An investigation into the enabling, and inhibiting, factors for effectively applying circular economy business models in the Electrical and Electronic Equipment (EEE) sector.

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Abstract

EEE is intrinsically linked to global economic development and prosperity. As a result, global demand for EEE products is increasing annually, which will require access to greater quantities of valuable resources, including plastics, scarce and/or precious metals, and critical raw materials.

The aim of this research was to investigate how production and consumption of EEE can be developed in a more sustainable way through the adoption of circular economy business models (CEBM). The theory currently lacks empirical data on adoption of CEBMs by the EEE value chain, a shortcoming this thesis addresses. The question is asked how adoption of CEBMs offers the opportunity to manage valuable plastics more effectively by slowing, closing, narrowing, and regenerating the flow of materials. The significance of this study is that it informs theoretical understanding of CEBMs by focusing on their current application within the EEE value chain, which increases understanding of how CEBMs work in practice.

Through the case study research undertaken, the findings show that collaboration across the value chain is an essential part of ensuring the success of CEBM adoption as it enables efficient material flows. The research shows that the EEE sector is already aware that CEBMs are an effective mechanism to deliver resource efficiency and carbon reduction and are looking at the best ways to implement them within their business strategies. The pace of transition to CEBMs will be determined by both the legislative framework and effective design of CEBMs so they are desirable to the customer, and economically and practically viable to the organisations delivering them.

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List of Acronyms

ABS	Acrylonitrile butadiene styrene
BFR	Brominated flame retardants
C2C -	Cradle to Cradle
CE -	Circular Economy
CEAP	Circular Economy Action Plan
CEN	Comité Européen de Normalisation
CPA	Circular Plastics Alliance
EC	European Commission
ECHA	European Chemicals Agency
EEE	Electric and electronic equipment
EFSA	European Food Safety Authority
EN	European Norm
EPR	Extended producer responsibility
EPS	Expanded Polystyrene
EU	European Union
GEC	Green Electronics Council
HDPE	High-density polyethylene
HIPS	High Impact Polystyrene
ICT	Information and communications technology
IT	Information Technology
LDA	Large Domestic Appliances
LDPE	Low-density polyethylene
Mt	Metric tonnes
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturer
PA	Polyamide
PBB	Polybrominated Biphenyls
PBDE	Polybrominated Diphenyl Ethers
PBT	Polybutylene terephthalate
PC	Polycarbonate
PC/ABS	Polycarbonate/Acrylonitrile butadiene styrene

PCB Printed circuit board

PCB Polychlorinated biphenyl

PCR Post-Consumer Recycled

PIC Prior Informed Consent

PIR Post-industrial recycled

PMMA Poly(methyl methacrylate)

PO Polyolefin

PolyCE Post-Consumer High-Tech Recycled Polymers For a Circular Economy

POM Polyoxymethylene

POP Persistent organic pollutants

PP Polypropylene

PPO Poly(p-phenylene oxide)

PS Polystyrene

PSS - Product Service System

PTFE Polytetrafluoroethylene

PU Polyurethane

PUR Polyurethane

PVC Polyvinyl chloride

PVDC Polyvinylidenchlorid

rABS recycled ABS

R&D - Research and Development

REACH Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals

rHIPS recycled HIPS

RoHS Restriction of hazardous substances

SAN Styrene-acrylonitrile resin

SEBS Styrol-Ethylen-Butylen-Styrol

SIN Sibstitute it now

SPI Sustainable Policy Initiative

UN United Nations

UNEP United Nations Environmental Programme

WEEE Waste electrical and electronic equipment

Chapter 1 Introduction

1.1 Background to research

Economic development and population growth have seen the global demand for materials grow from 27 billion tonnes in 1970 to 89 billion tonnes in 2017 and is forecast to roughly double by 2060 to 167 billion tonnes (OECD, 2019). Material extraction processing of the materials and consequently waste generation to satisfy this demand places pressure on the resource base and has environmental consequences such as greenhouse gas emissions, air pollution and toxic effects on ecosystems (OECD, 2019; OECD, 2016).

The rise in Electrical and Electronic Equipment (EEE) products has contributed to this growth. EEE has become an essential feature of modern daily life, facilitating communications e.g., through mobile phones and improving living and work conditions e.g., through use of IT equipment (Balde *et al.*, 2017; Forti *et al.*, 2020; Guzzo *et al.*, 2021). EEE is intrinsically linked to global economic development and prosperity. The central role in society of these EEE products, has led to global demand for these products increasing annually by 2.5 million metric tonnes per annum (Forti *et al.*, 2020). The EEE manufacturing sector covers a wide variety of products and devices including large and small household appliances, medical devices, lighting equipment, information, and communication technology (ICT) and electrical tools.

Increasing EEE production requires accessing greater quantities of resources including specialised plastics such as ABS and PC, valuable metals such as gold, platinum and copper, and critical raw materials for example indium in LCDs, neodymium in mobile phones, europium in low energy light bulbs and cobalt in rechargeable battery electrodes. Supplies of these raw materials are limited which leads to scarcity of these materials, which is economically and environmentally unsustainable for future growth (Kumar *et al.*, 2017;

Guzzo *et al.*,2021; Hanouz *et al.*, 2014). Scarcity of resources increases the cost and competition for raw materials, therefore for future sustainable economic competitiveness and resilience, the need for resource efficiency and security will be critical (Preston, 2012). Changing technology innovations to improve efficiency of EEE products, means that EEE products such as smart phones and computer equipment are constantly being updated. These products are therefore being used for relatively short periods of time, shorter than their designed lifetime, exacerbating the situation and piling further stress on resources (Meloni *et al.*, 2018; Prakash *et al.*, 2015)

The current global prevailing production and consumption patterns for EEE products is linear, which means they are based on a take, make and dispose model, resulting in a large loss of resources (McDonough and Braungart, 2010; Meloni *et al.*, 2018; Preston, 2012). As a result of the increasing production of EEE products, Waste Electrical Electronic Equipment waste (WEEE) often referred to internationally as e-waste, is one of the fastest growing waste streams in the world in terms of volume; in 2019 53.6 million metric tonnes were generated (Kumar *et al.*, 2017; Forti *et al.*, 2020). The consequence of the increasing growth in e-waste is its increasing impact on the environment; documented global recovery rates of e-waste are only 17.4% (Forti *et al.*, 2020). For comparison the EU recovery rates of WEEE in 2020 were 45.9% (Eurostat, 2022).

Global policy and legislation have aligned with adopting a more circular approach to resources in recent years and have implemented policy measures to drive this transition. Circular economy approaches aim to decouple material consumption from economic growth, reducing pressure on natural resources through increasing resource efficiency and reducing waste production (Ellen MacArthur Foundation, 2012; Schulte, 2013; Preston, 2012).

China, India, Japan, South America, the US and Europe all have policies relating to circular economy (WBCSD, 2019; McDowall *et al.*, 2017; Winans *et al.*, 2017; Ghisellini *et al.*, 2016; Bleischwitz *et al.*, 2022). Often the initial policies are related to closing resources loops, by promoting the use of secondary materials through materials recapture (Ghisellini *et al.*, 2016). For countries experiencing rapid industrialisation and urbanisation such as India and China, the initial focus has been on reducing the environmental pollution associated with industries by recycling and reuse (McDowall *et al.*, 2017; Bleischwitz *et al.*, 2022; Debnath *et al.*, 2016). In Europe the initial Circular Economy Action Plan (European Commission 2015) addressed waste management principles however the second Circular Economy Action Plan goes further than this by looking at developing designing for durability, repairability, upgradability and recyclability via the Ecodesign Directive (2009/125/EC). Article 4 of the WEEE Directive (2012/19/EU, 2012). encourages the “cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials. This directive made it mandatory for producers to take care of their End of Life (EOL) products which has galvanised business interest in Reverse Logistics (RL) and Closed-Loop Supply Chain (CLSC) (Govindan *et al.*, 2015).

1.2 Research Problem and Aim.

Circular Economy Business Models (CEBM) developed as part of an organisations business strategy can provide a solution to reducing resource use. There is therefore a need to understand what CEBMs are currently adopted by organisations and what stops them being adopted. The overall aim of this study was to identify and evaluate what are the most influential value chain opportunities and challenges that will enable companies in the EEE sector to develop business strategies which adopt CEBMs. This research identifies some of the gaps in the value chain to determine what it is that is inhibiting the adoption of CEBM.

1.3 Research Questions and Objectives

RQ 1 How are Circular Economy practices and CEBMS being adopted currently within EEE value chain organisations operating within the EU?

RQ 2 Where are the potential opportunities to apply new CEBMS in order to retain value of products and materials within the EEE value chain in the EU?

RQ 3 How do external and internal factors pose challenges and barriers to adoption of CEBMS by the EEE sector in the EU?

RQ 4 How do external and internal factors present opportunities that could be provided by adoption of CEBMs by the EEE sector in the EU?

To achieve the research aims the following objectives of this research were:

1. **Critically evaluate and identify key CEBMs being adopted by the EEE sector operating within the EU.** This enables an understanding of different types of products' existing value. Opportunities for intervention within the supply chain to apply Circular Economy business models to retain value and materials, will be identified.
2. **Critically evaluate the opportunities to apply different CEBMs within the value chain from representative electrical/electronic product groups and their constituent main plastic components**. Different CEBMs will suit different types of products depending on their functionality and the context that they are used in. Evaluating the appropriate CEBMs for different types EEE products or parts within the context of their use will identify the enabling conditions needed.
3. **Analyse the challenges, risks and barriers to adopting Circular Economy business models (CEBM) in the EEE sector operating in the EU.** This enables an evaluation of where decision control and an identification of where the influence to make changes within both EEE manufacturers and WEEE organisations, and the sector lies. Once the challenges, risks and barriers are understood, potential solutions to address these could be devised.
4. **Determine the economic, environmental, and social opportunities to use CEBMs as when developing and implementing business strategies within the EEE sector operating within the EU.** Evaluating the opportunities presented by implementing circular economy business models at various points in the supply chain, will identify

how CEBMS could potentially increase the value proposition of products, components and plastic materials and/or reduce environmental impact.

1.4 Research Process

The research adopted a case study approach, which is an intensive study of a specific unit, in this case the unit is the EEE sector in the EU. A case study approach was adopted as it allowed for research under real world conditions, within the context of the EEE supply chain, answering the how and why (Yin, R. K., 2014). The study was explorative in nature with the purpose of identifying the enablers and inhibitors to organisations adopting CEBMs as part of their business strategy. The case study data was obtained from the EEE sector through qualitative data from interviews, surveys and observations from site visits. This data was then analysed to look for emerging themes which were summarised, categorised, and structured in order to facilitate understanding of the EEE value chain. The focus of this research is to understand how resource loops in the EEE sector can be slowed, narrowed, closed and ultimately regenerate resources (Bocken, *et al*., 2021; Bocken, *et al*, 2016; Geissdoerfer *et al.*, 2017; Konietzko *et al.*, 2020). The research identifies the opportunities arising to increase the value proposition across the supply chain for stakeholders, investigating how collaboration with different actors in the supply chain to serve one another can attain value (Chandler and Lusch, 2015). Thus, by organisations within the EEE value chain, working with their supply chains in a different manner or by offering consumers alternative methods of accessing products, the value of products, components and plastic materials can be maintained or increased rather than reduced.

The research establishes a baseline of current reprocessing practice, as cost-effective, better-quality collection and treatment systems will improve the potential for keeping material flows circular either by the producers themselves or by third parties.

European standards, legislation, and infrastructure were reviewed to analyse and evaluate how these influences can act both positively and negatively in facilitating and driving the take up of different CEBM. A clearer picture of how and where CEBMs can be implemented emerged by identifying the enabling conditions needed. By identifying the current economic value for products, plastic or components; opportunities that the application of circular economy business models plays in increasing this value, were evaluated.

This PhD research ran alongside and contributed to the H2020 project Post-Consumer High-tech Recycled Polymers for a Circular Economy (PolyCE). PolyCE was a large-scale demonstration project, to show how a circular economy approach could be applied to the complex, high-tech plastics from the electronics sector; from the sourcing of post-consumer plastics to recycling processes, reprocessing of recycled tech-plastics and reuse in redesigned products of the electronics sector. The researcher had access through the consortium partners, to the full EEE/WEEE plastics value chain, including material and additives experts, plastics compounders, manufacturing SMEs and large electronics industry, WEEE collection and compliance schemes, the largest closed-loop plastics recycler in Europe, a global testing and certification organisation and experts in plastics market uptake.

Pilot studies from PolyCE and other CEBM case studies from the wider EU EEE sector, were critically evaluated to assess the potential for adoption of different types of CEBM in a wider context. The research identifies where CEBMs have been partially adopted within the EEE and WEEE sector operating in the EU. This included evaluating current practice in reverse logistics, where the Original Equipment Manufacturer (OEM) retains ownership and identifying where parts harvesting, and reuse/refurbishment occur at present. The research examined how the origins of the supply chain will influence enabling the CEBMs being adopted, for example the role of infrastructure and legislation in effecting the economic and practical viability of certain CEBMs. The literature review added to this by identifying how the country of original manufacture will impact on the supply chain and how this could influence the models being adopted.

1.5 Thesis Structure

Following this introduction chapter, the literature is on CEBMs was reviewed. The literature review was split into three different chapters; the first chapter to understand the emergence of the circular economy as a concept, the second chapter to determine the current status of the EEE sector in the EU, and the third chapter investigates the development of different types of CEBMS as a mechanism for delivery of CE within the EEE sector, further details of each of these chapters are described below.

In Chapter 2 the literature is reviewed to examine how the emergence of the circular economy has developed and evaluates how circular economy can be used to drive sustainable growth. The literature is analysed to show how the development of external influences, including finance, policy and legislation has driven the emergence of the circular economy in the EEE sector.

Chapter 3 explores the literature examining circular economy application in the EEE manufacturing process, and the impact of WEEE legislation as a driver for circular economy in Europe. An overview of the literature examining the use and recovery of different plastics within the EU EEE manufacturing sector is conducted, from a product perspective.

Chapter 4 explores the development of business model innovation as a business strategy and how CEBMs can be used as a mechanism for implementing circular economy. The different types of CEBM are investigated alongside the context in which each type can be effectively implemented.

Chapter 5 describes the methodological approach and methods. An overview of the philosophical approach taken is given along with the reasoning behind the approach to theory and knowledge. It then presents the research strategy in the form of a case study approach and the data gathering methods (semi- structured interviews and surveys) along with how they were interpreted to identify emerging themes.

In Chapter 6 the findings from the surveys and interviews are detailed. Themes and sub themes are identified from the analysis of the data.

Chapter 7 evaluates via PESTEL, Porters 5 Forces and strategic choice analysis, how the themes from Chapter 6, combined with the findings from the literature in chapters 2-4 demonstrate that the use of CEBMs can be developed to create an effective business strategy for the EEE manufacturing sector.

Chapter 8 summarises the conclusions from the research. Research limitations are identified and recommendations for opportunities for further research are discussed.

Chapter 2 Circular Economy Concept

2.1 Introduction

The concept of sustainability gained traction in the 20th Century as world leaders at the first Earth Summit in Stockholm in 1972, recognised that action was needed to prevent irreversible damage to the environment and led to the formation of the United Nations Environment Programme (United Nations 1972). The Brundtland report in 1987 laid the foundations for sustainable development goals and defined sustainability as:

*"Development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (*Brundtland 1987).

The UN published *Transforming Our World: The 2030 Agenda for sustainable Development in 2015*, which included 17 Sustainable Development Goals (SDGs) as a call to action to tackle environmental, economic, and social issues (UN 2015).

Circular economy (CE) principles align with sustainability principles in recognising that natural resources are not finite. CE requires a systemic and paradigm shift moving from the prevailing linear models of take-make-dispose, exploitative production and consumption patterns (Sousa-Zomer *et al.*, 2018; Kirchherr *et al.*, 2017)to consumption patterns which are restorative by design and intention (Stahel, 2016; EMF, 2012; Lehmann, *et al.* 2014).

There are many definitions in the literature for Circular Economy (CE) and Kirchher *et al.* (2017) systematically analysed 114 CE definitions, coming up with the following definition which encompasses the main principles.

"An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso-level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr *et al.*, 2017)

2.2 Historical Perspective – Circular Economy Emergence

Industrialisation and globalisation are the two driving factors that have enabled growth in economies and shaped how business activities have developed since the 19th century (Cain and Hopkins, 1993; Allen, 2003; McDonough and Braungart, 2010)

In the 17th Century strong economies developed in the UK and the Netherlands (through growth in the textiles industry), laying the foundations for the Industrial Revolution (1760-1840) (Allen, 2003). Technical innovations meant that production methods transitioned from labour-intensive cottage industries to mechanised systems, enabling amongst other advances the extensive mining of natural resources (Ayres *et al.*, 1997; McDonough and Braungart, 2010). Global exploration enabled increased access to materials and new methods of manufacturing. (Cain and Hopkins, 1993). Transportation of these materials was initially a limitation to growth, but during the late 19th Century innovations such as the railroads and steamboats allowed exports to be moved quicker and more reliably, leading to the globalisation of markets (Jacks, 2006). Increasing industrialisation and urbanisation led to the growth of support businesses such as banks, law firms and service industries (McDonough and Braungart, 2010).

Early examples of a circular system were observed during the 19th Century and were an integral part of economic growth during the industrial revolution (Desrochers, 2008). The expense of raw materials was a limiting factor in the 19th century; however, labour was cheap (McDonough and Braungart, 2010). The economic benefits of utilising by-products created by the main industries, to make new products, was seen as a good business strategy by industrialists who wanted to make as much product as possible with the resources that they had (McDonough and Braungart, 2010; Desrochers, 2008). Companies such as Croda, established in 1925, to utilise a by-product from wool processing to produce lanolin and now an international chemical company (Croda 2018). Several early economists saw those innovative uses of waste products as key to industrial development and demonstrate an early example of the importance of industrial ecology (Simmonds 1862; Marx 1894; Koller 1918; Marshall 1920 cited in Desrocher 2008). Another example of early circular economy was the establishing of dust yards, the equivalent to a modern materials recovery facility (MRF) to make valuable commodities such as “breeze “a (fuel product) and “soil” (a compost like product) from the late 1780’s, from household wastes. (Velis *et al.*, 2009).

2.3 Drivers for a more Circular Approach

2.3.1 Population growth

The world's population has multiplied seven-fold since the industrial revolution when the population was around 1 billion in 1800, growing to 7.89 billion in 2021 (UN 2022), concurrently a similar rise is seen in per capita consumption of resources (Schulte, 2013). Consumption of resources is linked to the emergence and rising numbers of the global middle class, defined by the OECD as: “*households earning between 75% and 200% of the median national income”* as they have more disposable income and wish to improve their quality of life (OECD, 2019b). It is envisaged that by 2030 another 3 to 3.6 billion people will enter the global middle class reaching a total of 5 billion people (World Economic Forum, 2014). EEE products are intrinsically linked to global economic development and prosperity, due to being an important feature of modern daily life, through facilitating communications and improving living and work conditions (Balde *et al*., 2017; Forti *et al*., 2020; Guzzo *et al*.,2021).

2.3.2 Sustainability and Circular Economy tackling finite resources.

Economic growth has been accelerating since mid-20th century, evidenced by economic booms of the 1970’s and 1980’s and is linked to increased consumption levels (Jackson, 2011). New innovations, further agricultural efficiencies, and the significant decline in commodity prices since the 1920’s contributed to these economic booms as the price of products were reduced (Schulte, 2013; Dobbs *et al.*,2013). Governments post World War II, promoted increased consumption as a mechanism for economic growth, generating increased demand for products (Ayres 1998; Braungart and McDonough 2010).

Economic growth has improved the lifestyle of many over the past decades, as mentioned earlier with the rise of the global middle class, however an annualised positive GDP implies exponential growth in the use of resources (Christmann, 2018). Traditional linear models work well when resources are abundant and waste disposal costs are low, as substantial amounts of waste are generated by human activities when compared with those found in nature (Benyus, 2002; Meadows *et al.*,1972). However, linear models contrast with the more cyclical way in which natural systems operate and therefore linear models cannot be sustained indefinitely (Braungart & McDonough, 2010). Meadows (1972) in the report to the Club of Rome “*Limits to Growth”* questions the earth's capacity to withstand constant human development and expansion. Overuse of resources in a finite world will ultimately exceed the limits of what the planet can support and there is a concern that demand for resources will soon outstrip supply. Costanza and Daly (1992) argue that the human economy is a subsystem of the finite global ecosystem, therefore the long-term growth of the economy cannot be sustainable. Daly (2015) puts the case that:

"The ecosystem remains constant in scale as the economy grows, it is inevitable that over time the economy becomes larger relative to the containing ecosystem." (Daly, 2015).

Pre- World War II, the economy was small relative to the containing ecosystem, which Daly refers to as an "empty world", where natural resources were plentiful. However, this "empty world", has become "full" as economies have grown driven by population growth leading to increased use of resources, this is illustrated in Daly's diagram, Figure 2.1, below. The rise in consumption and demand for EEE products such as IT equipment, mobile phones and household appliances (Akcil, 2016), intrinsically linked to economic growth, is part of this transition from an 'empty world' to a 'full world'.

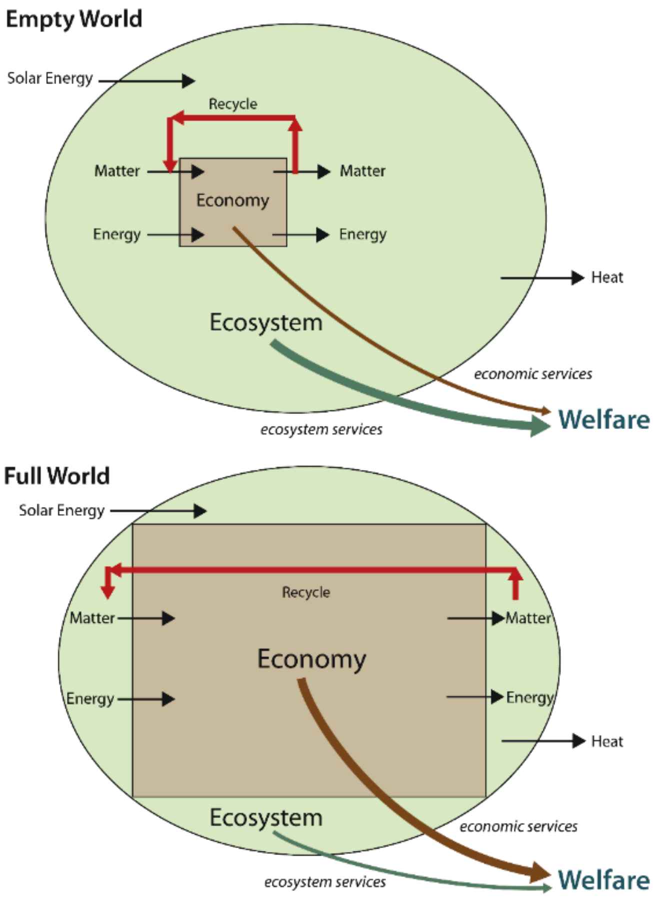

Figure 2-1 Welfare versus Growth. (Source: Daly 2015)

When economic growth stalled, such as during wars, and more recently during the COVID pandemic, consumerism stalls, leading to reduced use of resources in production of new products. A culture of "make do and mend" prevails as the less we have the more we adapt what we have; in essence this is a circular economy approach driven by need (Stahel, 2010; Sarkis *et al.*, 2020)

The linear process doesn't allow resources to be used to their full capacity and often leads them to prematurely reach the end of their life (Haas *et al.*, 2015). Sustainable economies are seen as a way of making the supply side more environmentally efficient, and circular economy is seen as a mechanism for implementation of sustainable development within businesses (Ghisellini *et al.*, 2016). Circular economy approaches have been gaining momentum since they provide a more efficient way of utilising raw materials to reduce wastage (World Economic Forum, 2014; Kirchherr *et al.*, 2017). In "Cradle to Cradle", (Braungart and McDonough (2010) suggests that in the same way that biological nutrients should be returned to the living system, such as in agriculture, industrial materials (technical nutrients), should be returned to the industrial system.

