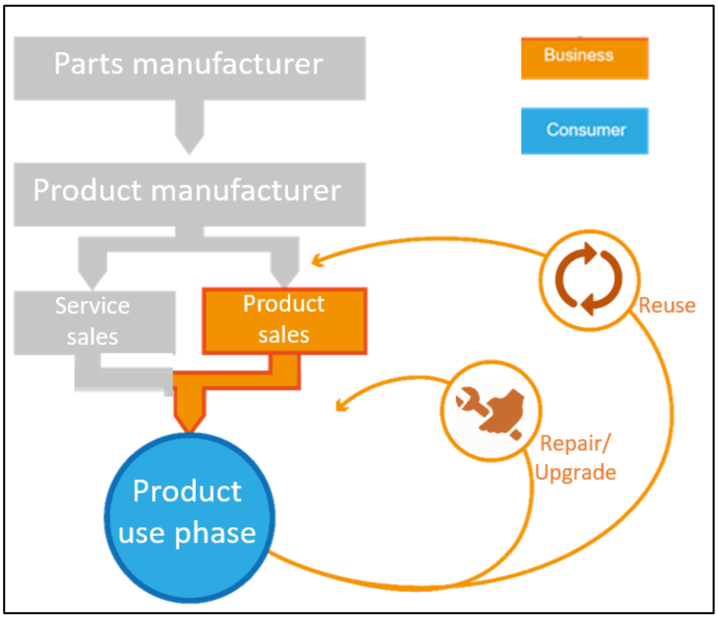

Figure 8: The Access Model (modified from Ellen Mac Arthur)

The business model is attractive for customers due to the flexibility of renting/leasing a device as a short-term solution as well as the economic feasibility of obtaining temporary access to a product otherwise too costly to purchase. However, the customer acceptance may be limited due to remaining attachment to the conventional concept of possession, lack of trust in the product quality or the workings of the leasing system, fear of impracticality or uncertain access, as well as merely the lack of knowledge of the existence of such offers. Examples include car sharing or equipment rental services

4.4.1 Case Study: Hom.ee

Hom.ee started in the Netherlands as a pay per wash business model with the ambition to test whether or not a pay per use business model is generally beneficial from an environmental point of view. Instead of designing and manufacturing an entirely new product, Hom.ee purchased commercial washing machines and then programmed and connected them via the internet to meet the needs of the newly implemented CBM strategy. The client does not purchase the device, but the washing machine is delivered home and the client but pays a fee per wash.

The aim of Hom.ee was to realize circularity also via repair and maintenance and to provide a positive example of the access business concept as well as to stimulate sustainable consumption. (Bocken 2017)

An important difference to other business models lies in the relationship between the product / service provider and the consumer, as in this case the provider is in contact with the consumer throughout the entire use phase of the product. With regard to more sustainable consumption patterns, it could be observed that consumers were far more cautious about the number of wash cycles and about the water temperature as a machine wash at higher temperature was more costly. This example indicates that a CBM which engages into a closer relationship with its customers can stimulate sustainable consumption through e.g. differentiated pricing. Product providers have the possibility to engage into educational campaigns to promote more sustainable consumption.

In the case of Hom.ee, informal newsletters were distributed including social comparisons on other clients' washing behaviour to influence sustainable consumption, an option that a traditional seller-buyer relationship does not have. Besides being responsible for repairing a broken device, Hom.ee also ensures the good condition of the washing machines by, for instance, granting occasional free hot washing cycles to procure good hygiene of the washing machine. The concept of pay per wash turned out to be very successful and hom.ee is now exploring the German as well as the Swedish consumer market.

4.5 The Service Model

The Service Model describes businesses which provide a service rather than sell a product (see Figure 9). The "purchased good" is the procurement of the desired performance (Bakker et al. 2014). In contrast to the Access Model, value is more closely related to the performance, rather than granting value to the material attribute of a product itself. (Stahel 1994) Consumers may be attracted to such an offer as it enables them to delegate a task to a professional.