In the past 50 years extraction of raw materials for manufacture has risen from 27bn tonnes in 1970 to over 100 bn tonnes in 2019 (Circle Economy, 2022; Christmann, 2018). EEE is manufactured from a complex mix of these raw materials including mined metals, a wide variety of polymers from fossil fuels and chemicals, which has led to global demand for these products increasing annually by 2.5 million metric tonnes per annum, this is explored in detail in Chapter 3 (Forti *et al*., 2020).

It is estimated that only 8.6% of these primary materials were recovered in 2020 to be used again in new products, which supports the theory that 90 % of primary materials are wasted or lost during the extraction and manufacturing process (McDonough and Braungart, 2010; Circle Economy, 2022).

Linear business development will continue the acceleration for increased extraction of raw materials, which as these materials are not finite, will lead to extensive scarcities of these non-renewable materials and increased waste generation (Wistetek, 2017; OECD, 2019). Extraction of these resources leads to reduction in natural capital, defined as "a stock that yields a flow of valuable goods or services into the future"(Costanza and Daly, 1992). Plastics are mainly sourced from non-renewable natural stock in the form of fossil fuels, circular economy offers a solution to this reduction of natural capital by the substitution of non-renewable virgin plastics with recycled plastics or biobased plastics (van den Oever and Molenveld, 2017; Singh *et al.*, 2022; Lovins *et al.*, 2007).

Electronic and Electrical Equipment (EEE) has a central role in society and has become an essential feature of modern daily life, facilitating communications and improving living and work conditions and are key in driving digitalisation and a greener economy (Balde *et al.*, 2017; Forti *et al.*, 2020; Guzzo *et al.*, 2021). Many of the resources needed for EEE manufacture, such as plastics (oil), gold, rhodium, platinum and palladium are subject to price volatility which therefore poses a risk to the supply and availability (Dobbs *et al.*, 2013; Althaf *et al.*, 2019). In addition to demand outstripping supply there are incidences of destabilising events such as the Covid-19 pandemic which saw a growth in consumption of EEE products, and various wars including the current war in Ukraine. These have led to increasing oil prices as shown in figure 2.1, which cascade around the world prompting people movement and interruption of supply chains (Althaf and Babbitt, 2021; Sarkis *et al.*, 2020).

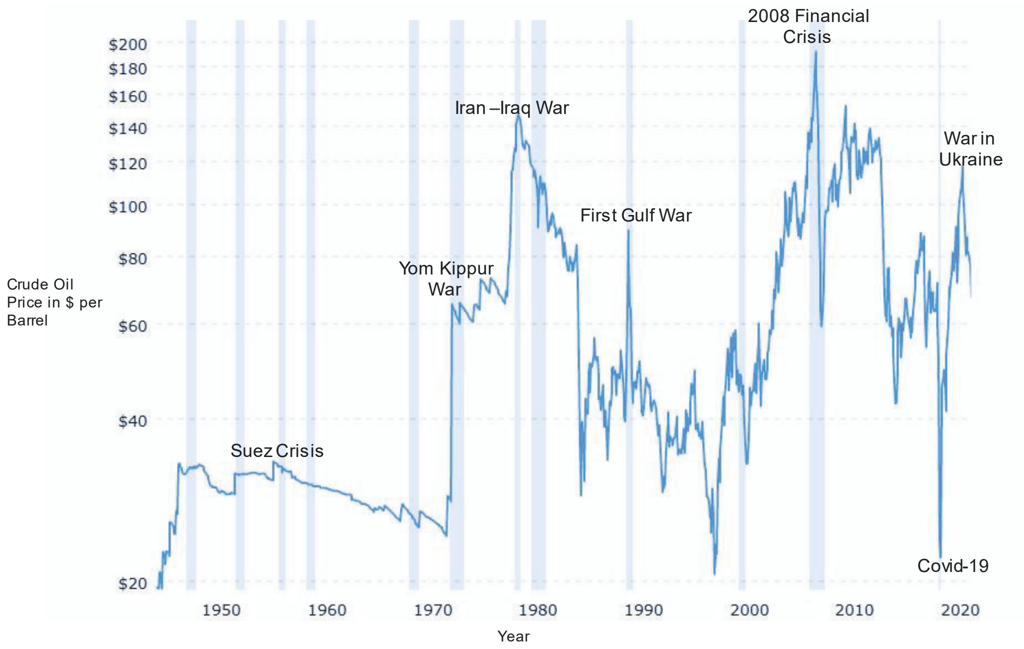

Figure 2-1 Crude Oil Prices showing impact of key events – oil data (Adapted from: www.macrotrends.net)

As global demand for EEE products is increasing so will the need to transition to a circular economy to develop resilient supply chains (Kumar *et al.*, 2017; Guzzo *et al.*, 2021; Hanouz *et al.*, 2014; Forti *et al.*, 2020). For future economic competitiveness and resilience, resource efficiency and security will be critical; this will require a shift in how businesses and countries manage these issues (Preston, 2012).

2.3.3 Reduction of environmental damage through a Circular Economy Approach

Material extraction, processing of the materials and consequent waste generation to satisfy demand, inevitably leads to environmental consequences such as greenhouse gas emissions, air pollution and toxic effects on ecosystems (OECD, 2019; OECD, 2016).

Indirect and direct pollution impacts on human health; however, historically little consideration was given to the economic or environmental cost of pollution such as soil contamination from chemicals, polluting watercourses with effluent from manufacturing and the release of particulate matter and other emissions to air (McDonough and Braungart, 2010). In Western Europe the cost of clean-up of historical pollution was left to be borne by later generations and is currently a problem facing the governments in the developing nations such as China, India and Brazil as the manufacturing base shifts to these countries (Tamazian and Bhaskara Rao, 2010). Porter and Linde (1995) argued that pollution equals economic wastage, and that material wastage should be of economic concern to businesses rather than being just an environmental concern.

Gore (2020) points out that in 2015 the poorest half of the global population, 3.5 billion people are responsible for only 7% of emissions attributed to consumption patterns, whilst 52% of total emissions can be attributed to the richest 10% of the global population (630 million people). Figure 2.2 shows how this has changed since 1990, with the biggest change being in the middle-income section which grown from being responsible for 41% of emissions associated with consumption to 44% (Gore, 2020), which corresponds to the rise in the global middle class mentioned in the previous section.

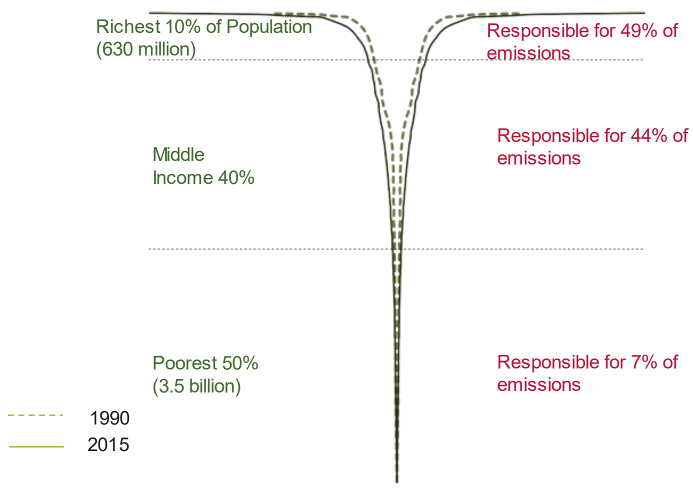

Figure 2-2 Percentage of CO2 emissions by world population. (Adapted from: Gore 2020)

As was discussed in the previous section, rise in consumption has led to rise in raw material extraction and the International Resource Panel (IRP) identified that 33% of pollution impacts, 50% of climate change and around 90% of biodiversity loss and water stress are linked to the extraction and further manufacturing and processing of resources (OECD, 2019c). Biodiversity is declining due to unsustainable land use such as fossil fuel extraction and mining of metals needed for manufacture of EEE, leading to a reduction the benefits that biodiversity provides, such as pollination. Loss of iconic species leads to destabilised ecosystems from which pests and diseases emerge which impact on public health (Benton, 2021).

Companies have already embraced the concept of innovation in improving product and process efficiency and need to do the same when considering the costs of pollution (Jackson, 2011) McDononough and Braungart (2010) argues that companies should adopt eco-effectiveness rather than eco–efficiencies. The premise behind this is that eco efficiency measures taken by companies are generally about reducing waste, energy and water but doesn't look at environmental protection, as products should not be detrimental to the environment in the long-term through bad design and use of harmful materials. Eco-effective design considers the whole lifecycle of the product thus avoiding re-circulating harmful substances.

Circular economy can be seen as a framework for delivery of more sustainable economic growth (Nasr, 2018), using this framework enables a re-think of the global economy and global use of resources. An economic model that is compatible with the interests of future generations is required addressing the triple crisis of biodiversity, climate change and pollution identified by the UN (UN 2015).

The Ellen McArthur Foundation see CE as;

"An *approach that entails gradually decoupling economic activity from the consumption of finite resources and focuses on regenerating economic human and natural capital*" (Ellen MacArthur Foundation, 2012)

The World Economic Forum (World Economic Forum, 2014) highlighted the need to scale up circular economy adoption stating that, by adopting restorative approaches to materials, savings of up to US$ 1 trillion per annum could be made by 2025. Financial institutions are increasingly seeing CE as a mechanism for reducing risk and building in long-term resilience and since 2018 there has been a growth in both private and public equity funds focusing on CE.   Other financial schemes such as lending for CE initiatives and CE corporate bonds have also emerged from several leading banks (ING, 2020; Ellen MacArthur Foundation, 2020). Increasingly long-term investors when making investment decisions are looking at the risk of investing in companies from the dimensions of environmental, social and governance (ESG) metrics perspective (Cort and Esty, 2020). Investors want to understand how companies are performing and mitigating risks through policies, programs and initiatives. ESG risks metrics will be evaluated through looking at corporate social responsibility (CSR) reports and other policy documents to measure company performance measures. EEE manufacturers such as HP (HP, 2022) and Philips (Philips, 2022) provide annual reports to demonstrate how they are increasing their revenues derived from sustainable products by incorporating CE principles into their manufacturing process such as eco-design, recycled content and offering product service models.

2.4 Circular Economy Theory Development

Circular economy thinking has developed from a several different approaches to sustainable economic development in the last decades of the 20th Century, as awareness of the unsustainability of the current consumption patterns increased. Several key approaches have been developed from the 1970's to promote more sustainable business practices and take a more circular approach.

Industrial Ecology (Frosch & Gallopoulos, 1989) looks at the preservation of materials and energy that are embedded in a product, focusing on life cycles of products to understand key resource use. 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). There are significant overlaps between Industrial Ecology and Circular Economy (Murray *et al.,*2017), with the main difference that CE includes the concept of a restorative economy, that not only focuses on minimizing waste and resource use but looks at repairing environmental degradation (Kirchher *et al* 2017).

Performance Economy Stahel & Ready (1981) introduced the concept of the loop economy and the concept of cradle to cradle, the report described this concept has having four main impacts; resource savings, job creation, economic competitiveness and waste prevention, the refurbishment of EEE equipment such as word processors was cited as an example of product life extension. Stahel (2010) built on this to develop his concept of" Performance Economy", which focuses on selling performance or services instead of goods, with all cost internalised in a closed loop system. Stahel (2010) argues that reuse and remanufacturing, such as the refurbishing of domestic appliances are a critical part of the performance economy as they reduce the material needed to create products thus maintaining capital stocks of material.

Biomimicry (Beynus 2002) takes the approach of developing design innovations based on emulating natures patterns and strategies to optimise technological design and minimise waste. Like circular economy biomimicry emphasises the importance of feedback loops and collaboration. An example of biomimicry approach in the EEE sector is the development of 3D printing technology which enables parts to be made as and when required thus reducing the potential for wastage of unnecessary spare parts.

Natural Capitalism has four key principles; to increase the productivity of natural resources, use biological inspired production models such as the closed loop systems found in nature, use service and flow business models and the reinvestment in natural capital (Lovins *et al.*, 1999) . An example of natural capitalism in practice is demonstrated by Dell. Dell commissioned Trucost, to assess the net environmental benefit of closed-loop recycled plastic in computer housings, in terms of lower pollution, reduced greenhouse gas emissions, and improved human health compared to using virgin plastic (Trucost, 2015). Positive and negative environmental impacts were quantified, and a monetary value was assigned to each reduction of impact, Dell has used this report to develop their circular business strategies for the development of closed loop systems for EEE plastics.

Cradle to Cradle (Braungart & McDonough 2010; Lewanddowski 2016) is based on treating materials as biological or technical nutrients to extend their 'in use' period. The key concept is also that of instead of doing less bad, to do "more good", by use of renewable energy and elimination of toxic chemicals. The aim is avoiding unintentionally recirculating toxic chemicals via recycling. Bang & Olufsen became the first consumer electronics firm to have cradle to cradle certification for their Beosound Level speaker, which was created using modular design principles in 2021 (Bang & Olufsen, 2022).

A Systems Approach. In her book "Thinking in systems – A primer" Meadows (2008) proposes the concept of Thinking in Systems to look at impact of a systems-based approach to problem solving, Meadows defines a system as "*an interconnected set of elements that is coherently organized in a way that achieves something"*. A systems-based approach can be applied to the design of electronics, EEE producers must consider closely their product design and the set-up of their supply chain and network of collaborators to extend the lifetime of products for example through design for refurbishment and repair or for ease of recycling of at end of life (Hannon *et al.*, 2016; Pauli, 2010). A systems-based approach requires a paradigm shift involving all stakeholders in the value chain (Hannon *et al.*, 2016; Boons and Lüdeke-Freund, 2013)

2.5 Governmental and Political Drivers

A radical transformation in the way the world uses natural resources is needed to achieve the 17 Sustainable Development Goals (SDGs), the global climate target of limiting warming to 1.5 ^{0}C and meeting the needs of future generations (UN, 2015) . Global policy increasingly regards CE, as a promising model for driving sustainable and resilient economic growth in both developed and emerging economies (Zhu *et al.*, 2011; Morioka *et al.*, 2005, European Commission, 2020).

The circular economy is emerging as a new framework for a green recovery however, until recently, the discussions around the circular economy have predominantly focused on waste management and recycling especially in countries such as Japan and China (Wu *et al.*, 2014; Ogunmakinde, 2019; Mathews and Tan, 2016; Sarkis *et al.*, 2020).

China is the world's largest manufacturer and exporter and is one of the EU's main trading partners, as such will have an impact on CE strategies in Europe (Morlet, 2018). The EU recognised the importance of bilateral collaboration with China in transitioning to a CE and signed an MoU with China in July 2018 (European Commission, 2018). Rapid industrialisation and urbanisation have meant that China is facing particularly extreme environmental, and social challenges and CE was seen as a solution to tackling these challenges, improving resource efficiency and decoupling economic growth from use of natural resources (Ogunmakinde, 2019; Wu *et al.*, 2014; Ghisellini *et al.*, 2016). CE has been implemented in China for the past 17 years and was first mentioned in the Chinese 11th Five Year plan in 2005 which laid out the concept. The 12th Plan in 2011, highlighted the circular economy as a mechanism to build a resource efficient society and the 13th Plan in 2015 laid out a programme for action (Mathews and Tan, 2016; Geng *et al.*, 2019).

Japan is a major EEE manufacturer and is therefore important in the global EEE value chain and as an exporter to the EU. Japan adopted a legislative approach and was the first country to implement CE legislation in 1991, requiring the effective use of recyclates (Ghisellini *et al.*, 2016). In 2002 the government introduced The Basic Law for Establishing a Recycling Based society which included targeting home appliances and highlighted the need for advanced loop closing techniques to retain original function at the highest level possible, as opposed to down-cycling (Morioka *et al.*, 2005).

In Europe, initial steps towards CE were also targeting resource efficiency and reducing pollution with the implementation of legislation such as the Waste Framework Directive (2008/98/EC), Packaging Directive (94/62/EC), WEEE Directive (2012/19/EU, 2012) and Batteries and Accumulators Directive (2006/66/EC) which aimed at preventing waste and encouraging recycling as opposed to disposal. The WEEE Directive (2012/19/EU) attempts to address the producer responsibility aspects of the End of Life (EOL) of the WEEE value chain, resulting in a partial reduction in waste generation.

The EU's Circular Economy Action Plan (CEAP) was launched in December 2015 (European Commission, 2015) which embedded CE as a mechanism for mainstreaming its sustainable development policy and targeted sustainable consumption.

The CEAP (2015) announced initiatives along the entire life cycle of products, targeting the design of sustainable products, promoting circularity in production processes, supporting sustainable consumption, and aiming to ensure that the resources used are kept in the EU economy for as long as possible. It is clear that, in order to achieve this collaboration needs to happen across the value chain (Hofstetter *et al.*, 2021). The Action Plan was supported by research and impact funding through the Horizon 2020 programme, which has led to collaborations between business and academia to pilot and facilitate the implementation of the main principles of product design, production, consumption and waste management.

The European Strategy for Plastics published in January 2018, as part of the CEAP (2015) and aims to push the EU towards a circular plastic economy, to support more sustainable production patterns for plastics, reuse, repair and recycling of products as well as to reduce marine litter, greenhouse gas emissions and dependence on imported fossil fuels (European Commission, 2018b). One of the key components of this strategy for the EEE sector in Europe was the launch of the Circular Plastics Alliance in December 2018 (CPA 2022) to help plastics value chains including the EEE value chain to boost the EU market for recycled plastics to 10 million tonnes by 2025 through voluntary pledges.

To further implement the transition to a circular economy in the EU, the European Green Deal (EGD) (European Commission, 2019) was announced in December 2019 which provided a roadmap with actions. The aim of the EGD was, to make the EU's economy sustainable by transforming the EU's economic model and includes all sectors including ICT. The EGD is supported by the European Green Deal Investment Plan to "enable a framework to facilitate public and private investments needed for the transition to a climate-neutral, green, competitive and inclusive economy" (European Commission, 2020b)

One of the main actions of the EGD was the updating of the 2015 CEAP in March 2020 (European Commission, 2020a)following conclusions from the implementation report of the 2015 plan. The new action plan lays out a new Industrial strategy for the EU economy to transition to a competitive climate neutral economy. Implementing the second Circular Economy Action Plan. The action plan addresses four key areas.

1. Sustainable product policy making sustainable products the norm on the European market.
2. Empowering consumers
3. Reduction of waste
    a. Making all packaging recyclable or reusable by 2030.
    b. Minimising waste exports
4. Taking action in nine key sectors with a high potential for circularity- electronics and ICT and plastics are two of these identified sectors, the other sectors are batteries and vehicles, packaging, textiles, construction and buildings and food, water, and nutrients.

The CEAP (European Commission, 2020a)is not just environmental policy but also economic and social policy. In the EU between 2012 and 2018 the number of jobs with a direct link to circular economy grew by 5% (European Commission, 2020c)

In March 2020 the proposal for Ecodesign for Sustainable Products was launched (European Commission, 2022)which looks to transform how products are designed through proposing an Eco-design Products Regulation building on and broadening the existing Ecodesign Directive (2009/125/EC). The proposal establishes a framework for specific product groups, including the EEE sector, to make products more sustainable, durable, reusable, repairable recyclable energy efficient and containing less harmful chemicals. This will empower consumers who need to be an active part. The proposals will enable consumers to be able to choose products that are circular and have a lower environmental impact by improving information about products environmental characteristics.

The transition to a circular economy is a global challenge as the value chains are global and the action needs to be global (Hofstetter *et al.*, 2021). UNEA (2019) recognised the circular economy as a pathway to sustainable development through sustainable production and consumption. To progress global cooperation the EU, as part of the CEAP 2020, has teamed up with UNEP and UNIDO to set up the global alliance on circular economy and resource efficiency (GACERE) launched in February 2021 (UNEP, 2021). GACERE has 16 members from Canada, Chile, Columbia, EU, India, Japan, Kenya, Morocco, New Zealand, Nigeria, Norway, Peru, Republic of Korea, Rwanda, South Africa and Switzerland. These set of countries have come together to support the shift to the circular economy globally and the global efficient use of resources through knowledge exchange (UNEP, 2023).

Chapter Summary

This chapter has investigated the emergence of circular economy principals in response to the economic and environmental impacts of industrialisation, population growth and increasing consumption patterns including the role of policy and legislation. The literature review demonstrates how circular economy has grown as an increasingly attractive business proposition, to ensuring sustainable economic growth, through responding to the issues price stability, secure access to raw materials and defends against the consequences of climate change. The next chapter considers in detail the importance of CE to the EEE sector.

Chapter 3 Electrical and Electronic Equipment

3.1 Introduction

The application of circular economy to the Electrical and Electronics Equipment (EEE) sector requires a system thinking approach, one which gives an understanding of the whole value chain and lifecycles of EEE including design and end of life. There is therefore a need to understand the wider context of how EEE is used and discarded in order to understand how the opportunities presented by the circular economy can be realised (Meadows *et al.*, 2018)

3.2 Electrical and Electronic Equipment.

EEE is a key and indispensable element of modern life. EEE consumption and global economic development are intertwined, enhancing living standards and increasing communication (Guzzo *et al.*, 2021). The central role in society of these EEE products, makes it one of the fastest growing manufacturing activities (Ardi and Leisten, 2016; Buekens and Yang, 2014). Global demand for these products is increasing annually by 2.5 million metric tonnes per annum (Forti *et al.*, 2020). Electrical and electronic equipment consists of a wide range of products and can be defined as:

"Any household or business item with circuitry or electrical components with power or battery supply." (StEP Initiative, 2014)

EEE includes for example household appliances, ICT, tools, musical instruments, lighting, security systems, energy generation systems, healthcare appliances and monitors. Electronics are also increasingly being used in Internet of Things (IoT) devices and sensors or devices and integrated into smart textiles and smart furniture (Bacher *et al.*, 2017; Köhler *et al.*, 2011). For example, at the end of 2019 there were 7.6 billion active IoT devices, a figure which is predicted to grow to 24.1 billion in 2030, a compound annual growth rate (CAGR) of 11% (Transforma Insights, 2020).

Key reasons for growth in EEE consumption are increasing industrialisation and higher levels of disposable income, as the higher the purchasing power per capita the higher the number of different appliances per capita (Forti *et al.*, 2020). High and middle-income countries will have an average one fridge (a high-cost item) per household whereas in low-income countries this drops to only one in ten households having a fridge in low-income countries (Forti *et al.*, 2020).

A further reason for the rapid growth of EEE is the recent trend, particularly in Europe, of limited lifespans of products, due to rapidly evolving technology innovations, which creates more demand (Debnath *et al.*, 2016; Lu *et al.*, 2014). The shortening of innovation cycles and product lifespans has led to increasing obsolescence and fast substitution, particularly in the ICT sector (Jaiswal *et al.*, 2015; Debnath *et al.*, 2016; Babbitt *et al.*, 2009; Kiddee *et al.*, 2013). Smart phones which are upgraded every two years on average in Europe, (Ongondo and Williams, 2011; Thiébaud *et al.*, 2018; Ylä-Mella *et al.*, 2022) are an example of this fast turnaround of products. This can be due to renewal of phone contracts and length of warranty (typically two years), or new innovations in the camera technology, however this trend is beginning to change as cloud storage means that phone memory is not as critical and new innovations tweaks rather than substantive changes (Ylä-Mella, *et al.,*2022)

Table 3.1 shows the examples of different categories of EEE in Europe with examples of products included in each category.