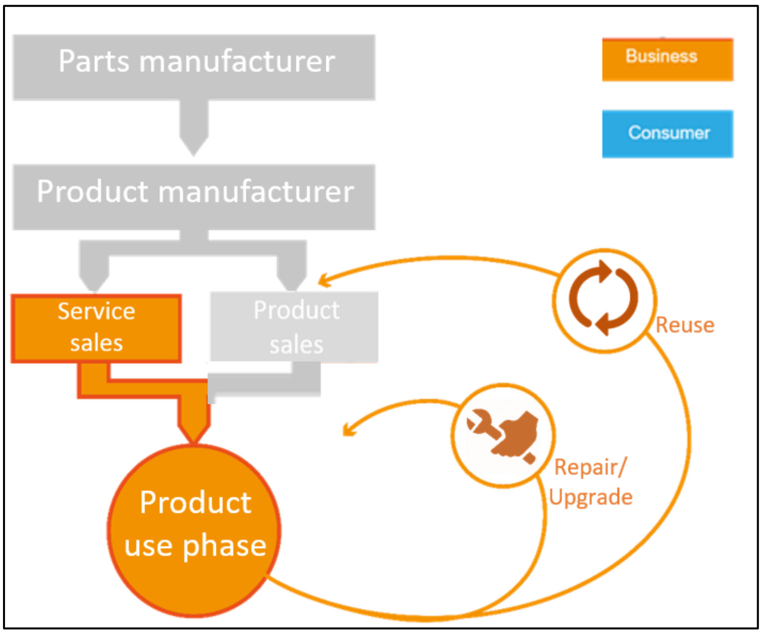

Figure 9: The Service Model (modified from Ellen Mac Arthur)

It focuses on the benefits of utilization which are obtained from products, without necessarily granting the product itself a high value. The product as service model relies on people wanting the service provided rather than longing to the product that carries out the service – for example paying for internet rather than buying routers. The customer has no contact to the actual devices and materials being employed to execute the task remain in the ownership of the business (Bakker et al. 2014). Service providers are contracted to provide reliable service and are therefore responsible for technical failures where repair/update or exchange of parts is granted to ensure a satisfied customer.

From a circular economy perspective, a product as service model has various advantages: easy access for repair and refurbishment- and the required skills needed, ownership of product ensures material and EOL product flows, and the ability to upgrade and repair of technical devices ensures efficiency. Furthermore, providers of a service business model have an interest to invest in long-lasting product systems in order to reduce internal costs. The model thereby results in material efficiency and circularity, as resource loops are slowed down. Examples include laundry services, internet providers or installation services

4.5.1 Case study: Philips Pay per Lux

Phillips Lighting, in exploring various options for making their products more circular, developed the "Pay per Lux" model – a product service model or "light as a service" as Phillips calls it. The Pay per Lux service can double the lifetime of the lighting system. As the manufacturer and owner of the installed systems, Phillips can implement smart services, which allows the company to optimize its products and put services in the right place. The benefit for the customer is that they are not required to pay for the lighting system, dispose of it or worry about maintaining the system. Phillips will provide this service, according to the agreement discussed with the client.

The concept of "Pay per Lux" is gaining some momentum. The first example was in the Netherlands, a collaboration between Phillips and Rau Architects (Ellen MacArthur Foundation 2017).

Philips and the National Union of Students (NUS) in the UK collaborated in 2013 to develop a tailored "Pay per Lux" scheme for their headquarters in London, where the NUS is renting the lighting fixtures from Phillips and plays a flat rate for light service which provides the stability of a predictable, fixed price over fifteen years. Should they exceed the expected energy usage, Phillips is required to give resulting money back. (Philips 2015)

In 2015 Phillips have partnered with a team of architects where they are jointly responsible for delivery of a lightning service to the Schiphol Airport in the Netherlands. The smart lighting systems used were collaboratively designed by Phillips and architect Kossmann and resulted in an energy efficient smart lighting system. (LUX Review 2017)

5 CBM Evaluation and next steps

In order characterize the different types of CBMs within the electronics sector, theoretical implications on CBMs need to be matched with currently available examples so that different dematerialization options can be assed consistently. The key characteristics of a CBM identified in Chapter 2.1 and 2.2 will be used as a framework to look at the business model types. Developing metrics criteria enables a classification of CBMs to better understand the drivers and limitations for businesses later on during the project.

5.1 CBM Characterization

The selected CBM types in this deliverable all have in common that traditional linear production and consumption patterns are interrupted to make room for a new philosophy towards a more circular economy business model. Looking at the matrix (Table 4), the selected dematerialization models have different approaches on how resource efficiency is ensured, how value is created, how material loops are encouraged, who the stakeholders are and how product design strategies differ.