Table 3-1 The 10 original categories of EEE covered by the WEEE Directive (2012/19/EU) Annex 1.

Category	Examples of types of Items included in the category
Large household appliances	Large cooling devices, refrigerators, freezers, washing machines, dishwashers, cooking appliances, heating appliances
Small household appliances	Vacuum cleaners, irons, toasters, fryers, coffee machines, shavers and other body care devices, hair driers, electric toothbrushes, clocks and scales

IT and telecommunications equipment	Centralised data processing, mainframes, minicomputers, printer units, personal & laptop computers (CPU, mouse screen and keyboard included), printers, copying equipment, electrical typewriters, calculators and telephones
Consumer equipment and photovoltaic panels	Radios, televisions, video cameras and recorders, audio equipment, musical instruments, set top boxes and photovoltaic panels
Lighting equipment	fluorescent lamps, high intensity discharge lamps, including pressure sodium lamps and metal halide lamps, low pressure sodium lamps, luminaries for fluorescent lamps with the exception of luminaries in households,
Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	Drills, saws, sewing machines, equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making holes, punching, folding, bending or similar processing of wood, metal and other materials, tools for riveting, nailing or screwing or removing rivets, nails, screws or similar uses, tools for welding, soldering or similar use, equipment for spraying, spreading, dispersing or other treatments of liquid or gaseous substances by other means, tools for mowing or other gardening activities
Toys, leisure and sports equipment	electric trains or car racing sets, hand-held video games consoles, video games, computers for biking, diving, running, rowing, etc, sports equipment with electric or electronic components, coin slot machines
Medical devices (with the exception of all implanted and infected products)	radiotherapy equipment, cardiology equipment, dialysis equipment, pulmonary ventilators, nuclear medicine equipment, laboratory equipment for in-vitro diagnosis, analysers, freezers, fertilization tests, other appliances for detecting, preventing, monitoring, treating, alleviating illness, injury or disability
Monitoring and control instruments	smoke detectors, heating regulators, thermostats, measuring, weighing or adjusting appliances for household or as laboratory equipment, other monitoring and control instruments used in industrial installations (e.g., in control panels)
Automatic dispensers	automatic dispensers for hot drinks, for hot or cold bottles or cans, automatic dispensers for solid products automatic dispensers for money, all appliances which deliver automatically all kinds of products.

3.3 Global Waste Electronic and Electrical Equipment Arisings

As a result of the increasing production of EEE products, Waste Electrical Electronic Equipment waste (WEEE) often referred to internationally as e-waste, is one of the fastest growing waste streams in the world in terms of volume. There are many definitions but an overall agreement that EEE becomes WEEE if its holder discards it or intends or is required to discard it (StEP Initiative, 2014).

As can be seen in Figure 3.1, in 2014 total e-waste generated worldwide was estimated at approximately 44.4 million tonnes, this increased to 53.6 million tonnes in 2019 average of almost 2 million tonnes per year (Kumar *et al.*, 2017; Forti *et al.*, 2020). Per capita this equates to a 1kg increase from 6.4kg in 2014 to 7.3kg in 2019.

Figure 3-1 Global E-Waste Generated by year. (Adapted from: Forti *et al.*, 2020)

Future growth of e-waste is predicted to be 74.7 million tonnes or 9.0 kg/capita by 2030. From an EU perspective, WEEE is growing at 3-7% per year, with a generation above 12 million tonnes estimated for 2020. To boost circular economy and enhance resource efficiency, prevention of e-waste, and improvement in collection and recovery is essential, as currently documented global recovery rates of e-waste are only 17.4% (Forti *et al.*, 2020).

A consequence of the increasing growth in EEE and consequently e-waste, is its increasing impact on the environment which occurs at the both the extraction and disposal stages (Meloni *et al.*, 2018). Significant environmental and health burdens can be associated with the primary extraction of materials stage, which can require large amounts of energy and use of hazardous materials and is often associated with dangerous working conditions (Fiore *et al.*, 2019; Cucchiella *et al.*, 2015; Meloni *et al.*, 2018) Due the potentially hazardous content in e-waste, if it is not properly managed through a controlled recycling process it can cause major environmental and health problems (Wilts and von Gries, 2016).

Policy and legislation need to be developed to drive the move to a more circular approach and reduce environmental and health impacts (Bates and Osibanjo, 2020). Seventy-eight countries globally have either policy, regulation or legislation to control e-waste which accounts for 71% of the global population, however only 22% have national legally binding legislation (Haarman *et al.*, 2020). More regulation still needs to be implemented to manage e-waste globally to improve collection rates allowing capture of the valuable materials contained within WEEE and reduction of health impacts (Bates and Osibanjo, 2020; Balde *et al.*, 2017). One step towards protecting health and environment against the adverse effects of hazardous e- waste has been the adoption of multi-lateral International Environmental Agreements (IEA), the Basel, Rotterdam and Stockholm Conventions, each of these three conventions are outlined in more detail below (Fiedler *et al.*, 2019). These three IEAs provide a framework for a cradle to grave approach to management of hazardous chemicals and wastes managed by a single secretariat (Núñez-Rocha and Martínez-Zarzoso, 2019).

The Basel Convention regulates the transboundary movements of hazardous wastes (imports and exports) and their disposal and was adopted in 1989 and came into force in 1992, it was developed in response to public concern about e-waste being shipped to developing countries (BRS, 2022). The EU directly transposed the procedural rules of the

Basel Convention into European legislation (Directive 2006/12/EC). One of the main decisions at the 14th meeting of the Conference of the Parties (COP) to the Basel Convention in 2019, was to include most plastic wastes into Annexes II and VIII, this entered into force in 2021 (Council of the European Union 2019). The consequence of the inclusion of these hazardous or difficult to recycle plastic wastes, is that transboundary movements these wastes will be subject to the control mechanisms of the Convention (Fraunhofer *et al.*,).

The Rotterdam Convention requires prior informed consent procedure for certain hazardous chemicals and pesticides in international trade to enable protection of human health and the environment (BRS 2022). The aim of the Convention which entered into force in 2004 is to ensure that governments have the necessary information to assess risks of hazardous chemicals, enabling informed decision-making on the import of certain chemicals (Núñez-Rocha and Martínez-Zarzoso, 2019; Andersen, 2021). The Rotterdam Convention was implemented in the EU via the Prior Informed Consent Regulation (PIC Regulation (EU) 649/2012). It administers the import and export of specified hazardous chemicals and obligations on enterprises that want to export these chemicals to non-EU countries (Fraunhofer *et al.*,).

The Stockholm Convention on persistent organic pollutants (POP) was adopted in 2001 and entered force in 2004. The Stockholm Convention aims to eliminate POPs globally by either prohibiting production and use or gradually reducing them and is implemented in the EU by the POPs Regulation 2019/1021(EU). Currently twenty-eight POPs are covered which include some of the brominated flame retardants found in WEEE (Fiedler *et al.*, 2019; Núñez-Rocha and Martínez-Zarzoso, 2019; Andersen, 2021).

3.4 Impact of Legislation in Europe

WEEE infrastructure and legislation is well established in Europe. Initial key legislation to tackle the increasing volumes of WEEE arising in Europe were established in 2002 with the introduction of the first WEEE Directive (2002/96/EC) and Restriction of the use of Hazardous Substances (RoHS) (Directive 2002/95/EC).

3.4.1 WEEE Directive

The WEEE Directive (2012/19/EU) has the goal to ensure that waste electrical and electronic equipment is properly treated within the EU. Its purpose is to contribute to sustainable production and consumption by the prevention of WEEE and by increasing the re-use, recycling, and other forms of recovery of the waste stream. The WEEE Directive (2012/19/EU) implements the principle of extended producer responsibility (EPR), under which producers are expected to take responsibility for the environmental impact of their products,when they become waste. EPR aligns with the CE principal of product stewardship making producers (manufacturers, importers and distributors) of EEE legally responsible for financing the recycling and recovery of their products at the end of life (Weetman, 2020). Producers need to ensure available facilities to enable the free take-back of WEEE by consumers and the provision of certain information (Goosey and Goosey, 2020; Shittu *et al.*, 2021). Producers have the option to manage their own products at end of life, but many choose to hand over responsibility to producer responsibility organisations (PRO) who manage this on their behalf (Andersen, 2021; Goosey and Goosey, 2020).

The first WEEE Directive (2002/96/EC) contained the creation of collection schemes where consumers returned their old devices free of charge and set a collection target of 4kg per inhabitant per year (in force until 2015). Article 4 of the WEEE Directive (2002/96/EC) encouraged the

"Cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials" (WEEE Directive 2002/96/EC).

Implementation of the first WEEE Directive (2002/96/EC) was left to the different member states, which posed several technical, legal and administrative challenges in transitioning to more sustainable practices, for both EEE manufacturers and WEEE handlers (Ylä-Mella, J. and Román, 2019; Andersen, 2021). As a result of the differences in implementation efficiency, in 2008, the EC proposed to revise the Directive. A recast WEEE Directive (2012/19/EU) entered into force in 2012, to improve WEEE recovery setting out ambitious targets for collection, recovery, preparation for re-use and recycling based on a step increase in collection targets from 2016-2018. The WEEE Directive (2012/19/EU) defined WEEE as:

'Waste electrical and electronic equipment' or 'WEEE' means electrical or electronic equipment which is waste within the meaning of Article 3(1) of Directive 2008/98/EC, including all components, sub-assemblies and consumables which are part of the product at the time of discarding. (2012/19/EU).

One of the main differences of the recast WEEE Directive (2012/19/EU) was the move from closed scope to open scope, in the original WEEE directive (2002/96/EC) only specific product categories were covered by legislation whereas the recast WEEE Directive (2012/19/EU) includes all EEE products. In addition, the recast WEEE includes reuse rather than just recycling, thus encouraging a wider scope of CEBMs (Andersen, 2021).

The collection targets from 2016 were a percentage of the EEE put on the market in the three preceding years and are 45% for 2016 rising to 65% in 2019. Figure 3-2 shows the relationship between EEE put on the market and WEEE collected and treated in the EU.

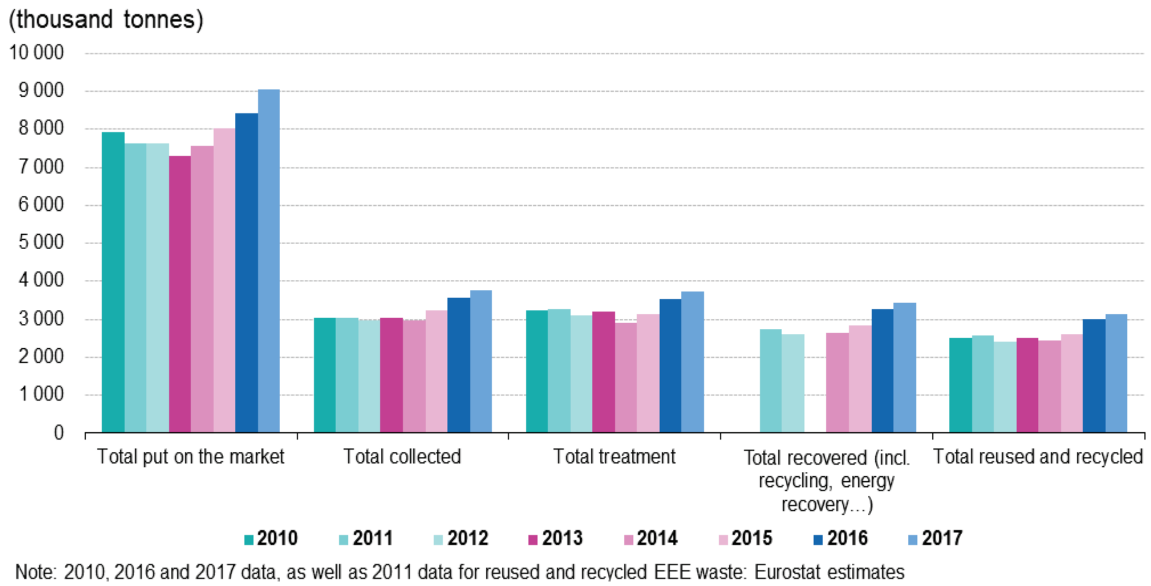

Figure 3-2 EEE put on the Market and WEEE collected and treated 2010-2017 (Source: Eurostat 2022)

EEE put on the market has been steadily increasing since 2014 (Figure 3-3) which means that the total amount collected needed to increase correspondingly. Overall, the EU average met the 45% target in 2016 with 20 member states surpassing it (Eurostat 2022). WEEE collected varies across EU member states, for example Switzerland, Bulgaria and Croatia are all collecting over 65% whereas countries such as Romania are only collecting 31%, typically this is where an informal collections system is more prevalent (Forti *et al.*, 2020; Ibanescu *et al.*, 2018).

In 2018 the open scope principle for WEEE reporting was implemented. This brought all electrical and electronic equipment into scope (unless they qualified for an exemption or exclusion). The 10 categories of EEE data reported was reduced to six categories as per Annex III of the WEEE Directive (2012/19/EU), which are outlined in table 3-2 along with the minimum recovery and recycled and reuse targets found in Annex V of the WEEE Directive (2012/19/EU).

Table 3-2 Current categories of EEE and minimum recovery targets

New categories of EEE (EU) Annex III from reference year 2019	Minimum recovery targets

Temperature exchange equipment	85 % shall be recovered, and 80 % shall be prepared for re-use and recycled
Screens, monitors, and equipment containing screens having a surface greater than 100 cm^2	80 % shall be recovered, and 70 % shall be prepared for re-use and recycled
Lamps	80 % shall be recycled
Large equipment (any external dimension more than 50 cm) including, but not limited to: Household appliances; IT and telecommunication equipment; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure, and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3	85 % shall be recovered, and 80 % shall be prepared for re-use and recycled.
Small equipment (no external dimension more than 50 cm) including, but not limited to: Household appliances; consumer equipment; luminaires; equipment reproducing sound orimages, musical equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3 and 6	75 % shall be recovered, and 55 % shall be prepared for re-use and recycled
Small IT and telecommunication equipment (no external dimension more than 50 cm).	75 % shall be recovered, and 55 % shall be prepared for re-use and recycled

3.4.2 RoHS Directive

The ‘Restriction of the use of certain hazardous substances in electrical and electronic equipment’ (RoHS) Directive complements the WEEE Directive (2012/19/EU) and entered into force in February 2003 (RoHS Directive 2002/95/EC).The RoHS recast (RoHS 2) Directive 2011/65/EU became effective on 3 January 2013 and was amended on the 15th of November 2017. RoHS explicitly targets electrical and electronic equipment and bans the use of products from the European market that exceed the maximum permissible concentrations of hazardous substances listed in Annex II of the Directive (Goosey and Goosey, 2020). The RoHS Directive (Directive 2011/65/EU) currently restricts the use of mercury, lead, cadmium, hexavalent chromium, and brominated flame retardants such as polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and Di isobutyl phthalate (DIBP)in EEE (RoHS2 Directive 2011/65/EU). The aim of the Directive is to protect human health and the environment by substituting these ten substances by safer alternatives. Reduction in hazardous materials also leads to reduced recycling costs (Charles 2018). Whilst the RoHS and WEEE Directives only apply to EU countries they have influenced related legislation globally (Goosey and Goosey, 2020; Charles, 2018).

3.4.3 REACH Regulation

The Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) entered into force in 2007. It has the main objective to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances. Producers and importers have to provide information on the properties of chemical substances and to register the information in a central database. REACH provides criteria to identify "substances of very high concern" (SVHC). SVHC are defined in Regulation (EC) No 1907/2006 (2006) as:

- Substances meeting the criteria for classification as carcinogenic, mutagenic, or toxic for reproduction (CMR) category 1A or 1B in accordance with the CLP Regulation.
- Substances which are persistent, bio-accumulative and toxic (PBT), or very persistent and very bio-accumulative (vPvB) according to REACH Annex XIII.
- Substances on a case-by-case basis, which cause an equivalent level of concern as CMR or PBT/vPvB substances.

If a substance is identified as a SVHC, it is included in the Candidate List. The European Chemicals Agency (ECHA) regularly assesses the substances on the Candidate List to determine if they should be moved to the Authorisation List (Annex XIV). Once a substance is on an Authorisation List, it can only be used or produced with a specific authorisation and under specified circumstances for defined applications. The Restrictions List (Annex XVII) is also regularly revised. The use of a substance on the Restrictions List is prohibited.

In 2013, the Commission published the first review of REACH. A second review report was performed in 2018 (European Commission 2018). The Commission works closely with the European Chemicals Agency (ECHA) and national authorities in the implementation of the regulation.

The WEEE, RoHS and REACH Directives as the main driving forces for WEEE treatment, concentrate on the removal of hazardous substances, and recycling rates in general which has been successful in driving up recapture and recycling of WEEE (Goosey and Goosey, 2020; Wilts and Gries 2016). WEEE collection and reprocessing infrastructure has concentrated traditionally on recovery of metals due to both the economic value and weight of metal materials, however, to achieve true circularity of EEE, other materials such as plastics need to be considered (Wilts and Gries 2016).

3.5 Overview of Plastics in EEE/WEEE

55 million tonnes of plastic were produced in Europe in 2020, which accounts for 15% of total plastics production globally, making Europe the fourth largest producer of plastics in the world (). Of the 49.1 million tonnes used by plastics converters in Europe in 2020; 6.2 % were used in the Electronical and Electronic Equipment sector (Plastics Europe 2021).

WEEE contains a complex mix of valuable metals, plastics and critical raw materials and the recovery of these could contribute to reduced use of virgin materials and represents a significant economic opportunity (Cucchiella *et al.*, 2015). Currently only a minor share, around 1-2% of post-consumer plastics from Waste Electrical and Electronic Equipment (WEEE) are recycled back into new EEE products, (RDC Environment, 2017). The associated negative environmental and social externalities of not recycling are numerous; impacts include greenhouse gas emissions related to avoidable virgin plastics production, landfilling and incineration of WEEE plastics (Wäger, Patrick A. and Hischier, 2015). Plastics make up considerable fraction of EEE presenting an opportunity to retain the value of PCR plastics by incorporating into the manufacture of EEE (Wilts and von Gries, 2016). The majority of plastics in EEE comprise four main polymers, Acrylonitrile Butadiene Styrene (ABS), Polypropylene (PP), Polystyrene (PS) and Polycarbonate - Acrylonitrile Butadiene Styrene (PC-ABS) (Haarman, A. *et al.*, 2020; Wilts *et al.*, 2016).

Currently whilst metals and electronic components are prioritized during recycling, plastics are often left in the background and the plastics value chain is fragmented (Wäger, Patrick A. and Hischier, 2015). Types of plastic commonly recycled from WEEE are PS, ABS, PC/ABS and PC (RDC Environment, 2017), these account for 56% of the plastics contained in WEEE (MGG, 2020) as can be seen in Figure 3.3

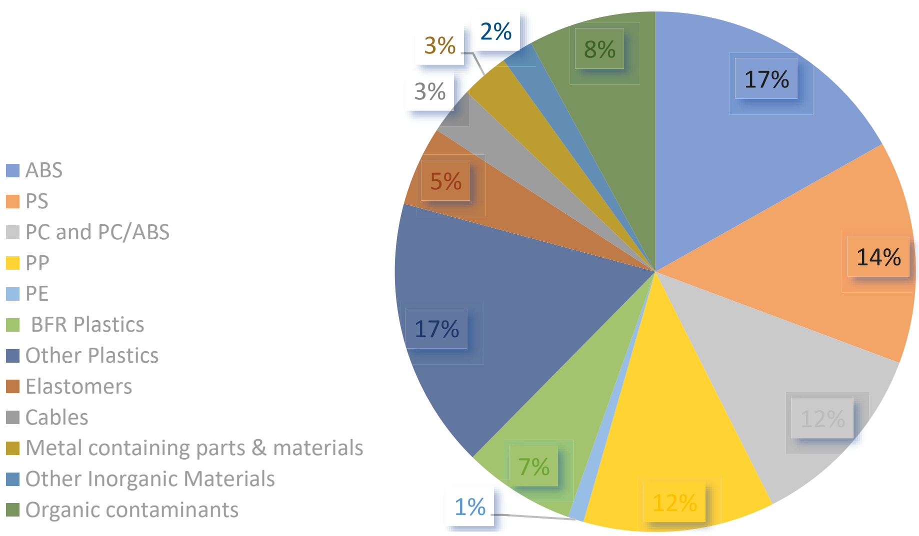

Figure 3-3 Average composition of WEEE plastics for recycling. (Adapted from MGG Polymers 2020)

Table 3.3 shows the how the different types of polymers are used in different EEE applications.

Table 3-3 Applications of plastics in EEE (adapted from Delgado *et al.*, 2007, EU, 2011, BPF 2018)

Type of Plastic	Application
Polypropylene (PP)	Components inside washing machines and dishwashers, casings of small household appliances (coffee makers, irons, etc.) Internal electronic components.
High Impact Polystyrene (HIPS)	Components inside refrigerators (liner, shelving) Housings of small household appliances, data processing and consumer electronics
Acrylonitrile butadiene styrene resin (ABS)	Housings of phones, small household appliances, microwave ovens, flat screens and certain monitors. Enclosures and internal parts of ICT equipment
PP0 (blend HIPS/PPE)	Housings of consumer electronics (TVs) and computer monitors and some small household appliances (e.g. hairdryers). Components of TV, computers, printers and copiers.
Polycarbonate(PC)	Housings of ICT equipment and household appliances. Lighting.
PC/ABS	Housings of ICT equipment and certain small household appliances (e.g. kettles, shavers)
PET(PBT)	Electrical motor components, circuits, sensors, transformers, lighting. Casing and components of certain small household appliances (e.g. toasters, irons). Handle, grips, frames for ovens and grills. Panel component of LCD displays
PolyUrethane (foam)	Insulation of refrigerators and dishwashers
Polymethyl Methacrylate (PMMA)	Lamps, lighting, small displays (e.g. mobile phones)
Nylon (PA)	Lighting equipment, small household appliances Switches, relays, transformer parts, connectors, gear, motor basis, etc.
PolyOxyMethylene (POM)	Gears, pinions
PolyVinylChoride (PVC)	Cable coating, cable ducts, plugs, refrigerator door seals, casings
Polyethylene (PE)	Cable insulation and sheathing
Unsaturated Polysterene (UP) Polymers	Housing, handles and soles of domestic irons, handles and buttons of grills and pressure cookers
Styrene-acrylonitrile copolymer (SAN)	Outer covers, e.g. printers, calculators, instruments and lamps. Other applications include scales, battery housings, winding cores, writing and drawing equipment and cylindrical impellers for air-conditioners.
Epoxy Resin (EP) Polymers	Printed circuit boards

Whilst overall plastics in EEE are calculated to be around 25% by weight, this varies depending on the type of EEE product figure 3-4, as some such as small household appliances have up to 36% whilst cooling and freezing appliances only have 13% (Accili *et al.,*2019).

Table 3-4 Plastic content of different WEEE categories adapted from (Accili 2021)

Plastic Content of different WEEE categories				
WEEE flow	Cooling & Freezing	Large Household Appliances	TVs& monitors	Small Household Appliances
Plastic content by weight (%)	**12.98**	**14.05**	**16.42**	**36.40**

The plastic composition of the different categories of WEEE will have an impact on how much plastics can be recovered from each type of category, and understanding this composition can be used to calculate the untapped potential. Specific products such as small household appliances with high percentages of plastics, can then be targeted to increase the quantities of specific polymers recovered from PCR plastics from WEEE (Accili, 2021). The categories are slightly different from the general EU WEEE categories as they were obtained empirically during the PolyCE project according to the Italian denomination (Accili *et al.,*2019).

The availability of post-consumer recyclate (PCR) plastic from WEEE will directly correlate with the amount of WEEE collected and the types of WEEE collected. Figure 3-5 shows that large household appliances account for the largest percentage by weight of EEE put on the market this across all EU countries at 51.8%, followed by consumer equipment at 14.8%, and IT and telecommunication equipment 14.6%, and small household appliances at 10.2% (Eurostat, 2022).

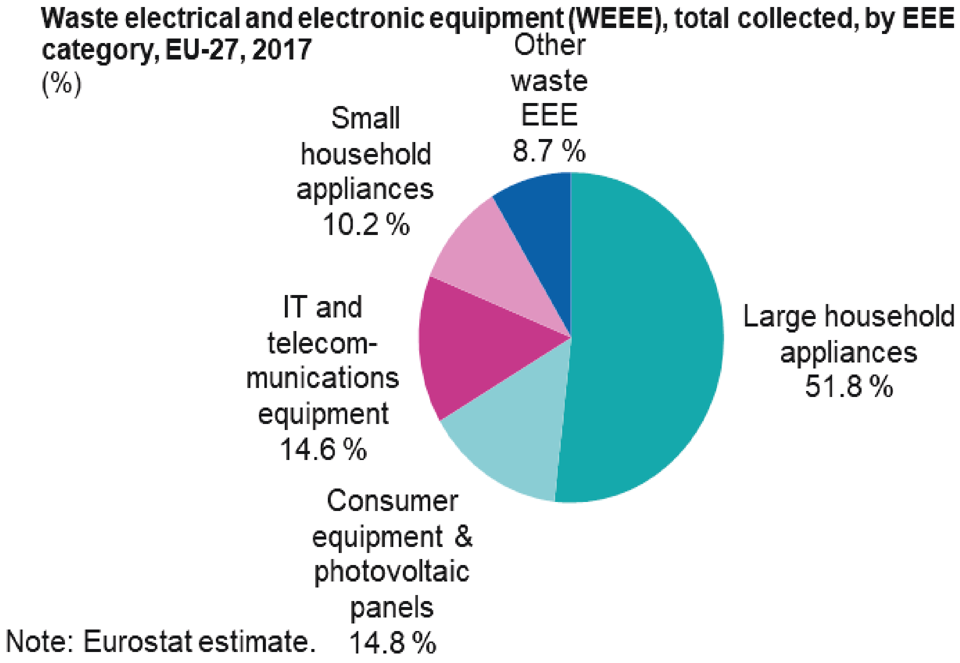

Figure 3-4 Electrical and Electronic Equipment collected by EEE category, 2017 (Source: Eurostat 2022)

Plastic convertors and manufacturers can face challenges in sourcing quality post-consumer recyclate (PCR) due to the complex mix of polymers and additives (Berwald *et al.*, 2021). To increase the recovery of these WEEE plastics and avoid them being incinerated or downcycled, new approaches in the design need to be adopted, as design decisions will impact the recyclability of plastics at end of life.

Chapter Summary

This chapter has investigated how and why EEE and consequently WEEE are growing. The composition of EEE and WEEE has been analysed at both a product and plastics level, as understanding the flows of materials will help organisations to design better. legislation in the EU has been examined to understand how it has developed in order to both mitigate environmental impacts, and aim to recapture the material, thus acting as a driver for circular economy in Europe. The composition of EEE and WEEE has been analysed at both a product and plastics level, as understanding the flows of materials assist when developing CE strategies and CEBMs. The literature has highlighted the need to investigate how production and consumption of EEE can be developed in a more sustainable way through transitioning to a circular economy system (Bocken, *et al*., 2016; Meloni *et al.*, 2018). A holistic approach to delivering circular business models for the electrical and electronic equipment has the potential to maximise resources and deliver a more effective solution to the wider sustainability of the EEE sector (Ellen MacArthur Foundation, 2012; Schulte, 2013; Preston, 2012). The different circular business models that could be used are discussed in the next chapter.

Chapter 4 Circular Business Models

4.1 Introduction to Business Models

New types of business models in general, have risen in prominence with the development of online businesses and emerging knowledge economy (Osterwalder and Pigneur, 2010; Teece, 2010). Business models can provide unique value proposition to execute a particular strategy (Casadesus-Masanell and Ricart, 2010) Circular economy business models (CEBM) could therefore be utilised to drive and implement company sustainability and circular strategies (Bocken, *et al.*, 2016; Ellen MacArthur Foundation, 2012; OECD, 2019).

4.1.1 Business model concept

The business model concept considers four main elements: value proposition, value chain, revenue model and customer interface as shown in figure 4.1 (Boons and Lüdeke-Freund, 2013; Gassmann *et al.*, 2013; Teece, 2018). This could include sustainable and circular innovations (Boons *et al.*, 2013).

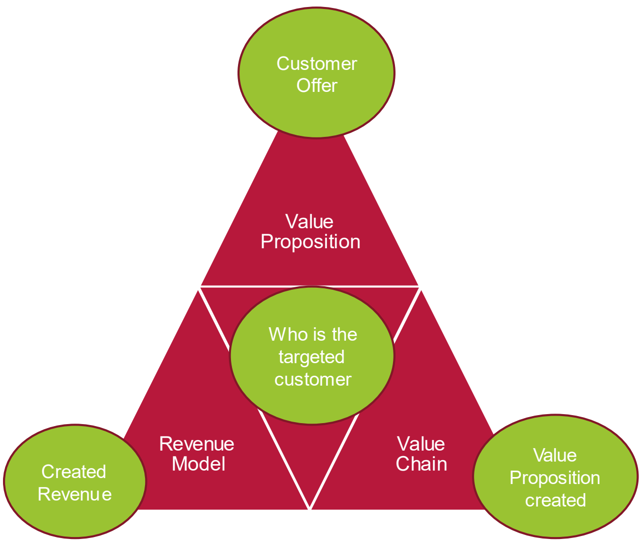

Figure 4-1 Considerations when developing a business model. (Adapted from: Gassmann *et al.*, 2013).

The value proposition is the product or service for the customer (Teece, 2018) which needs to be accompanied by a profit formula of key resources and processes which describe how that value will be delivered to the customer and the company (Johnson, *et al.*,2008). In sustainable business models, there are the additional stakeholders of environment and stakeholders and the value proposition to these stakeholders needs to be considered, circular economy business models provide a mechanism for developing this value proposition (Bocken, *et al.*, 2016)

Changing a business model involves changing the paradigm in which it goes to market, its sustainability is determined the business environment, or context that the company operates in, which provides the basis for a company's strategic position (Teece, 2010; ,Johnson, G. *et al.*, 2020).The business model concept provides a view of the logic a company has for creating and commercialising value (Osterwalder & Pigneur 2005). The different layers that show the context and environment that a business operates in are shown in Figure 4.2.

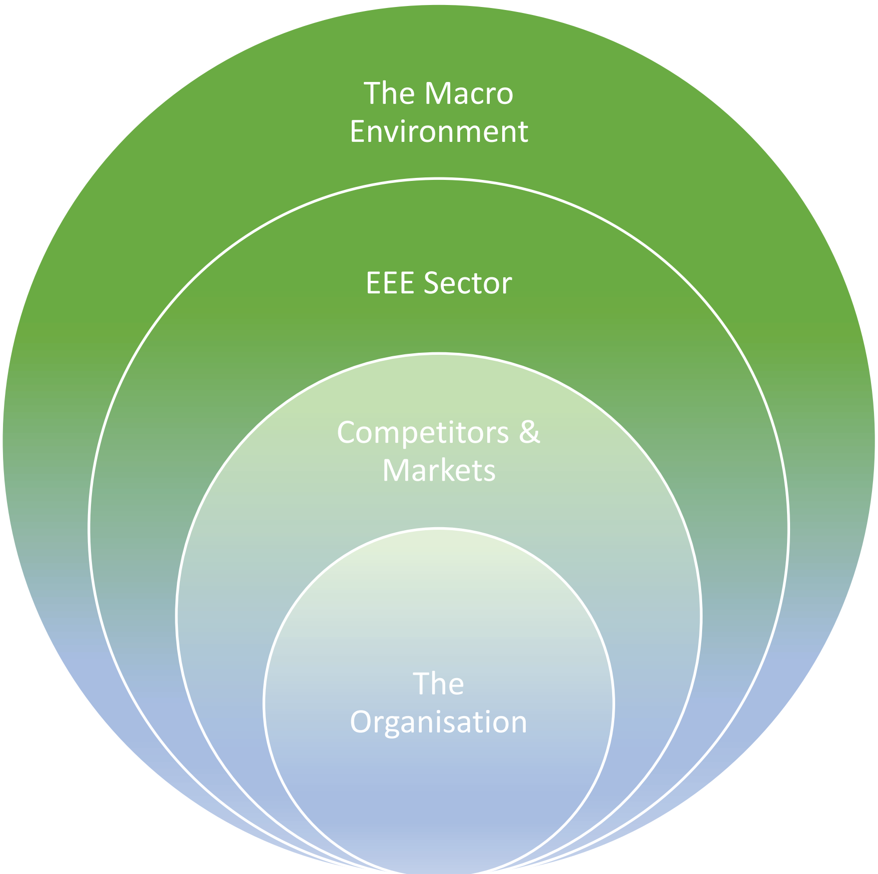

Figure 4-2 The different layers of an organisation's environment. (Adapted from Johnson, G *et al.*,2011)

Macro- environments include all the external aspects that influence a company's strategic position such as political, economic, social, technological, environmental, and legal (PESTEL). Often a business strategy will remain the same but the way in which it is delivered *i.e.*, the business model can be flexible to enable the business to adapt quickly to a changing environment (Teece 2010).

A company needs a good commercialisation strategy to be successful and to realise competitive advantage, business models therefore need to prove themselves through strategy analysis (Teece 2010).

> *"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*." (Teece 2010)

Good business design enables companies to benefit from technological innovation; innovative business model design can help translate technical success to commercial success. For example, with the iPod in 2008, Apple took a good technology that already existed and wrapped it in a great business model, now they are looking at how they develop that business model to reduce its environmental impact and make their products more sustainable. (Johnson *et al.*, 2008; Apple, 2022). Recent studies argue that the business model is of equal, if not greater, importance to society and business enterprise as technological innovation (Chesbrough, 2010, Teece, 2010).

Porter (2008) encourages organisations when developing a business strategy, to examine the forces at work in the wider business environment, in this case the EEE sector. Understanding the impact of Porters five force on developing strategies that include CEBMs, will enable businesses to develop strategies for the most appropriate business models. Brandenburger and Nalebuff (2021) make the case that a sixth force, "complements" should be added to the model, these are firms that are providers of complementary products or services, in the EEE sector an example would be complementary software. Porter (2008) argued that complements should be viewed through the lens of the five forces. Isabelle *et al.,* (2020) make the case that the threat of digitalisation is also a potential force that should be augmented to Porters five forces as they argue that the better digitalised an industry is, true of the EEE industry the fiercer the competition. Innovation is also identified as an important force impacting on competitive advantage, CEBMs have the potential to disrupt existing markets (Bruijl and Gerard, 2018; Isabelle *et al.*, 2020) These additional forces have been included in figure 4.2, however whilst these are important, it could be argued that all of these could be viewed through the lens of the existing five forces. In Porters model new entrants adopting eco-design principals will be less susceptible to resource price fluctuations. The use of innovative materials in products, new ways of providing services such as CEBMs reduce the threat of substitute products (Porter 2008).

Maintaining control of material flows and adopting models such as leasing will potentially shield companies from the bargaining power of buyers as they form longer-term contracts, (Johnson *et al.,*2008). Therefore, circular economy should be playing a major role in management strategy (Porter and Van der Linde, 1995).

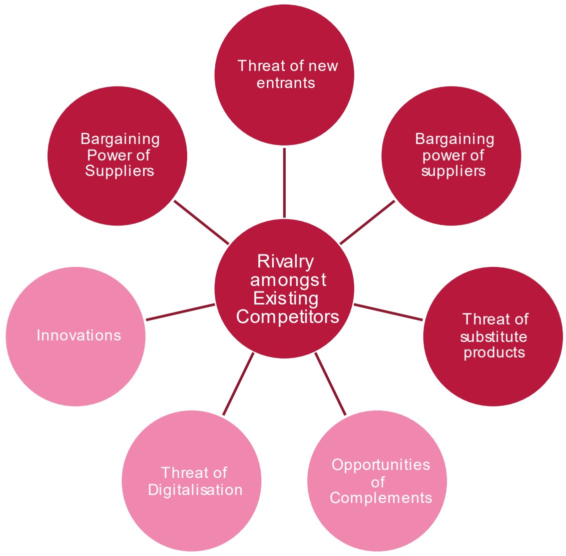

Figure 4.2: The five competitive forces that shape strategy plus the addition of complements, digitalisation and innovation. (Adapted from Porter 2008).

New business models expand the boundaries beyond the direct control of the company, requiring not just closer interactions and effective communications and liaison between the different units of the business such as production, marketing and finance, but also engagement with partners and customers (Chesbrough, 2010; Boons and Lüdeke-Freund, 2013; Osterwalder and Pigneur, 2010). Existing organisations will need to maintain performance using their existing models whilst rolling out pilots of the new model, this will be a delicate balancing act requiring a strong organisational culture. Emergent business model opportunities lack the wealth of data that exists for conventional models and only through testing and analysis will new data be generated (Chesbrough, 2010). Figure 4.3 shows all the nine blocks needed to be considered by businesses looking at new business models, this business model canvas is widely used when developing CEBMs. (Osterwalder 2010).

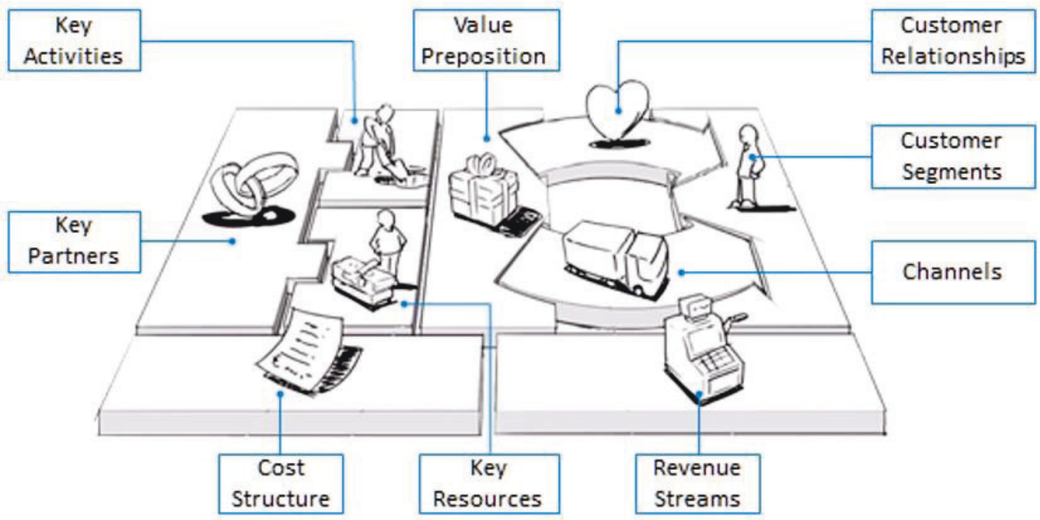

Figure 4-3 9 Blocks of Business Model Canvas (Source: Osterwalder 2010).

Business models need to be tailored to meet customer requirements; therefore, a company's capabilities matter; otherwise, the consequence is an inferior implementation of the process (Johnson *et al*.2008). To enable business model change to happen there will be a need to identify internal leaders that can drive forward that change. Business model innovation is needed to realise the design value invested in the design stage (Penderville 2014).

4.1.2 Circular economy business model's concept

A circular economy business model (CEBM) is not a new concept, recycling, repair and reuse and product leasing have existed for years; however, these models are growing in sophistication and diversity (OECD, 2019c). Circular business models ultimately aim to adopt an alternative approach to the value proposition (Teece 2010). CEBMs provide an opportunity to manage the flow of materials more effectively, allow greater retention of materials along value chains, thus reducing the demand for resource extraction (OECD, 2019 a, DEFRA, 2012; Bocken *et al.*, 2016). The potential effectiveness of circular business models in delivering the circular economy is recognised by the EU and the Circular Economy package was launched in December 2015 (EU 2015). EASAC (2016) identifies those linkages exist between the circular economy, human well-being, and sustainable economic development.

CEBMs must be financially viable, irrespective of how good they are ecologically and socially. A report commissioned by the Ellen Macarthur Foundation predicts that adoption of circular economy could deliver potential benefits of €1.8 trillion p.a. globally by 2030 (Schulze, 2016a). To achieve these economic benefits, scale up of the adoption of CEBMs as part of overall business strategy, within the EEE sector is needed. Those companies that have implemented circular economy-based strategies are not only gaining an immediate competitive cost advantage over competitors, but these companies are also in the longer term reducing future supply chain sourcing and costs risks (Wisetek 2017).

To deliver a good CEBM, there is a need to identify the key resources and processes to deliver the value proposition to the customer (Johnson 2008). Those businesses operating in the circular economy should create value for both the environment and customer (Bocken *et al.*, 2021; Bocken, *et al.*, 2016; Ellen MacArthur Foundation, 2012).

A holistic approach to delivering circular business models for the electrical and electronic equipment has the potential to maximise resources and deliver a more effective solution to the wider sustainability of the sector (Meloni *et al.*, 2018).

4.1.2.1 Designing for CEBMs

Circular economy and eco-design are intrinsically linked as eco-design brings about efficiencies in improvements to materials selection, standardisation or modularisation of components and design for disassembly (Lofthouse and Prendeville, 2018). For a brand owner the design of a CEBM must be desirable, i.e., make people want to utilise their product, it must be economically and practically feasible and be easy to deliver to the customer (Lofthouse and Prendeville, 2018).

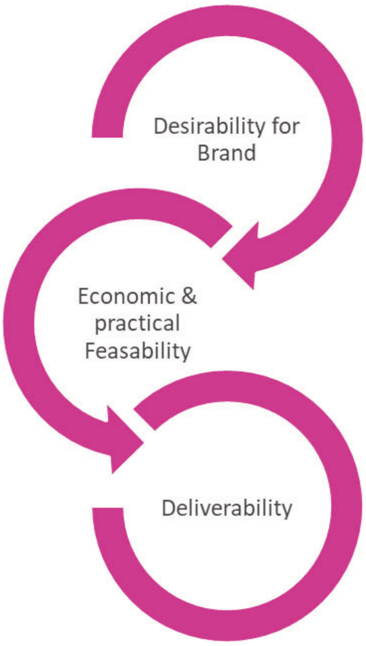

Figure 4-4 Design thinking. (Adapted from IDEOU 2022).

4.2 Circular Economy Business Model Strategies and Types

In recent literature four strategies have been developed to make effective use of resources and tackle the environmental impact of production through reduction of emissions and water consumption. These are outlined in figure 4.3 and look at how resource loops can be slowed, narrowed, closed and ultimately regenerate resources (Bocken, *et al.*, 2021; Bocken, *et al.*, 2016; Geissdoerfer *et al.*, 2017; Konietzko *et al.*, 2020).

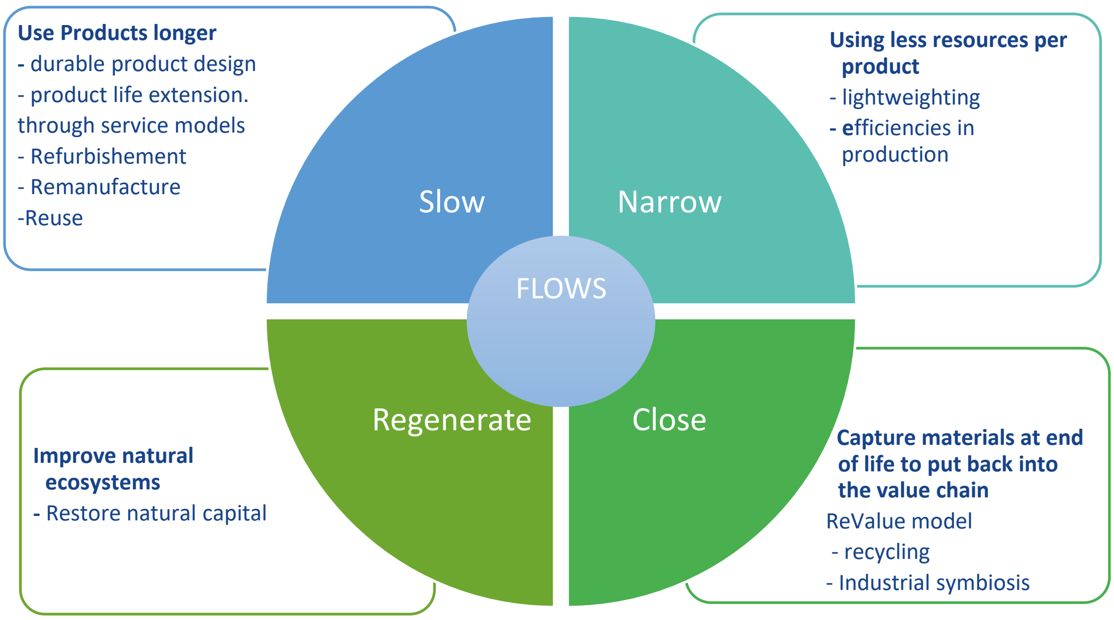

Figure 4-5 Business Model Strategies. (Adapted from: Bocken *et al.*, 2016).

4.2.1 Slowing Material Flow Circular Economy Business Models

Slowing material flows is about keeping materials in use for longer, it can refer to products components or materials, this includes CEBMs such as product service, refurbishment, reuse repair and remanufacture (Konietzko *et al.*, 2020; Bocken, *et al.,*2021; Mont and Tukker, 2006; Stahel, 2016). These types CEBMs are described in more detail below.

4.2.1.1 Product Service System (PSS)/Functional Service Economy

Product service system models are a CEBM have potential to reduce the use of resources whilst still offering the function of the product (Lingegård, 2020). Walter Stahel (Stahel, 2010) was one of the pioneers in developing the concept of a performance economy in the 1980s; promoting the move from an industrial economy to a functional service economy, conserving resources through CEBMs that focus on performance of goods and services (Stahel, 2010). From an intensive literature review by Bohem and Thomas (2013) the following general definition of a product service system type CEBM was given:

> *'A Product-Service System (PSS) is an integrated bundle of products and services which aims at creating customer utility and generating value.'* (Boehm and Thomas, 2013)

In a different literature review product service systems were split into three main types as seen in Table 4-1, product-oriented PSS remains a linear approach (Tukker, 2015).

Table 4-1 Types of PSS adapted from Tukker (2015)

Type of PSS	Description
Product oriented PSS.	Focused on selling products but some additional services are added, e.g. in form of after sales services.
Use oriented PSS	Ownership of the product remains with the provider but is made availability to one or more users. Products can be leased, rented, pooled or shared.
Result oriented PSS.	The provider and client agree on a result/capability and no pre-determined product is involved. This is the most circular and resource efficient business model.

Product Oriented PSS.

Product oriented PSS is most like a conventional business model in that it seeks to maximise products sold (Tukker 2015). This includes longer life or durable products complemented by maintenance contracts, advice and consultancy (ibid). Production can be managed to minimise material requirements and avoid potential losses from over-stocking products. The HP Instant Ink model where consumers buy a printer and then have a subscription for ink based on the pages they used, resulting in a longer life for the printer is good example of this, (Strandberg 2017).

Use orientated PSS.

Product Leasing or renting

Innovative service orientated product leasing business models can be used as an alternative method of fulfilling customer needs, rather than the traditional purchasing/ownership route (Bocken *et al.*, 2018). In a leasing model, the ownership of a consumer good remains in hands of a company offering the product as a rental or subscription service and the consumer returns the product after its paid use (Atasu *et al.*, 2021). Product renting can be defined as "*sequential use by different users.*" (Tukker, 2015). Access to product use is more important than owning the product. Thereby the utilisation factor of a product is maximised, as the resources inherent in an electronic product are being used more efficiently (Atasu *et al.*, 2021). Maintenance remains in the company´s hands, who will ensure that their products are easily maintained and can thus be accessed for a long period of time and prolonging an end of life (Maitre-Ekern and Dalhammar, 2019).