In case of the **Long Life model**, many of the traditional consumption patterns can be found. Ownership is acquired by the customer, and when the device is broken it is disposed of. Resources are saved not by necessarily bringing them back in form of internal loops, but consumption of resource is reduced because products keep their high value for a long period of time. Producing high-quality products through **design for Durability** requires technical know-how, years of customer experience and extensive testing procedures. The strategy **Design for Durability** may result in higher production costs, however by establishing a high value brand, the company is investing in stable business relations that may prosper long into the future. In the **Long Life model**, companies provide special services to their customers, including repair, maintenance, and installation of the product and customer support throughout the entire use phase. Therefore, the company and consumers remain in close contact. Even though Miele products are more expensive than products alike by other brands, customers are attracted because of the quality and the provided customer support.

The **modularity model** transforms linear consumption patterns through a more circular design strategy. Here, keeping the electronic device at its highest value is ensured by prolonging the product lifecycle through upgrading, repair and restoring functionality (Nissen et al., 2017). For a smartphone, this option tackles and important environmental problem where products are quickly replaced due to technology advancements.

This problem is evident for the wider electronics sector, which is a fast changing but resource intensive domain. For most electronics, particularly mobile IT devices, the environmental impacts are embedded mainly in the production phase. Thus, the goal of a CBM should be to prolong the use phase in order to balance out the environmental footprint embedded in the manufacturing of electronics (Nissen 2017).

By integrating modularity as a strategy the use lifetime of products can be extended. Thereby since components can be exchanged without replacing other (major) parts, resource are handled more efficiently

Whether spare parts or modules are returned through a reverse logistic system and refurbished again depends on the business, however incentives can be provided easily by granting deposits, for instance. The compatibility and thus exchange of parts is in our example reduced to replacement of parts produced by and destined for Fairphone only. In an ideal world, modular design together with compatibility amongst the components in similar products of different brands helps to sustain products much longer in use. However, in reality this option is still limited due to the absence design for standardization.

In a **Re-value Model**, companies are contributing to a CE by adding new value to products/materials that would otherwise be disposed. This can be done in a variety of ways, which all have in common that the ratio of product reuse is increasing. Thus, circular material flows are encouraged by treating discarded products or product parts as valuable input into a new value chain. The time of disposal is prolonged and material value is preserved. For consumers, this has several benefits mostly economically, since repair is often cheaper than buying a new product. A second-hand product is mostly cheaper than buying a new one as well. The example of Loewe Televisions however also demonstrated how important the knowledge transfer is in order to build up a re-value business model. The business, which aims to give new value to an already existing product, e.g. through repair, must possess vast knowledge of the design and technology of various products from the respective brands.
If components are standardized or compatible with each other, repair and refurbishment will be more likely. Product design also plays a crucial part, for example Design for Dis- and Re-assembly where upcycling requires the disassembly of certain parts of the product without complete destruction.
The **Access Model** tackles a situation in which very expensive and resource intense products have extremely low use phase. Many of the electronics products are used far below capacity. The products value can be retained by decoupling the service that the product provides from product ownership. Section 4.1.1 gave an example how renting instead of buying large home appliances leads to more efficient consumption patterns, but has a higher utilisation per product. The Access Model also entails advantages for reparability since products are well maintained by experts and customers can be educated towards a more sustainable consumption pattern. Furthermore, an important part of the CBM is the direct relationship with the customers, which are able to provide feedback on failure mechanisms and improvement options.
The relationship between provider and consumer of a product throughout its use phase is a key difference between the Access Model and the other three models discussed here. The provider has the possibility to influence the product material flows and safeguard a certain quality standard by issuing maintenance service when required.

The **Service Model** decouples any activity or product from the consumer. In this business model the consumer pays for the service and has no ownership over the product. The service is provided by the company’s employees, thus the consumer has no contact to the product. Repair, maintenance and refurbishment remain a company’s obligation. This model grants the company with the control over all material flows as well as with strategic planning on how the service can be provided most efficiently and effectively. This may lead indirectly to product design change towards more durable and robust design or modular design. Providing only the service may help the company to innovate its service system to be more efficient, thus achieve energy and resource savings.

The “Pay per Lux” example demonstrated that Philips could double the lifetime of the light system by optimizing their service regularly and integrating the most efficient technologies. Customer relationship is an important asset, since feedback can help the company to optimise their service system.

Table 4: Characterisation Matrix

Characteristics/ Key aspects	*Long Life Model*	*Modularity Model*	*Re-Value Model*	*Access Model*	*Service Model*
Ownership of product	**Customer**	**Customer**	**Customer**	**Company**	**Company**
Revenue streams (for company)	**Sales of initial product, Post-purchase services**	**Sales of initial product, Sales of spare parts**	**Sales of repaired/ refurbished products /recycled materials, Repair services**	**Access fee**	**Service fee**
Realization of resource efficiency/ Value exploitation	**Reduction in resource consumption through longevity of product**	**Reduction in resource consumption through lifetime extension**	**Addition of new value to products/materials after first life**	**High utilization per product, pay-per-use has effect on customer's use habit**	**Maximal value exploitation of resources due to professional planning**
Realization of resource circularity/ Material loop	**Encouragement of second-hand market and repair/ service market**	**Encouragement of reuse by facilitating repair/ upgrade**	**Encouragement of reuse by enabling second life**	**Prolongation of EOL through regular maintenance**	**Prolongation of EOL through regular maintenance**
Collaboration amongst stakeholders	**High quality demand throughout supply chain**	**Guarantee of compatibility between components**	**Knowledge transfer on technology, use patterns, failure mechanisms**	**Return of product post-consumption, Company-customer relationship**	**Recollection of product/ materials; direct feedback from customers**
Product Design	**Design for durability and reliability**	**Modular design/ ease of upgradability Design for easy exchange, upgrade and repair**	**Design for easy upgrade and repair**	**Design for durability and reliability, repair at high service level**	**Design for durability and reliability, repair at high service level.**
Customer motivation	**Emotional attachment to brand value /Customer loyalty, Possible revenues from post-use sales**	**Adaptability and upgradeability of individual needs, Environ-mental awareness**	**Environ-mental awareness, Economic feasibility of upgraded/ repaired products**	**Flexible short-term solution, Economic feasibility, Convenience of product return**	**Delegation of task to professional**

5.2 Shortlists of applicable dematerialization options

The analysis of different CBMs allows highlighting a shortlist of the applicable options for successful CBM in the EEE sector. It is one of the aims of the upcoming Task 1.2, Task 1.5 and T1.6 to explore and fill in the gaps.

	T1.1& T.1.2	T1.2	T1.2	T1.5 &T1.6
	EEE products most suitable	**Benefits of the adoption of the CBM**	**Risks of implementation of the CBM**	**Main changes in the EOL management**
Long life Model	Mature product; medium-high price; Frequent use	Increased brand value; long term customer relationship		
Modularity Model	Medium-high price; Quickly-outdated devices (IT)	Knowledge transfer on failure mechanisms from customers		
Re-Value	Mature products, medium-high price,	Revenue streams from outsourced products; technical knowhow		
Access Model	High-priced products	Control over material flows; opportunity to influence consumer behaviour		
Service Model	Devices needed for daily life	Control over material flows; control over device condition		

Table 5: Shortlist of dematerialization options

5.3 Discussion

The electronics sector is growing on a fast pace and acts as an urban mine of a huge amount of valuable resources, mostly under-recovered. It is essential that electronics companies engage in business models, which are sustainable and strive to close the material cycles. There are different options to transform the business as usual, nevertheless all CBMs have a common aim - to create and deliver value for the company and society in the most sustainable way.

CBMs require changes on multiple levels. It leads to transformation of product or service design, of marketing approaches towards customers and new relationship with them, different production processes and different revenue models, investments, which will return in the longer run. Different approaches away from linear production and consumption models have been evaluated in this report. Strategic decisions to transform into a CBMs can occur at different steps of the value chain. For the Long Life Model and the Modularity Model, circular design strategies are integrated at the very beginning before the manufacturing phase while the Re-value Model is increasing the reuse of materials inherent in products that have endured a first use phase. The Access and Service Model both challenge traditional manufacturer/customer relationships, moving closer to a sharing economy and increasing the utilization of resources.