Hilti Fleet Management (Hilti 2023) is a good example of a B2B version of this model. Hilti provide high quality construction tools. They saw an opportunity 10 years ago to sell tool use rather than the tool itself, as contractors using their tools make money through using the tools as efficiently as possible rather than owning them. For a fixed monthly fee customers can access all the tools they need, Hilti provides work with the customer to choose the tools they need to limit tool redundancy. With over 100,000 customers the company has shifted its focus from manufacturing and distribution to service, developing a new profit formula, new resources and new processes.

As there is less income for retailers from leasing products than direct sales, this needs to be supplemented by attracting new customers providing opportunities for new sales (Mont *et al*., 2006).

Retailers, manufacturers and consumers can work together to share value, by use of retailers to administrate a leasing model, Figure 4.6 demonstrates how this could be done (Mont 2008). There is a need to provide a bundle of complementary products which will create value for the customer allowing the manufacturer and retailer to capture value.

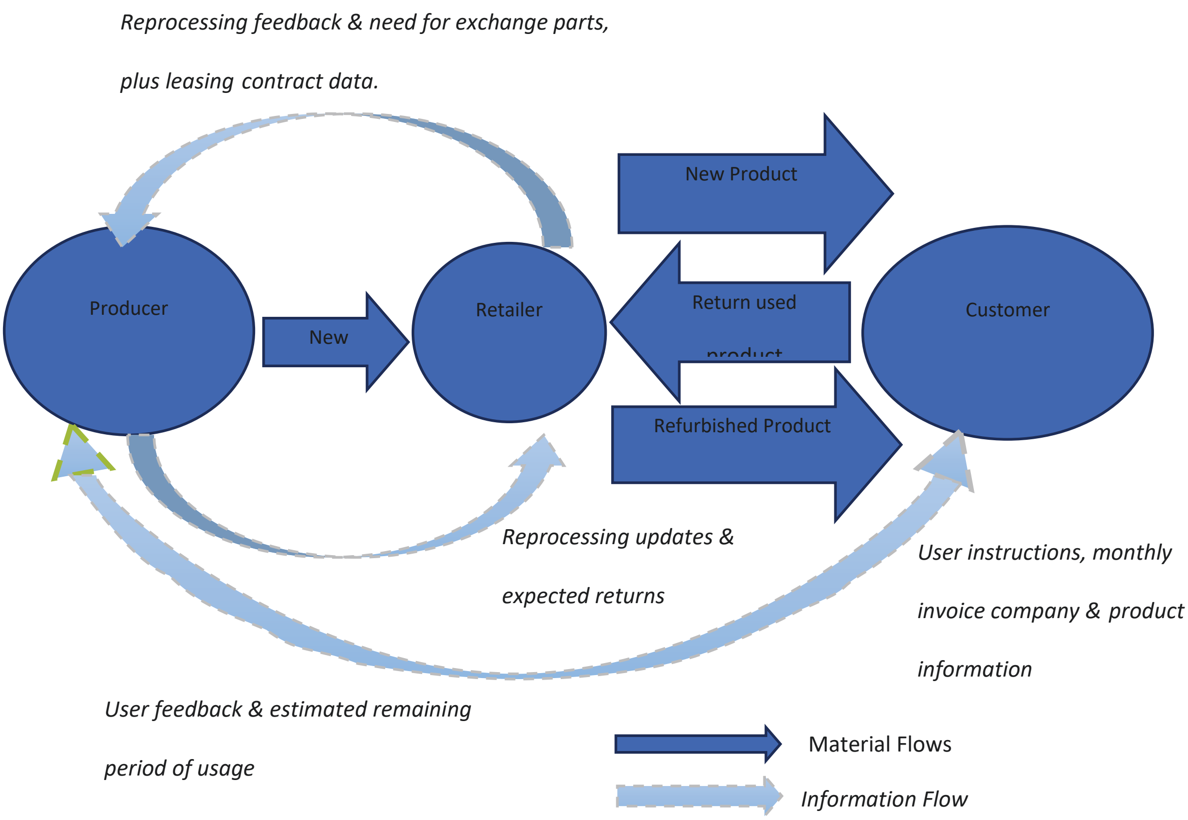

Figure 4-6 Service Model. (Adapted from Mont 2006)

Product pooling/Collaborative Consumption

Product pooling is defined as simultaneous use of the same products, such as tool libraries (Tukker 2013) an example of this is Benthyg in Wales (Benthyg 2023), who operate a network of Library of Things where you can borrow items such as DIY and gardening tools. It can be referred to as a sharing platform where goods can be used between businesses or peer-to-peer (Habibi *et al.*, 2017). Collaborative consumption is rapidly growing business model with businesses such as BlaBla Car, facilitating ridesharing and AirBnB, facilitating renting out spare space, capitalising on providing sharing systems (Curtis and Mont, 2020; Sundararajan, 2013).

Result Oriented PSS

In a result orientated service model, the focus lies on the benefits of an electrical good rather than to the material attribute of the product, consumer is interested in the service that is obtained from the product rather than the product itself (Tukker, 2015) . The service which is provided by an electronic product is fully delegated to a company who is providing a desired performance (Bakker *et al.*, 2014). From a material resource aspect, the electrical or electronic product remains in the hands of producers or service providers, who have access to maintaining and servicing the machines/devices. The service provider is also in full control of the material flows and the product status. This type of business model is likely to favour energy efficient devices as well as long lasting high-quality devices.

Signify, deliver a turnkey approach to lighting known as circular lighting ((Signify, 2023)), their managed services include everything from design and build to operation and maintenance of lighting systems). Customers choose to simply buy the light they use, instead of owning the equipment. Typically, a new lighting system has an average of 10 years lifetime, then for either technical or economic reasons users might want to change it. A product service combination, which is very agile, can postpone this to 20 years basically maintaining value into the system, The Pay per Lux model doesn't so much focus on an input model where economic value is brought into the economy, it's much more about how much economic value is maintained in the economy. Initially starting as pilot projects, the lighting managed services model is gaining widespread acceptance with applications including lighting for car parks, airports, offices and power plants (Signify, 2023).

4.2.1.2 Remanufacturing, Refurbishment and Reuse

Remanufactured, refurbished or reuse is a way of prolonging the lifetime of a product by giving it a second life. For effective re-manufacture, refurbishment and reuse the products need to be designed specifically designed for disassembly, remanufacture and re-use (Prendeville *et al.*, 2014). Designing with refurbishment or remanufacture in mind requires integrated thinking between designers, engineers, disassemblers and finance units of a business (Chesbrough 2010). Often remanufacture or refurbishment is included as of the product service model which requires reverse flow logistics. If the company already offer the products as a PSS then the infrastructure is in place and this is easier to achieve, for example BT a UK telecommunications company, refurbished 43% of returned home hubs and set top boxes in 2022 (BT 2023).

Reuse systems encourage the use of products for a second life, examples of this include carpets, textiles, electrical goods and furniture often using third sector organisations (Sinha *et al.*,2013). Materials for re-use are often collected by third parties (Ayres et al 1997) requiring collaboration.

Reuse and repair of EEE provides opportunities for retaining the value of products and component parts, particularly for items with a short lifecycle such as mobile phones. With technological advances in EEE, the lifetime of products is being as reduced as customers replace more items frequently to take advantage of the technological improvements (Babbitt et al., 2009).

Remanufacturing

Remanufacturing is the process of recovering, disassembling, repairing and sanitizing components for resale at "new product" performance, quality and specifications. Remanufactured products or parts should be considered "like new" (European Commission 2020). The key difference with remanufactured devices is the rigour, standardisation and completeness of the process. A remanufactured machine is re-built from individual components to match the same specifications as those of new machines, using a combination of reused, repaired, and new parts (Duberg *et al.*, 2021; Canon, 2022). The whole product or components of the product, "parts harvesting" can be re-manufactured, reducing the quantity of raw materials and preserving the added value of manufacturing (Sundin and Bras 2004; Guidat *et al.,* 2014). Companies adopting re-manufacture such as

Google see this as a win-win situation where they reduce costs by asset recovery and reduce environmental impact (Goggle, 2018).

Refurbishing

Refurbishing is the process of returning a product to good working condition, often these are returned to a manufacturer or vendor for redistribution (Canon 2022). Items suitable for refurbishment can include unwanted new or older items, defective products under warranty, or products needing an update. Components that are faulty or close to failure are replaced or repaired and ‘cosmetic’ changes are made to update the appearance of a product, such as cleaning, changing fabric, painting, or refinishing (Ellen MacArthur Foundation, 2012).

Repair

Items such as mobile phones and some IT equipment are extremely resource-intensive in their manufacture and yet have a short life cycle of around two years, (Yla-Mella 2014). A reuse and repair approach could optimise the use phase of EEE, (Pérez-Belis *et al.*, 2017)extending its life span and achieving greater resource efficiency. EEE items can be returned to a working condition with relatively small interventions (Agrawal *et al.*, 2015)

Whilst there is a growing interest in repair there are many reasons why consumers are still reluctant to repair broken EEE items (Pérez-Belis *et al.*, 2017) . One of the main reasons for lack of repair is the cost and easy availability of new products (Guiltinan, 2009). Often there is an intent to repair but items such as mobile phones are kept and stored in case they are need in future (Yla-Mella, 2015). This means that potentially re-useable EEE is left stored beyond its re-useable life as technological advances and newer models, mean that software may not work. Repair charges are often high relative to the value of the product (Hennies and Stamminger, 2016).

Designing Physically Durable Products.

Consumption of products is reduced by designing in durability and long-life (Jackson 2011).

Eco-design of products can result in an 80% reduction waste (Babbitt, C. W. et al., 2021).

Upgrade and adapt existing products.

Enabling upgradability and adaption often known as a modularity model, prolongs the lifetime of a product through a more modular design. Modular devices are defined as containing modules which are structurally independent elements or sub-assemblies with clearly defined interfaces ((Kashkoush and ElMaraghy, 2017)). By easily replacing, or repairing, parts, or enabling a product upgrade, costumers are motivated to keep using products for longer. The need, or desire, for early purchase of a new, replacement, device before the product has reached its ultimate end-of-life is thereby reduced. Replacing only certain parts of an electronic device is a step towards balancing out the relatively large environmental footprint of the manufacturing process of electronic goods (Nissen et al. 2017).

4.2.2 Narrowing the loops CEBMs.

Narrowing the loops is about innovative design such as utilising low-impact materials or reducing inputs through light weighting of products. (Konietzko *et al.*, 2020). Narrowing the loops can also be about enabling and incentivise users to consume less through CEBMs such as Homie which incentivises users to wash less and at lower temperatures (Lofthouse and Prendeville, 2018; Bocken *et al.*, 2018).

4.2.3 Closing the material flow Circular Economy Business Models –

Closing the loops allows the capture of raw materials at the end of use, when they can be reprocessed and used as alternative to raw material extraction, providing resource and energy savings (Graedel and Allenby 1995, Ayres *et al.,* 1997). Closed loops are predominantly the area where the recycling sector operates and is classed as being in the outer loops of circular economy (Schulze, 2016). Circular economy through closing the loop, represents a solution to the global WEEE problem through recycling of EEE and its components, and through provision of secondary raw materials/components for manufacturing (World Economic Forum, 2014; European Commission, 2020; Pollard *et al.*, 2021; Schwarz *et al.*, 2021).

4.2.3.1 The EEE plastics ReValue model.

The technological development of products and increasing collection targets for WEEE, are pushing the need to develop new business models, seventy percent of plastic reprocessors highlight the need for quality recylate (Polymer Comply,2017; Buekens and Yang, 2014; Cucchiella *et al.,* 2015). Closed loop CEBMs provide a means of exploiting greater value from WEEE presenting economic, social and environmental benefits Maximising the value of WEEE requires suitable recovery processes to be available; product design to accommodate circular practices; and appropriate reverse logistics, business models and legislation to be in place (Pollard *et al.*, 2021).

Fifty nine percent of plastic converters, according to the European plastics convertors (EuPC) industry survey) stated that it is hard to get recycled plastics that meet customer specifications and have all the supporting information needed (Polymer Comply 2017). Plastics recovered for post-consumer recycling (PCR) pose several challenges including managing the end of life (Azzone, 1995).

To drive circular material flows sufficient economic value must be derived from WEEE to cover costs incurred throughout recycling process chains. Collection systems should be designed to reduce contamination by other materials as shown by the Finnish example (Ylä-Mella, Jenni *et al.*, 2014). An important part of making steady supply of recycled polymers viable, is the use of reverse logistics to maximise economic and environmental efficiencies of transporting large volumes of low value goods, (Govindan *et al.*, 2014; Agrawal *et al.,* 2014).

WEEE contains a complex mix of different plastics and materials, including a variety of polymers and additives (Martinho *et al.*, 2012; Cafiero *et al.*, 2021; Mugdal *et al.*, 2011).

Reprocessing plants will need to be able to intercept different mixes of EoL products which will require the development of more flexible plants (Cucchiella *et al.,*2015). There are issues with dismantling the newer more complex WEEE items as they often contain complex mixes of polymers. Better design for dis-assembly of the products and design with materials suitable for primary recycling would help to reduce this challenge (Schwarz *et al.*, 2021; Kumar *et al.*, 2017). To achieve this design for recycling, more collaboration between EEE manufacturers and recovery centres is needed (Cucchiella *et al.*, 2015).

There several WEEE specific challenges identified when recycling plastics including.

- Potential long lifetimes of EEE products, can lead to degradation of the plastics. Degradation can be due to heat exposure during the use phase and exposure to UV during the collection of WEEE. The addition of compounds such as chain extenders can improve recycled ABS properties (Wang *et al.*, 2015).
- Hazardous substances within the plastics such as Brominated Flame Retardants (BFR) also pose a challenge for effective polymer sorting, as they come under Regulation of chemical substances REACH and RoHS and have to be removed or plastics containing them can't be recycled (Wäger, P. A. *et al.*, 2011; Balde *et al.*, 2017).

4.2.4 Regenerating the loops- Circular Economy Business Models

CEBMs such as those adopted by Fairphone look to eliminate non-toxic materials from their products and stimulate ethical supply chains (Fairphone, 2021). Using renewable energy sources such as hydropower or solar to power the production process is a good example of a regeneration loop (Fairphone, 2021; Apple, 2022b).

4.3 Conceptual Framework

The need for data on applied business models is acknowledged by many authors (Chesborough 2011; Johnson 2008). Tukker (2013) identifies a need to better understand the intangible benefits of business models for example customer loyalty, brand value and social value. recommends the study of good working examples as a method of de-mystifying the CE concept. Bocken (2016) also discusses the need for experimentation of CEBMs by industry to test the performance of the theoretical models in practice.

Adoption of CEBMs will be influenced by external factors. The PESTEL framework, is a useful tool for analysing the macro-environments, these are the broad external influences that can impact a business' strategy and success. Understanding these external influences and how they work together is critical in identifying the key external drivers and barriers to change. The key factors considered in the PESTEL analysis are political, economic, social, technological, environmental and legal.

Internally within an organisation, a choice will be made on which types of business model are most appropriate in terms of slowing, narrowing, and closing loops (Konietzko *et al.*, 2020; Bocken *et al.*, 2016). These two elements are combined to develop a conceptual framework to analyse the findings of the research as shown in figure 4.7.

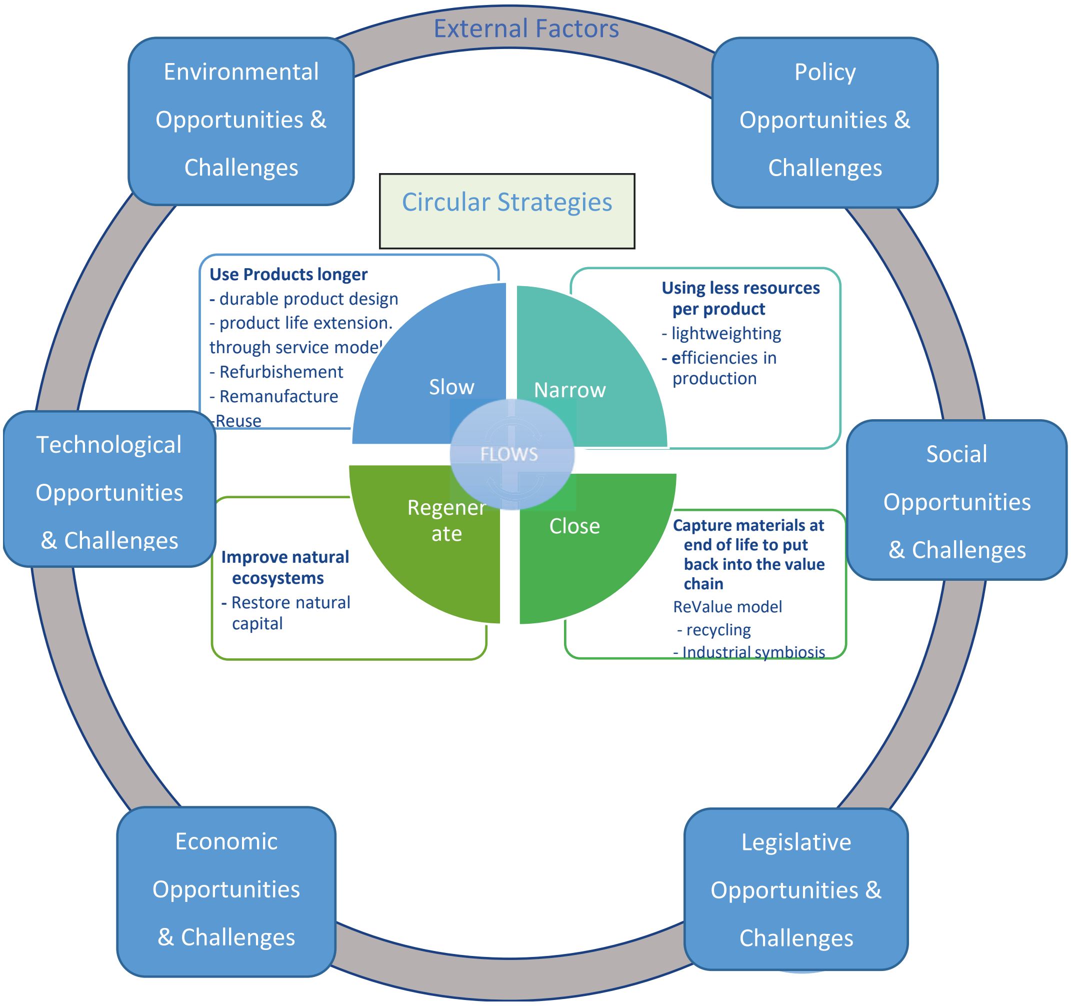

Figure 4-7 Conceptual framework for assessing adoption of CEBMs (adapted from Bocken *et al.*, 2016 and Johnson *et al., 2011).*

Chapter Summary

Chapter 4 has investigated the literature around the development of CEBMs and looked at examples in the literature of how these are being applied, and the opportunities that each CEBM might bring to an organisation adopting CEBMs as part of their business strategy. The literature has demonstrated that CEBMs adopted will depend on the what the customer wants, i.e., the value proposition to the customer and could be dependent on the type of product that the organisations can offer. The conceptual framework developed enables the findings of the research to be looked in terms of external influence and the internal strategies of organisations to slow, narrow, close or regenerate flows of material.

Chapter 5 Methodological Approach and methods

5.1 Introduction

The literature review shows that circular economy business models require adoption of a system-based approach and as such are influenced by both external influences and internal organisation values. Whilst several authors have considered the theoretical viability of circular business models as a method of achieving sustainability goals within business in a generic business sense, the adoption of CEBMs practices in the EEE sector is less understood. The gap in knowledge for the CEBMs in the EEE sector forms the basis for the research objectives outlined below. Much of the work around the outer loops of circular economy such as recycling concentrates on Critical Raw materials and metals as that is where the perceived value in recycling of WEEE is, whereas this research considers the capture and reutilisation of the plastics within WEEE.

5.1.1 Research Objectives and specific research questions

Research Objectives:

1. Critically evaluate and identify key CEBMs being adopted by the EEE sector operating within the EU.
2. Critically evaluate the opportunities to apply different CEBMs within the value chain from representative electrical/electronic product groups and their constituent main plastic components.
3. Analyse the challenges, risks and barriers to adopting Circular Economy business models (CEBM) in the EEE sector operating in the EU.
4. Determine the economic, environmental, and social opportunities to use CEBMs when developing and implementing business strategies within the EEE sector operating within the EU.

In order to achieve the research objectives and aim, the following research questions need to be answered:

I. How are Circular Economy practices and CEBMS being adopted currently within EEE value chain organisations operating within the EU?
II. Where are the potential opportunities to apply new CEBMS in order to retain value of products and materials within the EEE value chain in the EU?
III. How do external factors and internal factors pose challenges and barriers to adoption of CEBMS by the EEE sector in the EU?
IV. How do external and internal factors present opportunities that could be provided by adoption of CEBMs by the EEE sector in the EU?

5.2 Philosophical Approach

The research onion as shown in Figure 5.1 (Saunders *et al.*, 2019) was used as an initial guide to develop the research design and methodology. Understanding the researcher's philosophy and assumptions is critical, as it will affect the research design and determine which types of data the researcher believes will be suitable for answering the research questions (Easterby-Smith *et al.*, 2018; Saunders *et al.*, 2019; Creswell and Creswell, 2017).

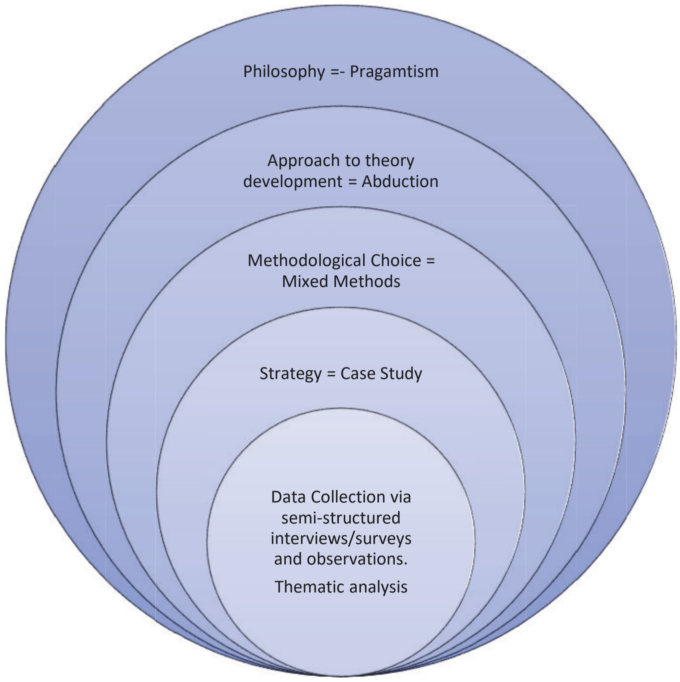

Figure 5-1 Approach to research, based on research onion (adapted from Saunders *et al*., 2019)

Using the research onion enabled the adoption of a systematic approach in developing the design of the research, indicating the different methodological issues that must be considered – from the researchers epistemological and ontological approaches taken, to determination of the types of data collection methods employed (Saunders *et al*.,2019). Working from the outside of the onion the philosophical basis of the research is concerned with the worldview assumptions and perspectives of the researcher which will influence data collection and data analysis (Crotty 1998). The worldview assumptions can be split into ontology which considers the basic assumptions that the researcher makes about the nature of reality, and epistemology which is about the assumptions the researcher makes about the best ways of inquiring about the world (Cresswell and Cresswell 2015; Easterby-Smith *et al*., 2015; Saunders *et al*.,2019).

5.2.1 Ontological position taken by the researcher.

Ontological assumption are the personal assumptions the researcher makes about the world and the nature of reality and will determine how the researcher sees what they are researching (Crotty 1998). As the researcher has worked in area of circular economy and sustainability for several years, then assumptions are made based on this experience which influences the research design approach (Saunders *et al*.,2019). The experience of the researcher impacts on the theoretical framework and the types of data that are examined and considered (Johnson, P. and Clark, 2006). The ontological approach taken by the researcher was that reality for organisations in the EEE value chain is complex and rich, influenced by both external factors such as legislation and policy and by internal factors such as company culture, structure and consumers of their products and services.

5.2.2 Epistemological position of the researcher

The epistemological approach is about what the researcher counts as valid legitimate and acceptable knowledge and will influence and impact on data types collected and how findings are communicated (Johnson, P. and Clark, 2006). Epistemological assumptions of the researcher are that knowledge is specific to context that it is generated. Theories and knowledge developed should be able to be acted upon, by focusing on problem solving and contributing to informing future practice.

5.2.3 Axiological position of the researcher

The axiological position looks at the role of values and ethics in the research process and determines how personally involved the researcher is in the research process (Saunders *et al*.,2019). The researcher because of prior experience in the field initiated the research due to their own beliefs in the circular economy and brought their own values to the research.

5.2.4 Philosophical approach taken.

From looking at the ontological, epistemological, and axiological assumptions of the researcher the philosophical approach to be taken aligns most closely with **pragmatism** (Saunders *et al*.,2019).

5.3 Approach to theory and knowledge

Circular economy and resource efficient business models can be looked at from many angles depending on what is being researched. This research builds on the knowledge from the PolyCE project which concentrated on the recycling business model, by further analysing the implementation of circular business models and the factors that influence their uptake and success by exploring beyond the published literature and gaining greater detail through direct communication with those involved.

The purpose of this research is to understand why and how different CEBMs identified in the literature, such as product service, refurbishment and recycling models, are adopted by organisations. As circular economy is a complex rapidly changing field of study, the research therefore aims to elaborate on theory as a result of data analysis of the case study of the EEE sector in the EU, leading to the adoption of an abductive approach as shown in figure 5.2 (Costa *et al.*, 2016; Ketokivi and Choi, 2014; Saunders *et al.*, 2019).

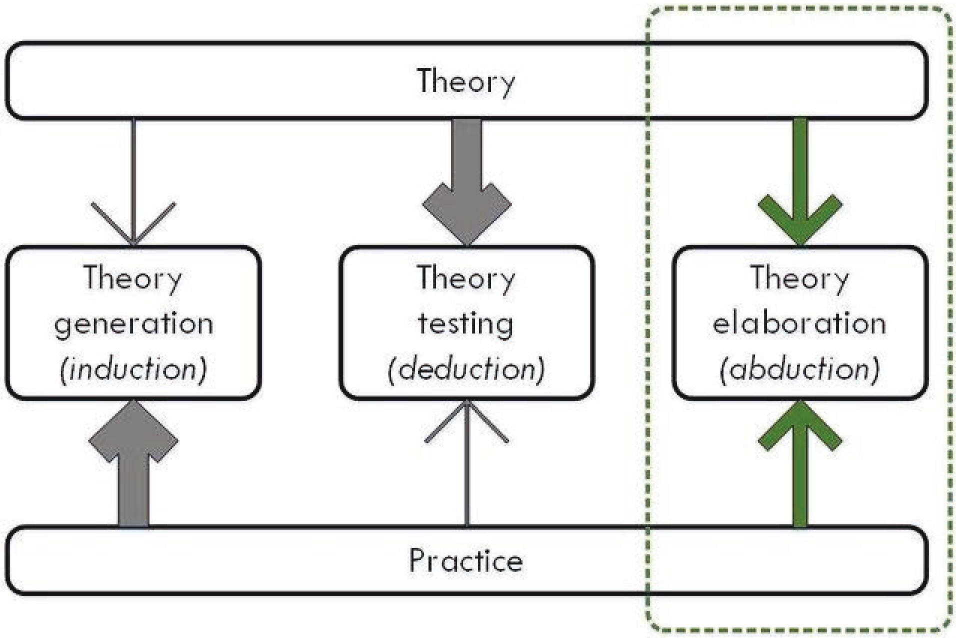

Figure 5-2 Three methodological approaches to case study research (Source: Costa *et al.*, 2016)

Using an abductive approach enables a study of the context in which these models are applied which is critical as there are many different influences and reasons why they have happened.

5.4 Research Strategy - A Case Study approach

> *"The research design is defined as the logical sequence that connects the empirical data to a studies initial research questions and conclusions" (Yin 2018).*

In taking a pragmatism approach the case study strategy provided the best methodology as it provides a detailed examination of a specific subject, in this case the EEE sector within the EU. There is little or no control over behavioural events, therefore the case study approach taken, provided an appropriate research method by allowing the researcher to study the EEE sector under real world conditions (Yin, Robert K., 2018).

Using a case study approach produces context dependant knowledge, which is at the heart of developing expertise (Flyvbjerg 2006). Case studies can connect concrete details with the theory, allowing an expansion of this theory so suitable for an abductive approach. By incorporating new concepts and ideas that emerge from the research, existing theory can be built on (Gomm *et al.,* 2000). Case study research can be used across a wide range of disciplines to examine in-depth, diverse issues, this offers a rich picture of the EEE sector with many insights from different angles. (Harrison *et al.*, 2017; Gomm *et al.*, 2000).

Within the literature there are several different philosophical variations to the case study approach that have developed over time in different disciplines (Harrison *et al*.,2017). Common to all approaches is that the case study is a mechanism by which to explore and understand primarily the how and why type of research question, that it should be contemporary and that is a detailed, bounded unit of analysis (Merriam, 2002; Stake, 1995; Yin, Robert K., 2018).

The case studied, is an in-depth evaluation of the EEE sector, using the EEE value chain as the unit of analysis. The case study pinpoints enablers and challenges with the different actors in the value chain, these are divided into stakeholder groups as each section of the value chain will have different internal and external factors which influence them.

The literature review demonstrates that there is a large body of work looking at the advantages of circular economy and circular economy business models and a lot of discussion on the theoretical value of the circular economy. The literature review was used to define the research questions and objectives by developing sharper and more insightful questions (Yin 2018). The research objectives are about exploring the why and how organisations have or haven't adopted circular approaches and as such needs to frame the research questions in the real-world context using EEE sector within the EU as a case study. The focus of the study is contemporary, investigating the phenomenon of adoption of circular economy within the real-world context of the EEE value chain as opposed to a hypothetical or laboratory setting. This allowed the capture of perspectives of the main actors in the value chain by focusing on understanding individual knowledge and experience within the different organisations.

This research is bounded by the value chain of EEE sector within the EU. The case study approach offers the opportunity to study the whole system as operations of each organisation are intertwined and changes will impact on the whole value chain, behaviour occurs in the context of others activity (Thomas 2015).

The aim will be to understand and interpret how internal and external factors can be used to encourage additional businesses to adopt a circular economy approach. Commonalities, similarities and differences in the various stakeholder views will be explored to understand, i.e., what is motivating the actions of the stakeholders (Saunders *et al* 2009), to enable understanding of those actions.

Semi-structured interviews were identified as the main primary data collection method. New insights could be gained into what types of models' participants have adopted and why, by allowing the interviewee to talk around the subject (Seidman, 2012).

5.5 Methods

The overall methods used to design and analyse the data followed the cyclical pattern (Yin, Robert K., 2018) as shown in figure 5.3. The cyclical pattern was useful in adopting the abductive approach as allows for iterative learning during the data collection process, the researcher can move backwards and forwards throughout the process.

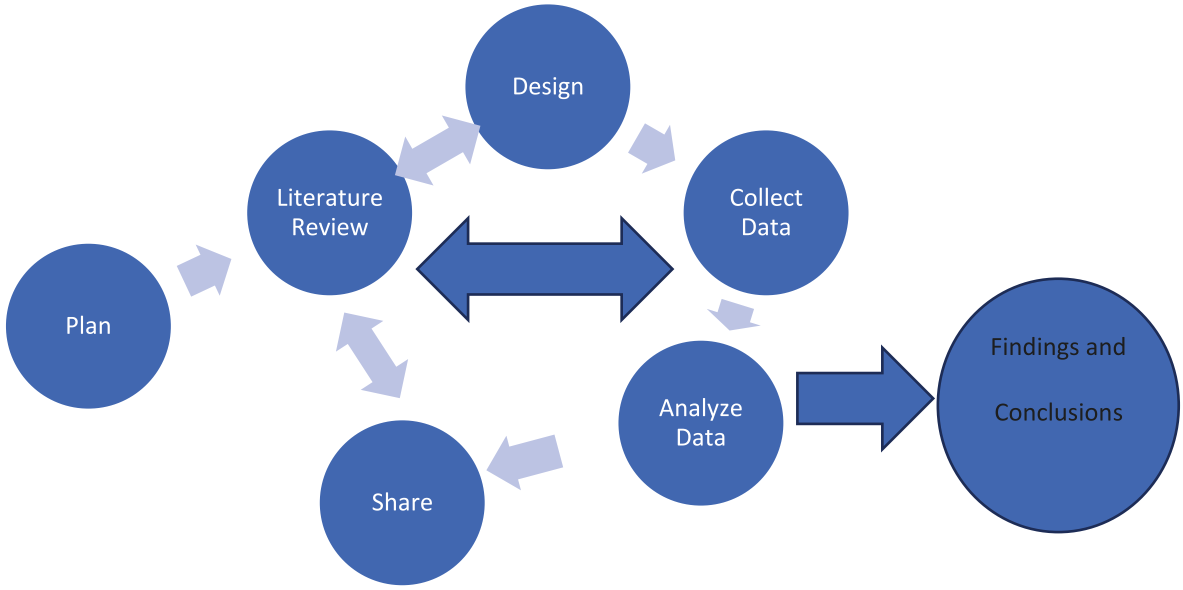

Figure 5-3 Phases of the research (adapted from Yin, 2018)

5.5.1 Participant Selection

An important consideration for this study was to capture the perspectives of the different stakeholders in the EEE value chain and the context in which they were situated. From the researcher's prior experience in this field, they were aware that by using companies drawn from across the EEE value chain, the depth and breadth of the data required to establish the research objectives could be achieved. A judgement sample or purposeful self- selection approach, defined as the researcher actively selecting the most productive sample to answer the research question and choosing a representative sample was adopted (Lucas, 2014). The researcher wanted to engage with specific businesses adopting or looking to adopt circular economy approach within the EEE value chain. As OEMs are the main group of businesses that adopted different CEBMs for different products they were targeted. To identify and select the organisations to be sampled the researcher was informed by the PolyCE project, recommendations from peers and information gained from the literature review. The requirement for selection being that the participants had the potential to be particularly informative for different parts of the value chain and were influencing the adoption of a variety of CEBMs as shown in figure 5.4.

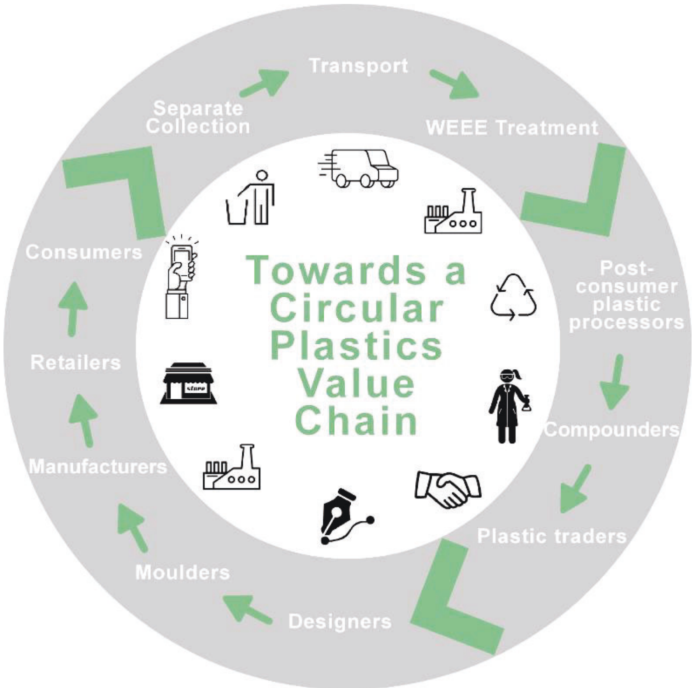

Figure 5-4 EEE value chain (courtesy of PolyCE project)

In addition, participants were selected to represent a range of different business models being adopted. Initial interviewees provided details of other potential interviewees a process known as snowballing often these recommended interviewees had different characteristics and experiences such as adopting different business model approaches. Snowballing is defined as the non-random process of identifying participants for research on the suggestion of other participants, thus identifying other cases (Easterby-Smith *et al.*, 2015; Saunders *et al.*, 2019).

5.5.2 Data collection

In adopting a case study approach for the research, the aim is to develop a rich picture of the EEE sector being studied from different perspectives. To achieve a rich picture several methods of data collection were adopted. Primary data was collected through stakeholder surveys, interviews, and participant observations via the PolyCE project progress (e.g., site visits, meetings, and project deliverables). Secondary data consisted of publicly available data such as websites and corporate documents (e.g., policy papers, marketing documents and presentations).

5.5.3 Stakeholder Surveys

Two stakeholder surveys were conducted during the research which can be found in annexes B and C. An initial stakeholder survey on circular practices targeting EEE sector organisations (Annex B) was developed using “SurveyMonkey” as it was thought that most participants would be familiar with this platform, and it is easy for them to use, and results are presented in a format that supports analysis. This structure of the survey was developed with the PolyCE team so that it could be used both for this PhD study and for the PolyCE project. The survey was designed to take 10-15 minutes. The survey identified both current practice and future ambitions of organisations within the EEE sector in relation to CEBMs and aimed to develop a clear view of current supply chains, challenges, and barriers. Following completion of the survey participants indicated their willingness to take part in a semi structured interview. Closed questions were used to make the surveys quick and easy to complete, this was felt to be acceptable as more detail would be obtained in interviews. The survey opened on the 8th February 2018 and closed 21st May 2018 and received a total of 62 responses.

A further stakeholder study was conducted by a PolyCE partner organisation with input from the PhD researcher. This survey was distributed in a similar manner to the first and aimed to get the consumer perspective of circular economy this survey is included in Annex C. The aim was to provide insight into consumer adoption levels of different new and disrupting consumer practices. The survey also aimed to provide an insight into consumer perspectives on the benefits and risks of adopting circular consumption models. The survey opened in June 2018 and was closed in 2020. It was translated into different languages to encourage participation, 150 individuals participated.

The links to the surveys was put on the PolyCE website. A standard tweet was agreed by consortium members and was shared on social media. In addition, an agreed email was circulated by consortium members to contacts including trade associations such as Plastics Europe and European NGO EEB.

5.5.4 Semi-Structured Interviews

Semi-structured interviews were identified as the main primary data collection method. New insights could be gained into what types of models' participants have adopted and why, by allowing the interviewee to talk around the subject (Seidman, 2012). Questions posed during the interview needed to be open and to be flexible enough to allow for a detailed discussion. Schedule questions, which can be found in Annex A, were designed as a mixture of shorter and longer open-ended questions to get rich detailed data (Bryman and Bell, 2011). The semi-structured interview schedule was developed to allow the flexibility to gain an understanding and perspective of why each organisation within the value chain has adopted their various types of circular economy business models. Participants were also chosen to reflect the different circular business model types across a range of different product or service types. In order to allow the research to feed into additional research being conducted by the PolyCE the interview schedule was developed with consultation from the wider consortium. Research participants were initially recruited through the PolyCE project.

The interview was designed to explore the key themes of the survey in more detail and to give experts, and stakeholders, along the value chain, the opportunity to explain the detail. The interview examined what the interviewee perceived circular economy adoption would mean for their organisation in the case of manufacturers, or how it impacts on other suppliers within the value chain such as reprocessors and designers and what the aims of each company in adopting circular economy were. The interview also needed to be constructed to enable exploration of the potential challenges that the companies envisage might be obstacles in them achieving success and what would need to change to enable this.

Thirty-four interviews were conducted, spanning thirty-three different organisations from across the value chain. These were made up of nine OEMs, five pre-treatment processors (which had both recycling and or reuse elements), three converters, four compliance schemes, three trade bodies, three refurbishment organisations, three designers, two circular finance organisations and an EU project. These are detailed in Table 5.1. Once no new information was being identified and several points were being repeated frequently the interviews were felt to have reached saturation point and therefore felt to be sufficient; according to (Fusch and Ness, 2015, Guest *et al.*, 2006).

Table 5-1 List of participants and sectors

	Participant ID	Type of organisation	Sector
1	OEM 1	Manufacturer	Appliances and Consumer Electronics
2	OEM2	Manufacturer	Appliances and Consumer Electronics
3	OEM3	Manufacturer	IT & Telecommunications
4	OEM 4	Manufacturer	IT & Telecommunications
5	OEM 5	Manufacturer and service provider	IT & Telecommunications
6	OEM 6	Manufacturer and service provider	IT & Telecommunications
7	OEM 7	Manufacturer	Appliances and Consumer Electronics

8	OEM 8	Manufacturer and Social Enterprise	IT & Telecomunications
9	OEM 9	Manufacturer	Appliances and Consumer Electronics
10	PT 1	Pre-treatment and refurbishment	Recycling and Reuse
11	PT 2	Pre-treatment and refurbishment	Recycling and Reuse
12	PT 3	Pre-treatment	Recycling
13	PT 4	Pre-treatment and refurbishment	Recycling and Reuse
14	PT 5	Pre-treatment and refurbishment	Recycling and Reuse
15	Conv 1	Reprocessor	Compounder
16	Conv 2	Reprocessor	Compounder
17	Conv 3	Reprocessor	Compounder
18	RF 1	Social Enterprise	Reuse and Refurbishment
19	RF 2	Social Enterprise	Reuse and Refurbishment
20	RF 3	Refurbisher and pre-treatment	Reuse and Refurbishment
21	EPR 1	EPR	Compliance Scheme
22	EPR 2	EPR	Compliance Scheme
23	EPR 3	EPR	Compliance Scheme
24	EPR 4	EPR	Compliance Scheme
25	EPR 5	EPR	Compliance Scheme
26	O 1	Trade Association	Trade Body representing the plastics industry
27	O2	Trade Association	Trade Body representing the technology sector
28	O3	Specialist lab and technical consultant	

29	O4	H2020 project	
30	F1	Bank	Investment
31	F2	ESG analyst	Investment
32	D1	Technical Design Agency	Designer
33	D2	Technical Design Agency	Designer
34	D3	Technical Design Agency	Designer

Whilst face to face interviews are the best method, as a greater amount of information can be gleaned accessed through this method (Saunders *et al.*, 2019; Bryman and Bell, 2011; Yin, R. K., 2014), due to restrictions such as the locations of the interviewees, COVID regulations and the volume of interviews, face to face interviews were not in general possible. As interviewees were familiar with the online platforms such as Teams and Zoom these applications were used as an alternative to face-to-face interviews. The experience and knowledge of the researcher in the circular economy field assisted in establishing trust; however, care was taken to not disrupt the procedure. The potential influence of the researcher was mitigated by the number and variety of the sample size, framing it around the circular economy framework and triangulating with participant observations.

A further interview with one of the demonstrator manufacturers from within the PolyCE project, was conducted twenty-eight months after the initial interview to assess the potential impacts that had occurred due to the development of successful demonstrators.

during the PolyCE project. The demonstrators included incorporating recycled content onto vacuum cleaners, shavers and hairdryers. The aim of this interview was to evaluate whether once solutions to including recycled content had been resolved whether the organisation started to focus efforts on other types of circular economy business models. This element provided a nested longitudinal case study research.

Interviews were digitally recorded, after obtaining the participants consent, using the researcher’s phone or platform recording options. The purpose of recording the interview was to allow for a more relaxed atmosphere, as opposed to over focussing on note taking which would have disrupted the process. Recording also allowed the researcher to capture all the data that could then be referred to and listened to as frequently as necessary. Interviews ranged in duration from 45 minutes to 2 hours depending on when the interviews naturally came to an end.

Additional Interviews undertaken by the PolyCE project

In addition to the interviews carried out by the researcher and following consent by the interviewee for them to be used, several additional interviews with policymakers and NGOs undertaken by the PolyCE consortium were passed on to the researcher for analysis.

Site visits

Nine site visits were undertaken as shown in Table 5.1 throughout the research to observe current practice and to see the various processes in practice.

Table 5-2 Site visits undertaken as part of the research.

Site Visit No.	Place in the value chain	Description
1	Pre- treatment plant	Large WEEE recycling plant with fridge treatment facility. Located in Italy
2	Pre – treatment plant	Large WEEE recycling plant with fridge treatment facility. Additional reuse and refurbishment facility for large household appliances Located in UK

3	Pre – treatment plant	Large WEEE recycling plant. Additional reuse and refurbishment facility for large household appliances, IT and screens. Located in UK
4	Refurbishment and Reuse facility	Social enterprise based in the UK, refurbishing large household appliances for reuse.
5	Takeback facility for warrantied returns.	Location UK
6	Refurbishment centre	IT recycling and refurbishment centre – contract refurbishments. Location Ireland
7	Design Lab	Designer of new EEE products. Location Netherlands
8	Original Equipment Manufacturer	Location Netherlands
9	Original Equipment Manufacturer	Location UK

Stakeholders were identified and contacted via email asking them if they were willing to undertake an interview, and if so a date and time were arranged. Each interviewee was sent a copy of the flexible schedule of key issues likely to be discussed to understand the types of questions that they could potentially be asked, prior to the interview, once they had agreed to the interview. Some interviewees were keen to see this prior to agreeing to the interview, a flexible approach was taken to this. The schedule of questions was a guide rather than detailed as it was important for the interviewee to provide information from their perspective rather than be constrained to a detailed schedule (Bryman & Bell 2011). Once transcribed the interviews were sent to the interviewee for approval and any sensitive content was removed if requested.

5.5.5 Research Ethics

Prior to commencing the data collection phase, the researcher successfully applied for ethical approval from the University of Northampton's Research Ethics Committee as per the ethics policy of the University. The ethics were also compliant with the European Commission agreed ethics procedures, carried out during the PolyCE project. The procedures were implemented for data collection, storage, protection retention and destruction, and confirmation that they comply with national and EU legislation. In addition, privacy policy and informed consent were provided to individuals who participated in data activities involving the collection and processing of private data in accordance with GDPR. No sensitive personal data was collected, basic information was collected about individual participants encompassing name, email address, employers name and position within the company. The participation in any of the research activities was by prior consent. All participants were provided with information informing them of the purpose of the research prior to the interviews and they had the opportunity to ask questions regarding the content of the interview and the research. This process was repeated at the beginning of the interview.

All participants were informed that.

- participation was voluntary and that they had the right to withdraw without having to give a reason.
- Participants were given the right to refuse to answer any questions without giving a reason.
- All participants gave their permission for the interview to be recorded. They also had the opportunity to stop the recording at any time during the interview.

- Participants were informed that the content of the interviews would be used in the researcher's PhD thesis and could be used in publications and presentations. These were in accordance with confidentiality and anonymity parameters agreed to prior. The data was anonymised with the exception of where participants have agreed to be used as case studies.

For GDPR purposes all research data was stored on the researchers encrypted and password protected laptop and backed up on a secure external driver as approved by the University of Northampton.

5.5.6 Data analysis

Data analysis was carried out using thematic analysis (Saunders *et al.,* 2009), as the data was being collected certain themes began to emerge and this had implications on collection of data from the later interviews. These themes were identified and evidenced by the content of the interviews. Once all the data was collected the interviews were played back and listened to systematically (Bryman and Bell 2011).