Establishing a CBM does not mean for a company having to transform the entire value chain, nor does it mean that circular decisions have to include all segments of the production line. The example of the iameco laptop has shown that even for smaller companies there are options to implement circular economy ideas, such as establishing a trade in/buy back service, offering repair upgrade and maintenance. Circular Economy should be seen as a value-creation driver and not only as an image builder. It core principles imply finding creative solutions through collaboration, partnering and leveraging the ecosystem to build up a resilient network of material flows.

5.4 Next Steps

The shortlist of options will be subject to detailed investigation and exploration to identify and complete the gaps. A questionnaire will be circulated to external stakeholders to determine their perceptions and attitudes to CBM, together with side effects and risks. Questionnaires will be followed by detailed interviews to determine steps and interventions necessary to move towards a circular economy in the EEE sector.

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ANNEX I: CBM EXAMPLES FROM THE EEE SECTOR

		Ownership of product	Revenue streams from customer						Realization of Resource Efficiency		
			Sales of primary product	Re-sales of products	Sales of exchangeables	Access fee	Service fee	Sales of post-purchase service	Engineered longevity of product	Extension of lifetime of product	Heightened use-per-product
Miele	(laundry machines)	Customer	x		x			x	x		
Puzzle Phone	(modular phone)	Customer	x		x					x	
Canon	(printers + cartridges)	Customer	x		x					x	
Red	(modular camera)	Customer	x		x					x	
Aiaiai	(modular headphones)	Customer	x		x					x	
Fairphone	(modular phone)	Customer	x		x			x		x	
Loewe	(repair service)	Customer	x		x			x		x	
Ifixit	(sales of repair equip.)	Customer	x		X			x		x	
bb-net/ tecXL	(sales of refurbished EEE)	Customer		x						x	
reBuy	(sales of used EEE)	Customer		x						x	x
LKR Recyclate	(sales of recycled plastics)	Customer		x						x	
eBay	(sales of used EEE)	Customer		x						x	x
asgoodasnew	(sales of refurbished EEE)	Customer		x						x	x
Hom.ee	(laundromat)	Company				x				x	x
Leihbar	(leasing equipment)	Company				x				x	x
Hilti	(leasing construction equip.)	Company				x				x	x
Bundles	(leasing washing machines)	Company				x				x	x
car2go	(car sharing)	Company				x					x
DriveNow	(car sharing)	Company				x					x
cambio	(car sharing)	Company				x					x
Phillips Lighting	(sales of lighting services)	Company					x			x	x

		Realization of Ressoure Circularity				Cooperation amongst stakeholders			Product Design Strategy		
		Realization of Ressoure Circularity	Reuse	Refurbishment	Recycling	Transmission of knowledge	Feedback from Consumers	Return of product post-use	Design for Durability	Design for Standardization and Compatibility	Upgradability and Adaptibility
Miele	(laundry machines)	x	x						x		
Puzzle Phone	(modular phone)	x		n.a.	n.a.					x	x
Canon	(printers + cartridges)	x		n.a.	x			(x)		x	x
Red	(modular camera)	x		n.a.	n.a.					x	x
Aiaiai	(modular headphones)	x		n.a.	n.a.					x	x
Fairphone	(modular phone)	x		n.a.	n.a.		x	(x)		x	x
Loewe	(repair service)	x		x		x	(x)			x	x
Ifixit	(sales of repair equip.)	x		x		x					
bb-net/ tecXL	(sales of refurbished EEE)	x	x	x		x					
reBuy	(sales of used EEE)	x	x								
LKR Recyclate	(sales of recycled plastics)	x	x		x				x		
eBay	(sales of used EEE)	x	x								
asgoodasnew	(sales of refurbished EEE)	x	x	x					x		
Hom.ee	(laundromat)	x	x	n.a.	n.a.	x	x		x		
Leihbar	(leasing equipment)	x	x	n.a.	n.a.		x	x	x		
Hilti	(leasing construction equip.)	x	x	n.a.	n.a.		x	x	x		
Bundles	(leasing washing machines)	x	x	n.a.	n.a.		x	x	x		
car2go	(car sharing)	x	x	n.a.	n.a.		x	x	x		
DriveNow	(car sharing)	x	x	n.a.	n.a.		x	x	x		
cambio	(car sharing)	x	x	n.a.	n.a.		x	x	x		
Phillips Lighting	(sales of lighting services)	x	x		n.a.		x		x		x