The NVivo software package was used to organise, analyse, and find insights into the data as it enabled the researcher to capture different types of data including the survey and interview data. The tool had the advantage of being able to manage the large quantities of data generated. By coding the data within NVivo, it was possible map key themes and ideas and establish relationships between the key words and the different parts of the value chain. Commonalities and differences between the actors could easily be established by the ability to query key words. The software was flexible so allowed for modification of themes during coding and analysis and so worked well for this exploratory research.

5.5.7 Validity

Often case study research is not seen as rigorous and to demonstrate the credibility of the research it was important to establish validity (Creswell and Miller, 2000; Lincoln and Guba, 1985; Yin, Robert K., 2018). Several different methods were adopted in order to establish that the findings and analysis accurately and credibly represented the participants of the research. Validity procedures were done to reduce the risk of bias from the respondents, research and reactivity and is shown in table 5.1 below.

Table 5-3 Methodology of bias reduction (adapted from Creswell 2000)

Bias	Validity Procedures	Method engaged	Impact
Lens of the researcher	Triangulation of data,	Different sources of data – interviews, observation, documentation	Reduces reliance on single incident or data point
	Triangulation of methods	Mixed qualitative and quantitative	Consistency of evidence
	Triangulation of theory	Comparison with existing theory	Increased confidence in research data.
Lens of the Respondents	Member checking	Sending interview transcripts for changes/additions and follow up discussions.	Confirmation of credibility of the account.
	Prolonged engagement in the field	Working closely with some of the respondents with the PolyCE project	Establishes trust.
	Collaboration	Collaboration with some respondents on producing deliverables for the PolyCE project.	Respects and supports the respondents adding to the credibility
Lens of People external to the study	Peer debriefing	Internal meetings e.g. supervisor meetings, PolyCE webinars. External meetings conferences and webinars.	Awareness of limitations of the study. Increased objectivity – reducing researcher bias.

Consistency of interpretation was maximised by transcribing the interviews fully and triangulating interviews with non-participant observational data such as the site visits and secondary data through content analysis of associated project documentation as seen in

Figure 5.5 (Bryman and Bell 2011). This approach was successful as data from all three sources proved consistent.

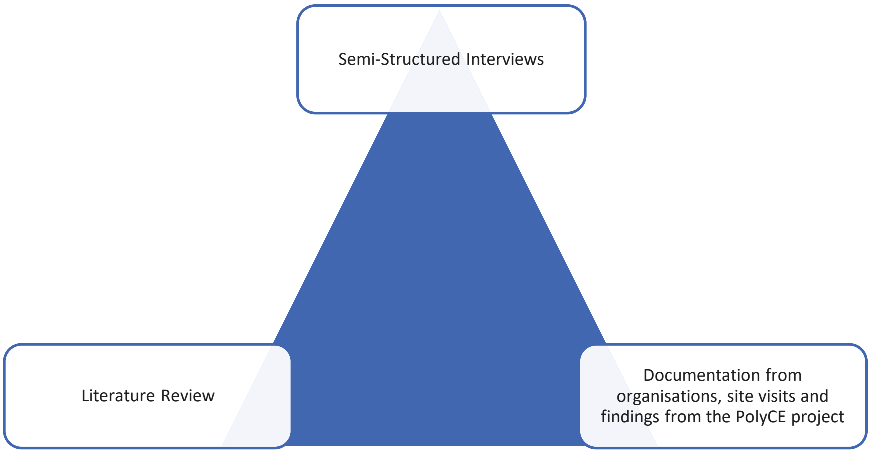

Figure 5-5 How the researcher triangulated data (adapted from Bryman & Bell 2011).

Chapter Summary

This chapter shows how the research design was developed and implemented in order to achieve the objectives of the research. The philosophical approach taken was a pragmatic, abductive approach using a case study strategy. Data collection was achieved through semi-structured interviews, surveys, site visits and observations. Validity to reduce risks of bias was done via triangulation of data and prolonged engagement with interviewees.

Chapter 6 Research Findings and Analysis

From the interviews and surveys several themes and sub themes were extracted as shown in Table 6.1. These themes explore the different influencing factors of adoption of circular business models.

Table 6-1 Identified themes and sub-themes

Theme Number	Sub-Theme Number	Theme/sub theme
1		Circular Economy and Sustainability
	1.1	*Measuring Circularity*
2		Circular economy and climate
3		Resource Efficiency and Circular Economy
4		Transition to CEBMs
5		Importance of Design for CEBMs
6		Product Service models.
	6.1	*Business to Business Product Service Models*
	6.2	*Business to Consumer Access and Service Models*
7		Remanufacturing /Refurbishment and Reuse Models
	7.1	*Refurbishment and repair via the OEM*
	7.2	*Reuse and refurbishment via 3rd parties*
	7.3	*Social benefits of Remanufacture/Reuse*
8		Collection Systems
	8.1	*Take back Systems/Reverse Logistics*
	8.2	*Collection via Designated Collection Facilities (DCF)*
9		Recycling processes
	9.1	*WEEE Reprocessing*
	9.2	*Design for Recycling*
	9.3	*Compounding*
10		Use of Recycled PCR
	10.1	*Quality and Quantity of Recycled PCR*
	10.2	*Collaboration and Supply Chain*
	10.3	*Design from recycling*

The findings have been split into three main parts.

1. Part 1 investigates the themes of overall circular economy awareness and how CE aligns with the sustainability and resource efficiency goals of organisations. It evaluates the themes associated with external and internal drivers for organisations to make the transition to a circular economy.

2. Part 2 evaluates the themes which consider changing the value proposition for access to Electrical and Electronic Equipment by businesses and consumers through slowing the loop CEBMs, that extend the lifetime of products.
3. Part 3 evaluates the themes that are connected with closing the loops CEBMs that capture EEE plastics and parts at end of life enabling the recirculation of material

6.1 Part 1 Overall Circular Economy awareness

From the interviews, the schedule of which can be found in Annex A, all organisations interviewed are aware of the Circular Economy (CE) as a concept. It is often seen as being linked to, and as a mechanism for, achieving sustainability, resource efficiency and climate change goals. The survey data of the EEE sector detailed in Annex B corroborates this with 95% of respondents from the EEE sector describing themselves as having excellent knowledge of circular economy, and 80% of consumers from the consumer survey stating that they feel very familiar, 15% somewhat familiar and only 5% that are not familiar with the concept of circular economy.

6.1.1 Theme 1 Circular Economy and Sustainability

Sustainability is seen by interviewees as the overarching principal, encompassing social, economic and environmental aspects. In particular, the OEMs interviewed, see circular economy as an important part of delivering their sustainability strategy.

> *Sustainability very much goes beyond circular economy. CE is an element of sustainability, but sustainability is much broader than the CE. CE cannot replace an entire sustainability strategy, but it's definitely an important part of your sustainability strategy* ***OEM 1***

Many of the OEMs have been developing their sustainability strategies for several years, decades in some cases. The approach has often been top down, with founders and CEO's recognising the importance of environmental sustainability to the success of the business:

Our founder said in 1957 – "the betterment for our society is not a job to be left to a few, it's a responsibility to be shared with all". One of the top strategies of the organisation is the environment, from the very beginning of the company. So that is nothing new, we started it from the very beginning. ***OEM 3***

We were one of the first signatories of the Paris Climate Change Agreement. We signed up to the UN sustainability goals. It's massively important from the top down. As I said, our CEO is incredibly passionate about it and that's not something he just says. ***OEM 2***

Most of the OEMs sustainability strategies are published and updated every year and have evolved over the years to now include circular economy principals. All the OEMs highlighted that CE is important in being able to obtain sustainable materials for building resilient supply chains and achieving corporate social sustainability goals. CE is seen as a mechanism to reduce reliance on mining or use of virgin plastics.

Most relevant is the origin of materials, we work with several parties and several supply chains to improve the working conditions across the supply chain, not only in mining. So there, we work with component manufacturers and our assembler ***OEM 8***

Sustainable and circular supply chains however are not as straightforward as linear ones, OEMs must work in a different way with their supply chains as CE requires a collaborative approach.

I think circular economy forms part of an overall sustainability package. It's one cog in the wheel, if you like. I think where it differs is that, with a lot of the sustainability stuff we can do ourselves, we can control how we produce, we can control where our energy comes from, we can control how clean our production processes are. Circular economy requires involvement and buy-in from a number of other stakeholders and that sets it apart slightly. ***OEM 2***

The role of a circular economy as a mechanism to develop sustainable supply chains, reduce environmental impact, and improve economic sustainability, is also a view shared by finance and ESG analyst interviewees. Institutions such as F1, see circular finance, as a critical factor in contributing to more sustainable consumption and production.

the role of financiers is, basically, to provide the financial means needed to conduct circular business. So, circular businesses need financial capital. And especially the product-as-a-service mode, ***F1***

Financial institutions are also becoming more aware of the environmental and economic risks associated with not pricing in externalities. The financial sector recognises that linear model of production doesn't currently include external risks such as security of supply of raw materials and loss of biodiversity due to mining of raw materials, however they cannot yet estimate these risks.

So, it is true that the financial sector underestimates the risks related to linear models. So, for example, the Dutch Central Bank has recently published the risks related to biodiversity loss, and I think that financial institutions overlook these types of environmental risks. ***F1***

Interviewees stressed that the finance sector is beginning to recognise the importance of CE. This they attribute to research conducted by institutions such as the Dutch National Bank and Ellen McArthur Foundation (EMF) on the importance of the role of nature in producing economic capital.

Financial institutions are not yet organised to finance the circular economy, but I think that the main obstacles are that externalities are not priced in, and also that the costs of conducting circular businesses are, in general, higher than the linear alternatives. They are used to calculating financial risks and they have their instruments to do so, but we do not yet, as society, understand what the environment risks mean in financial terms—what they do with financial profitability on the long-term. So, we need to invest in developing these types of instruments to be able to estimate environmental risks. ***F1***

Interviewees explained that investor risk rankings look at companies from the dimensions of environmental, social, and governance (ESG). Analysts assess company performance in mitigating ESG risks through investigating the companies' policies and programs and initiatives that they are implementing or part of. The ESG risks to the company investors are then ranked.

While we do not have a particular indicator that looks at how a company implements circular economy, we have three different indicators, one that looks at the revenues that the company is deriving from sustainable products, i.e. also products that incorporate sustainable features or are looking at closing the loop in life cycle analysis, then we're looking at eco-design—so, how a company is looking into incorporating recyclable or sustainable raw materials in its final product—and product stewardship, which is sort of at the end of the lifecycle, namely how a company is making sure that it's taking back its product, it's limiting its waste footprint, and how it's closing the loop when you're looking at a circular model. **F2**

OEMs recognise these ESG risks and the need to act in order to reduce these risks.

In other words, it's risk mitigation. Its more and more frequent in our industry, not only for us but for everyone dealing with a lot of raw material consumption that we face a crisis, because of some shortages of materials on the market. We know that in the future this might increase, the situation will not improve so we need to be ready with backup solutions. ***OEM 7***

Several OEMs have looked at mitigating these risks by developing circular economy goals which look at a great percentage of total organisational revenue coming from circular business models. OEMs such as OEM 1 finance this through green bonds.

Circular revenues -we look at the total revenue that the organisation makes, and we are aiming by 2020 for 15% of these revenues to come from CE business models. ***OEM 1***

Different OEMs are doing things at different scale, for some it is an organisation wide approach, for others they are focusing on specific areas or products, however all OEMs recognise the importance that needs to be placed on the reduction in use of total raw materials being used and the decoupling of economic growth from consumption.

The circular economy it's, the decoupling of growth from consumption. That means keep materials in use at the highest state of value, reduce. Having a greater percentage revenue from sustainable products helps to mitigate these risks. ***OEM 3***

6.1.1.1 Sub Theme 1.1 Measuring Circularity

OEMs responses on what indicators are used by OEMs to measure environmental/ circularity performance of their products and services, indicate a range of methods are employed. Each organisation has its unique method and therefore comparisons between respondents is not simple. These include natural capital, CO_2 savings, recycled material incorporated into closed loop systems and number of total products containing recycled content.

> *We do have this tool to measure the circularity, which is essentially a circularity in materials flow, it's very simple. We have a matrix for sustainability, we have a thing developed, we are still on the journey, a product environmental scorecard. The intent is to measure the sustainability content of our appliances, which is based on three indicators, and the base is the lifecycle assessment. So, we base our metrics with an LCA.* ***OEM 7***

There are some key similarities however, with all organisations reporting on circularity in terms of improvements or goals achieved, set against pledges and internal benchmark. Individual products as well as whole company performance are reported on. Currently the tendency for external communications is to cite the impact, in terms of benefits to sustainability, thus aligning directly with UN Sustainability Goals rather than report in terms of economic benefits. However internally the economic benefits are what is measured.

6.1.2 Theme 2- Circular economy and carbon reduction

Circular economy is often aligned with Net Zero/climate change reduction measure and is seen by interviewees as a way of being able to reduce their CO_2 levels in the future. Net Zero is becoming an increasingly important way for several interviewees to measure organisational success in achieving sustainability goals linked to climate change reduction, using CO_2 as a metric. Interviewees are commonly to align their circularity measures with climate change goals for their own sustainability reports. Interviewees are actively looking at where circular economy and climate change overlap.

> *A lot of the embodied emissions are from the devices and products we have, so finding those bits where circular economy and climate come together is another piece, I'm trying to do more of.* ***OEM 5***

OEMs see that, as large users of fossil fuels for both energy in their processing, and users of petroleum based raw material, that they can really make a tangible difference in CO_2 reduction through scope 1 and 2 emissions.

I think our big marketing focus is Net-Zero, and that will be the big story for the next ten years. I would like to think, as customers become more educated in this, we can push our stories about the circular economic model and demonstrate that it is reducing our CO_2. ***OEM 6***

When OEMS provide their client/customer with an alternative CEBM, they can often also provide the customer with the improved climate change metrics associated with a different way of accessing EEE. The customer can then use these as a way of achieving their own climate change reduction and sustainability goals as it reduces their scope 3 emissions.

We help our big customers doing their own sustainability impact reports. So, we do the calculation, for example, for their printer fleet. So, we know what they have, if they have it from --, of course, and then we do the calculation, how many metric tonnes of CO_2 they saved, how much electricity and water consumption they saved and all kinds of other environmental factors. ***OEM 3***

6.1.3 Theme 3 - Resource Efficiency and Circular Economy

The interviewees acknowledge that there has long been dissemination by researchers and others on resource efficiency and waste prevention and these have been adopted by varying degrees mainly due to economic and environmental considerations. Many of the organisations have a long history of embedded sustainability and resource efficiency goals.

Resource efficiency, CE all have similar elements. The benefit of circular economy is that the economy is much more visible in the whole discussion, from a sustainability view it's not very different. The only difference between resource efficiency and CE are that the business models are much more prominent in CE than they were ever in resource efficiency. ***OEM 1***

Large organisations also recognise the purchasing power they and their value chain have in being able to disrupt the system and shift the way that things are done.

Getting the right information together, where a telecommunications company like us could use its purchasing power to actually change the system. ***OEM 5***

Interviewees are aware that by investing in new innovations and technologies, current barriers and challenges can be overcome in the long term, leading to systemic change in how things are done and an increase in resource efficiency.

We aim to digitise supply chains and production. That's what we do for example, with our 3D printing technology, which means transform the product design, manufacture and distribution, disrupt the traditional supply chain and also create products and services in a more efficient and environmentally sound way. ***OEM 3***

Circular Economy is seen to achieve resource efficiency and builds on work that started years ago, a natural progression to using and consuming products in a more environmentally sustainable way. CE is seen as an important mechanism which provides the business with an opportunity for control of their material flow and overall framework to deliver resource efficiency.

We were talking about integrated product policy and then that turned into eco design and it then there was sustainable consumption production and resource efficiency and so it feels like we've been progressing on this whole thing which is now called circular economy. For me it doesn't feel like a new thing it feels like a rebranding and a bigger political push, maybe. None of the concepts are really new. We've all been working on this for ages now. ***EPR 4***

Those interviewees more involved in the reprocessing and capturing of materials, tend see CE in terms of a mechanism of delivering resource efficiency via a closing the loop business strategy, rather than the wider potential for CE business strategies. CE is seen as an opportunity for recycling materials therefore CE is perceived as the same thing as resource efficiency just alternative words.

CE is only a materials approach keeping the material in use. It is a broader thinking that any kind of material can be again used for whatever after purposes. ***Other 1***

As has been identified interviewees see a strong link between sustainability, circular economy and resource efficiency.

The only difference between resource efficiency and CE are that the business models are much more prominent in CE than they were ever in resource efficiency. ***OEM 1***

The tendency has been to wait and see what the political drivers and instruments would be to support them or to conduct further research. The exception has been the early adopters, (which include some of the interviewees). Sustainability is perceived as the why, resource efficiency is seen as the what and circular business models are seen as how this can be achieved.

I always say the CE is not the what but the how, the big what is resource efficiency, and the CE is a way, it's probably the best or most level way to reach or to optimise resource efficiency. ***OEM 7***

6.1.4 Theme 4 – Transition to CEBMs

Interviewees from across the value chain highlighted that, due to EU legislation such as the WEEE Directive (2012/19/EU), and strategies such as Circular Economy Package (European Commission, 2020a) and the Plastics Strategy (European Commission, 2018a), tangible changes are happening in progressing CEBMs at a faster pace than in the past. Companies were aware of CE previously, but they were reluctant to implement the required changes due to the potential disruptions this would cause to their core business.

Normally they are very limited to their own business and how they operate, so a new business model for them is very difficult. Making a product easier to recycle and to use recycled material, is easier to convince them to use that. ***D2***

Designers and OEMs were more aware of the different types of slowing the loop models such as service models, whereas compounders and pre-treatment organisations were more familiar with the material capture models such as reuse and recycle.

Many of the interviewees acknowledge that it is generally simpler for business to be conducted in a linear way, and the adoption of CEBMs will need to run in parallel with linear business practice before a paradigm shift is achieved. This was reflected in the EEE sector survey, Figure 6.1 shows that adoption of CEBMs is seen as a major shift in current business practices with 78% of respondents replying that it was a large or major shift.

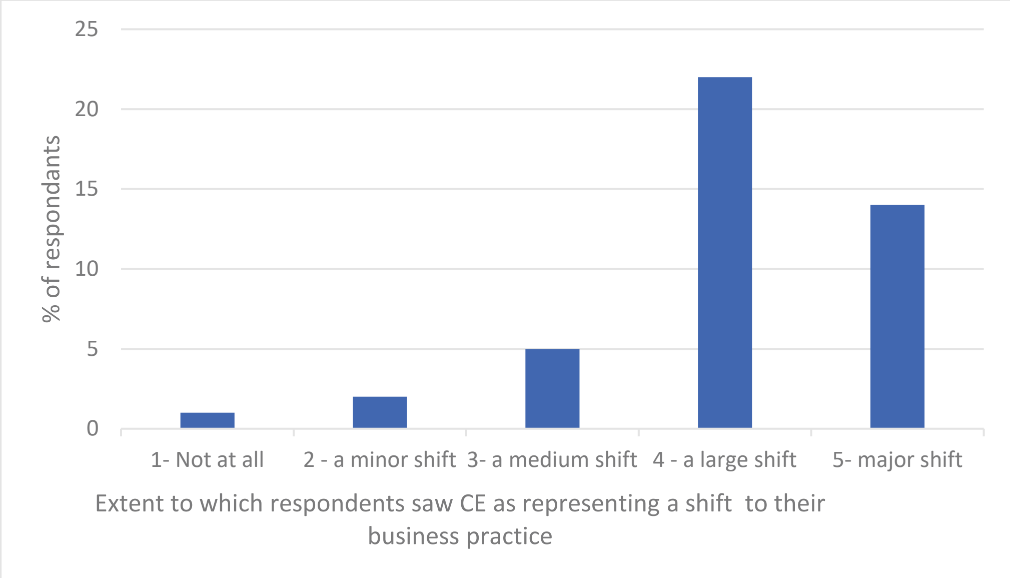

Figure 6-1 Extent to which circular economy represents a shift to respondents' current business practice.

Views on how this shift will be monitored and the pace that it can happen vary, but it is generally agreed by interviewees that the pace will be determined by both the legislative framework and the commercial attitude to change.

> *Number one, what is it that the European Commission is going mandate? Will it be designs for recyclability? Will it be design for durability? Because there will be trade-off, between the two then they're not necessarily mutually exclusive and you would design certain things different ways, right, for durability than recyclability.* ***Other 2***

Increasingly, organisations are seeing added value in developing closed loop systems and other CEBMs both from an economic and environmental perspective.

> *Do you remember the service models? So, this is in the second pillar, that's the shift to serviced models and reduce waste and cost, extend product lifespan and increase reuse and recycling.* ***OEM 3***

Design of products and development of alternative business models are also seen as a major factor in how different types of products will be used in the future. Designing of products should consider the potential lifetime of the product and whether products are being designed for recyclability, reduced material use or refurbishment.

> *Shifting to and designing new service models and cartridges, that also takes years because you have to change everything or if you change the cartridge design that is also - you have to create different moulds and different product lines and that's a huge cost effort investment and therefore of course we have to*

build up solid business cases and really try to prove that it's also good from an economical perspective of course. ***OEM 3***

Different electrical and electronic products will have varying projected lifetimes, and some OEMs are researching which types of business model are the most appropriate long- term for their products, depending on product durability.

The economic feasibility, in addition to positive environmental impacts, need to be understood in order to adopt a CEBM. CEBMs have been traditionally implemented by the sustainability sections of organisations, but only when they are recognised by the whole organisation as economically feasible are they adopted and become viable.

First it came from the sustainability development team and quality team, environment team. Then when we were looking to work with someone to work with from the factory, one girl from marketing said," I'm in." We started with the one project and now we are using a lot of recycled plastics in other products. But when you are doing your first trial, your first success story you need someone really involved. At the beginning its more of a people project to develop your first success story, now it's more into the process. ***OEM 9***

Changes in consumption patterns, due to better environmental awareness by consumers, is increasing demand for more sustainable goods. The result of the increased demand is pushing organisations to offer alternative business models. OEMs have seen a rise in consumers considering environmental implications as part of their purchasing decisions in the last couple of years, OEM 1 identified this a major shift in consumer attitude which has led them developing new CEBMs. From the consumer survey as shown in figure 6.2, respondents were either positive with 80% of respondents indicating that they would consider renting appliances rather than purchasing them, or negative with 20% said they wouldn't consider renting.

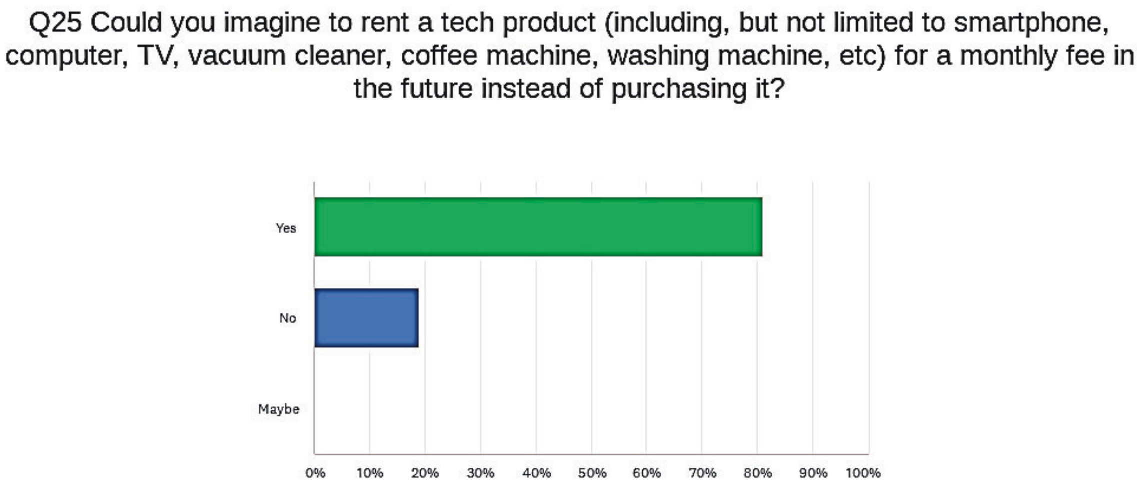

Figure 6-2 Willingness to consider an alternative CEBM.