		Customer Motivation						Best-fit circular business model Type
		Upgradability	Delegation of task to professional	Economic feasibility	Brand appeal	Environmental awareness	Flexible short-term solution	
Miele	(laundry machines)				x	x		**Long Life**
Puzzle Phone	(modular phone)	x		(x)		x		**Modularity**
Canon	(printers + cartridges)	x		x		x		**Modularity**
Red	(modular camera)	x		x		x		**Modularity**
Aiaiai	(modular headphones)	x		x		x		**Modularity**
Fairphone	(modular phone)	x		(x)		x		**Modularity**
Loewe	(repair service)		x	(x)		x		**Re-Value**
Ifixit	(sales of repair equip.)			x		x		**Re-Value**
bb-net/ tecXL	(sales of refurbished EEE)			x		x		**Re-Value**
reBuy	(sales of used EEE)			x	x	x		**Re-Value**
LKR Recyclate	(sales of recycled plastics)			x		x		**Re-Value**
eBay	(sales of used EEE)			x		x		**Re-Value**
asgoodasnew	(sales of refurbished EEE)		x	x	x	x		**Re-Value**
Hom.ee	(laundromat)			x	x		x	**Access**
Leihbar	(leasing equipment)			x	x	x	x	**Access**
Hilti	(leasing construction equip.)			x	x		x	**Access**
Bundles	(leasing washing machines)			x	x		x	**Access**
car2go	(car sharing)			x	x	x	x	**Access**
DriveNow	(car sharing)			x	x	x	x	**Access**
cambio	(car sharing)			x	x	x	x	**Access**
Phillips Lighting	(sales of lighting services)	x	x	x				**Service**

Puzzle Phone	(modular phone)	http://www.puzzlephone.com/
Canon	(printers + cartridges)	https://www.canon.de/recycling/ https://www.canon-europe.com/press-centre/press-releases/2016/01/canon-wins-the-circulars-award/?_ga=2.188041966.794313833.1504515783-277687222.1504515783 https://www.canon.de/about_us/press_centre/press_releases/corporate_news/green_apple_awards_2015.aspx
Red	(modular camera)	http://www.red.com/
Aiaiai	(modular headphones)	https://aiaiai.dk/headphones/tma-2/about
Fairphone	(modular phone)	https://www.fairphone.com/de/
Loewe	(repair service)	https://www.loewe.tv/de
Ifixit	(sales of repair equip.)	iFixit Myself: User-Generated Content Strategy in "The Free Repair Guide for Everything", 2016. IEEE TRANSACTIONS ON PROFESSIONAL COMMUNICATION, VOL. 59, NO. 1 https://de.ifixit.com/ https://www.ellenmacarthurfoundation.org/ce100/directory/ifixit
bb-net/ tecXL	(sales of refurbished EEE)	https://www.bb-net.de/
reBuy	(sales of used EEE)	https://www.recyclate.de/de
LKR Recyclate	(sales of recycled plastics)	https://asgoodasnew.com
eBay	(sales of used EEE)	https://www.rebuy.de
asgoodasnew	(sales of refurbished EEE)	https://www.ebay.de/
Hom.ee	(laundromat)	https://hom.ee/ Nancy Bocken (2017): Plate Live: Design for longevity - business as unusual? Plate Conference
Leihbar	(leasing equipment)	https://leihbar.net/ https://www.greenality.de/blog/leihbar-org-der-trend-weg-vom-kaufen/
Hilti	(leasing construction equip.)	https://www.hilti.de/content/hilti/E3/DE/de/services/tool-services/elektrowerkzeuge-flottenmanagement.html
Bundles	(leasing washing machines)	https://www.bundles.nl
car2go	(car sharing)	https://www.car2go.com
DriveNow	(car sharing)	https://www.drive-now.com
cambio	(car sharing)	https://www.cambio-carsharing.de/
Phillips Lighting	(sales of lighting services)	Circular Economy Snapshop: Philips Light as a Service, National Zero Wase Council 2015; https://www.ellenmacarthurfoundation.org/case-studies/selling-light-as-a-service; Geschäftsmodelle zur Förderung einer Kreislaufwirtschaft Grundlagenbericht und Workshopergebnisse, Schweizerische Stiftung für Nachhaltige Entwicklung 2016