Willingness to rent varies depending on the type of appliance shown in figure 6.3, with 80-70% responding that they would consider renting large household appliances (refrigerator, washing machine, oven, dishwasher, drier, etc) or consumer electronics (phone, laptop, tablet, headphones, etc), whereas only 50% would consider renting a smaller household appliance (microwave, coffee machine, toaster, iron, etc). In the other category, respondents specified that they would consider renting power and garden tools. This corresponds with the main types of appliances that interviewees identify as products that consumers are willing to buy refurbished and is related to financial cost.

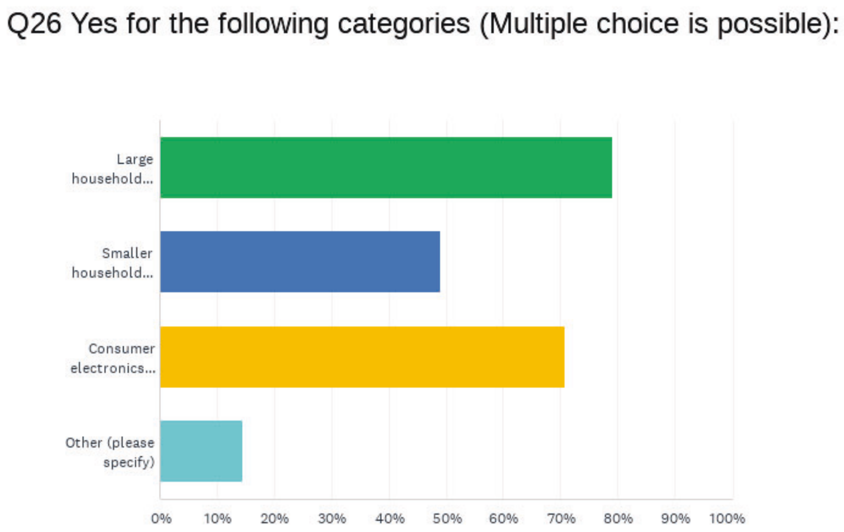

Figure 6-3 Types of appliances respondents would consider renting.

6.2 Part 2 - Slowing the loop through extended product lifetime of EEE - CEBMs

Extended lifetime CEBMs are identified by the interviewees as being slowing the loop business models, which keep products in use for longer. Findings from the interviews and surveys on each type of business model are analysed separately but in summary the types identified from the data include:

- Durable products purchased by the consumer which retain extensive value after use, so repair and refurbishment is more likely such as large domestic appliances.
- Modular products which can be upgraded such as data centres, printing equipment and some mobile phones.
- Use based PSS business models where the OEM retains ownership such as large healthcare appliances.
- Results oriented PSS models where the product is used to access services such as TV set top boxes.
- Refurbished, remanufactured, or reused goods such as phones and IT equipment.

6.2.1 Theme 5 – Importance of Design

Design of products and development of alternative business models are seen as major factors in how these types of products will be consumed in the future. Design will look more at the potential lifetime of the product and would vary depending on whether the product was designed for recyclability, reduced material use or refurbishment.

Different electrical and electronic products will vary depending on their projected lifetime, and some OEMs are researching which types of business model are the most fitting/suitable for their products in the long term and engaging with their supply chain to help design them.

> *We have migrated to efforts where we are working directly with industrial design as well as cosmetics, materials and finishes groups and with the product design teams to design the products from the start to enable the use of recycled content and to enable things like modularity, component reuse as well.* ***OEM 3***

Producers and designers interviewed indicate that designing with end of life in mind is becoming much more the norm with telecommunications and IT (ICT). ICT mobility products are moving towards the thinner and lighter design resulting in less material being required to manufacture.

> *It's basically an innovation challenge with our suppliers but we focused it on circular economy this year to say we kind of went out to our consumer suppliers and said, 'Bring us your circular economy innovations,' and did a bit of training with them about what that meant, and then we had about eight of the suppliers enter, in the end. Some of them were mobile phone suppliers and a lot of those focused on refurbished phone opportunities.* ***OEM 5***

Extended life business models are being tested with existing linear products at pilot scale, to establish whether the CEBM works. Experimenting at pilot scale, allows feasibility testing of the model, and a more accurate assessment of the potential market for that CEBM. The results of the pilot, enable the investment case to be made for the financial and logistical mechanisms required to support rolling out the service at full scale.

> *If you don't know if the business model will work, you will not invest a million or two million into a new design, because it's highly uncertain that you'll ever get*

the payback. If it's the other way around, you can quite quickly do through these pilots, through these lean start-up methodologies. You can quite quickly test if this is a model that'll work. ***OEM 1***

Practical findings from the pilot also highlights aspects of the design of the product or service which need changing to facilitate the new CEBM as previously seen in Theme 4. This leads to products being designed for longer life, which can include becoming more modular and component based and/or making products easier to dis-assemble facilitating repair and refurbishment. The design changes will depend on the type of CEBM being adopted and the product or service being offered.

For us, as a company, we pride ourselves on designing with the environment in mind, and so one of those pillars is that our products are pretty easy to dis-assemble. They are very modular, and component based. ***OEM 4***

Easy of disassembly is becoming increasingly important for CEBMs, as products being developed remain the property of the producer and are used as a way of facilitating service models.

From a servicing point of view, our boxes, we design them, actually, to have quite a long life. So, the boxes that we were getting back were usually over ten years old. [----] It actually quite suits a service model. So, we had changed design, originally, our products, where we were going to outside manufacturers, may have had 20 screws to take them apart. We had worked through a process, so they now have four screws. ***OEM 6***

6.2.2 Theme 6 Product Service models.

Access and service models were identified by OEMs as becoming more prevalent in telecommunications, IT infrastructure products, IT and print services, lighting and medical devices. Often the end user needs to be willing to change the way they access goods, particularly for the product service models as rather than purchase a product they are entering into a contract with the OEM to use the product or access a service via the product. The impact of this is a direct relationship between the OEM and the consumer.

They provide more stability, because you go into a much more long-lasting relationship with the customer. You don't have the one off where you continuously need to recruit new customers, which is an economic driver. ***OEM 1***

This has implications for both parties from the interviews the OEMs identified several benefits and challenges for them and their customers which are outlined in Table 6.2.

6.2.2.1 Sub- Theme 6.1 Business to Business Product Service Models

Due to the long-term commitment business to business (B2B) applications particularly suit access and service models and many of the OEM interviewees have been implementing them for several years. The concept and implementation of CEBMs are easier on a B2B level, as the relationship between producer and customer is more direct and can therefore be tailored to meet their needs, for the timeframe required and to a scale that make it financially viable.

B2B it is something which has been growing for a very long period already, such as leasing/pay per scan – managed services we call them. [….]. It's growing, growing rapidly, we are increasingly focused more on those solution offerings as we call them, it's been a considerable part of the portfolio and its steadily growing but not a lot of surprises there. ***OEM 1***

Often these services are referred to as managed services and are provided to large organisations, where it makes economic sense to both parties. The OEM will assess the client company needs and expectations. Examples from interviewees include lighting, print services, healthcare appliance, and IT services (laptops, desktops and other IT equipment). The OEMs highlighted that company culture in those organisations wanting these services is important as they have to ready work with their employees to make it work and it's a long-term commitment.

Businesses using the product service models, often have their own sustainability goals to achieve, so they are more responsive to using CEBMs as a solution to meeting those goals, again reflecting the customers company culture and business strategy.

in B2B they're already on a climate journey so they just want the net-zero version, ***OEM 5***

6.2.2.2 Sub-Theme 6.2 Business to Consumer Product Service Models

In the business to consumer scenario there were several barriers to delivering access/service models as many of the benefits identified in Table 1 are not so applicable due to the investment needed. Traditionally there have been very few B2C access and service models. However, B2C business models are becoming more prevalent with interviewees highlighting some recent successful access/service models in a B2C context. Examples of successful access B2C models were in high-end innovative personal health products which allow the user to try them out, reducing financial risk.

So, that's why it works so well for [], because there are a lot of women out there who are not sure: 'Does this really work? Really? It sounds too good to be true. So, I laser my leg once every month, and I have no more hairs there? That sounds too good to be true. So, okay, am I going to spend €500 on it, or just €40 per month? I'll go for the €40 per month. ***OEM 1***

These products are piloted in a selected geographical area to assess need/demand, in the longitudinal case study, at the initial interview with the OEM the product was in this stage. From the second follow up interview the demand for this type of business model has now been established, and as a result the OEM has invested in the financial infrastructure to enable an access model via a subscription. These didn't exist previously as normally these products would be sold via retailers or online. However, once this investment is made and the infrastructure in place it is easier to apply to other products.

So, basically, this goes through an almost adventuring kind of model. So, you start something really small, you become a start-up, scale up until it becomes a standard business. So, at this moment, [] is a standard business model. So, it has really exited this piloting phase and is used off the shelf, any country. ---. All the IT infrastructure has been sorted out. All of those kinds of things are done. And it's also now being used by other product groups to go and try-and-buy. ***OEM 1***

In addition to high end products, B2C service models were identified as working well on a for utilitarian services such as Wi-Fi hubs and TV boxes, where the customer is subscribing to a service such as streaming ability or internet services. The service provider needs to provide good quality equipment as without the equipment the customer can't access the service, the issue for the provider is then to get the equipment back from the customer. Increasingly drivers such as gratuitous bailment is being written into contracts with service users, where the device remains the property of the service provider (bailor) is provided free of charge to the user, on the proviso that it is returned to the service provider at the end of the contract otherwise fines will be payable. This is resulting in a much higher return of appliances.

> *Before COVID, because I think we haven't been asking people to send stuff back with COVID—was returns were about 30%, and we think we can get that return rate up into 70% with the fining system. Yeah. So, there's an accounting term called gratuitous bailment, which is what that ownership model is called, so that it remains on [our] books rather than on something we sold, and it's gone.* ***OEM 5***

Service providers offer easy takeback options to facilitate the return of products, resulting in products that are increasingly being designed for refurbishment. The ability to upgrade and improve products digitally *in-situ* is also being designed into products negating the need for the product to be returned and improving the service offered.

> *if we continue to own the devices there will be more reason to design it so that you could increase the refurbishment rates [--] Our products, now, can be replaced with a repaired product—a refurbished product. So, I think we are moving in the direction of refurb products are competing against our factory products for the amount that are going back onto the market, which, again, means we don't have to manufacture all those products, which is a significant reduction in cost, significant reduction in transportation, significant reduction on climate change—all of those aspects.* ***OEM 6***

For appliances which require high levels of consumables for example printers and subscription services are being made available where they subscribe to a flexible printing plan, their cartridges are replaced when needed and sent back to the OEM where they are refilled and reused. According to OEM 3 the cost of ink cartridges is high, often leading to a replacement of the printer rather than the cartridge itself which reduces the lifetime of the use phase of the appliance increasing both the environmental impact and resource use. These types of solutions provide the user with a more sustainable and easier way to access printing at a known cost. The benefit to the OEM is that they can invest in the development of more durable cartridges, and they maintain a relationship with the consumer.

> *It's better for the customer because we can meet their needs much more accurately and we can plan more accurately. We can design our cartridges accordingly to meet these services. And also, it's less effort with the packaging and everything. So, we have to protect the cartridges during transport in a lighter way and all these kinds of things.* ***OEM 3***

Table 6-2 Summary of drivers and barriers for product service CEBMs from the perspective of the OEMs interviewed.

Drivers for Product Service CEBMS	Barriers for Product Service CEBMS
Consumer Benefit Long term savings, no requirement to buy or dispose of consumables. **OEM Benefit –** worth investing in design of durable equipment as retain ownership so can recoup residual value and refurbish at end of life. Regular maintenance maximises the residual value.	**Consumer Barrier** Long term commitment. **OEM Barrier** Paradigm shift from traditional model - Moving away from selling numerous units and requirement to provide maintenance services requiring a whole different approach.
Consumer Benefit Pay only for the service used rather than purchasing equipment. **OEM Benefit –** Revenues from service	**Consumer Barrier** Different way of accessing services have to change finance model. **OEM Barrier** Paradigm shift from traditional model, requires investment in financial infrastructure.
Consumer Benefit Customer gets access to the latest and future technology updates. **OEM Benefit –** Immediate market for technological updates. Opportunity to design End-to-end solutions.	**OEM Barrier** commitment to updating products and associated investment.
Consumer Benefit Prolonged lifecycle of products, extends both the technical and economic lifetime. **OEM opportunity –** Development of innovative replacement units	**Consumer Barrier** Requires a change in employee behaviour. **OEM Barrier** - Requirement to get products back.
Benefit to OEM & Consumer Collaborative approach which strengthens relationship between both	**Consumer Barrier -** Reliant on one supplier
Consumer Benefit - Optimisation of return on investment due to no requirement for capital expenditures or maintenance and replacement costs	**Consumer Barrier** Takes longer to set up and requires long-term financial planning so not suitable if an unexpected pot of money becomes available.

OEM opportunity – Reduction in reliance on raw materials	**OEM Barrier –** reduction in unit sales.

6.2.3 Theme 7 - Remanufacturing /Refurbishment and Reuse Models

From the interviews remanufacture, refurbishment and reuse are seen as important business models to extend the lifetime of EEE products. Refurbishment was identified as important in large household appliances, telecommunications, IT infrastructure (data centres), IT and print services and medical devices. Of CEBMs adopted by the OEMs interviewed, the refurbishment/reuse model emerged as a key aspect of the EEE sector in transitioning to a circular economy. The key benefits of this CEBM being retaining maximum value of materials in products for as long as possible, as can be seen in Table 6.3. This model is adopted by both large organisations and smaller organisations interviewed.

Table 6-3 Summary of drivers and barriers for remanufacturing, refurbishment and reuse CEBMs

Drivers for Remanufacturing /Refurbishment Reuse CEBMs	Barriers for Remanufacturing /Refurbishment Reuse CEBMs
Many clients preferred/positively encouraged having reuse and refurbishment options from their asset management providers.	Brands and retailers have PR concerns around exportation.
Market demand for refurbished and remanufactured products	Some brands prefer to have their products rebranded so as not to weaken the brand.

For the OEMs refurbished products represent substantial cost savings to the as it enables the recovery of valuable products and components.

Our products, now, can be replaced with a repaired product—a refurbished product. So, I think we are moving in the direction of refurb products are competing against our *factory products for the amount that are going back onto the market, which, again, means we don't have to manufacture all those products, which is a significant reduction in cost, significant reduction in transportation, significant reduction on climate change* ***OEM 6***

For social enterprises this model provides an opportunity to generate revenue and provide affordable products to society.

For refurbishment organisations it provides a valuable revenue stream, which additionally benefits retailers by reducing disposal costs and contributing to sustainability goals.

This type of model also has an important social impact with skills development being important, generating apprenticeships and helping people gain valuable new practical skills in repair and refurbishment.

One of the critical aspects of this model was identified as developing the systems infrastructure to get products through the EEE value chain. Several sub themes were identified, outlined below which demonstrate the various systems employed to accomplish this capture of products.

6.2.3.1 Sub-theme 7.1 Refurbishment and repair via the OEM.

From interviews and site visits there are two main systems used by OEMs to refurbish products; either products are returned directly to themselves via reverse logistics operations or outsourced to be refurbished by a third-party specialist provider.

Direct refurbishment by the OEM is common where product service models are being provided as was covered in the theme 2. For example, for OEM 3 where managed print services are being provided, refurbishment is part of the service. For other appliances in use orientated PSS models, such as large healthcare appliances, some components have a shorter lifetime than the main appliance and these components are designed to be replaced and refurbished.

A good example for instance is the x-ray tubes, an x-ray tube may last 10 years, the machine may last 15 years, and we could put in an entirely new x-ray tube, *but we know the machine has only 5 years left. It makes much more sense to refurbish the old tube, make sure it lasts another 6-7 years and put that into the device, because the lifetimes are much better matched. There is a big driver for that.* ***OEM 1***

In a managed service system, the OEM audits equipment provided and where needed removes, upgrades and refurbishes the equipment, this can then be used for the same or a different client. Often the client is unaware whether they have new or refurbished equipment.

The interesting thing about these companies is that they have strong logistics. They are much more geared to do the reverse logistics than some of the other manufacturers of consumer electronics. They've managed to develop a business model which makes it profitable to remanufacturer, because of that logistical network. ***Other 2***

On site visit 9 the system for refurbishing printers was experienced, it was explained by the OEM that one of the key barriers in the past was that equipment was not designed for refurbishment, however as these services have become more prevalent, current machines are designed to be refurbished. Smart technology can be utilised, so the OEM or service provider is aware that a fault has occurred.

Specialist re-furbishers such as those specialising in IT infrastructure like RF 3, have emerged as global data centres recognise that the level economic savings potential in recovery for reuse is substantial. Google was cited as by RF 3 as an example of having sufficient scale to do this in-house but other cloud services organisations have partnered with specialist partner organisations to support them. Strategically, adopting a circular approach is important for these industries is important, as typically enterprise IT systems have the shortest primary economic lifespan of any capital asset. This was attributed by the RF 3 as being down to two main reasons; affordable processors speeds double every two years and capacity densities within data storage technologies increase in similar fashion. The ability to upgrade components, refurbish parts and remanufacture machines therefore is critical for sustainable economic growth and to secure a resilient supply chain for materials.

> *So, we've processed over 7,000 enterprise racks since about 2013, as well. In terms of the value, which is a good number, the bigger companies, so we've recovered over a $1billion worth of components across all the client base.* ***RF 3***

Part of the third-party specialist role is to audit client's datacentre equipment and remove any equipment not up to specification. There are good markets for server equipment and RAM sticks, these are configured to customer requirements. Plate 1 shows an example of RAM which has been recovered, refurbished and is ready for reuse. The system used was observed during site visit 7.

Plate 1 Refurbished RAM produced by RF3.

Other examples of use of a specialist third party provide are via the warranty or returns system, examples of this from the interviews included large household appliances, IT equipment and consumer electronics such as televisions. Often OEMs recover these via the retailer who sold the product, several OEMs interviewed have their own dedicated processing centres for these or use a contracted third-party Figure 6.4 shows an example of this provided by PolyCE partner Whirlpool and is reflective of what was observed by the researcher on site visits OEM 4 and OEM 2.

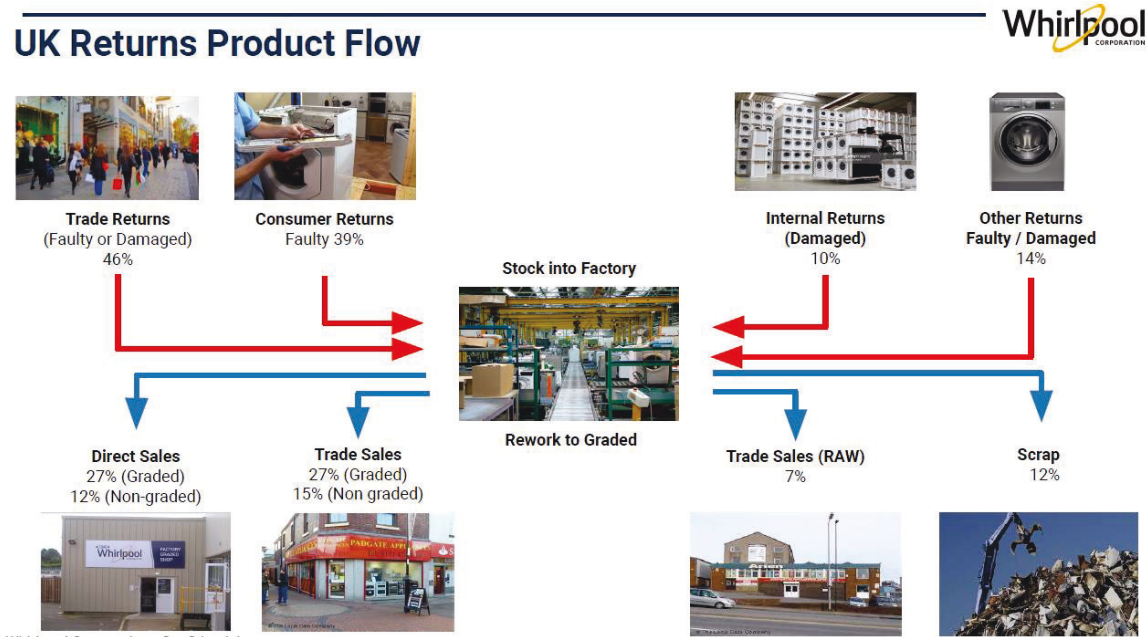

Figure 6-4 PolyCE partner, Whirlpool's returns system (Source: courtesy of Whirlpool)

From the OEMs interviews and observations during site visits, appliances or products that come through this system are graded, depending on the condition of them. The highest grades are those which are often still in their original packaging and have no or minor blemishes, generally received during the original manufacturing or logistics processes typically these are resold with a manufacturer's warranty, these were referred to as A grade R grade or excellent. The next grade of refurbished products is those which have been returned as faulty or damaged, all appliances are fully functional, and safety tested these are also sold either with a manufacturer's warranty or a warranty from the refurbisher.

There are varying views about goods that have a quick and high turnover for example mobile phones, with some interviewees stating that more needs to be done, to capture more devices, whilst others highlighting that this is an area where we are already seeing a radical shift to longer use of these products through a growing reuse market.

6.2.3.2 Sub – theme 7.2 - Reuse and refurbishment by a 3rd party

The other route identified by interviewees is for reuse and refurbishment models facilitated by the end -of- life infrastructure. Reuse at end of life also happens by consumers directly selling on platforms such as eBay, however whilst this was mentioned as an option during interviews it's not the focus of this research. The three main EEE groups where reuse is prevalent are large household appliances, IT and telecommunications equipment, mobile phones and consumer electronics such as TVs and entertainment systems.

Commercial organisations or public sector bodies and education establishments can send back EEE such as IT equipment via specialist recovery collectors, those who use a managed asset service as mentioned previously will work with their service provider. Interviewees identified that there is a big demand for this equipment.

> *We are always out there looking for new clients. We're actually quite good at getting enterprise equipment. We get a lot of it, --, there's a demand for it. The stocklist that comes from the US, we tend to sell PCs and laptops and stuff like that in pallets, I was at a conference last week in Amsterdam and every second person was looking for client equipment. So, there's a really big demand in Europe for it.* ***RF 3***

An important service that specialist recovery collectors provide is data erasure/destruction process where computers or smart devices are given bar codes so that each item can be tracked, any data on them is then erased or destroyed by specialist software. Bar codes, an example of which is shown in Plate 2, are used to track each product through the whole refurbishment (or recycling if not good enough for refurbishment), process. Information about the origin of the product and the processes it's been through can be easily identified and audited.

Plate 2 Barcoded Equipment

In Europe under the WEEE regulations (2012) used EEE is collected either by retailers or via the local municipality or national collection scheme. The majority of this is recycled however around 30% can be recovered for reuse according to PT1 and PT4. Takeback from retailers occurs when a new appliance or product is bought and the old one is collected either in store or from the home. These are assessed once they reach the refurbishment facility for suitability for reuse and refurbishment.

> *We are committed to maximising recoverable value whilst achieving sustainable and environmentally sound solutions for over 1000 different waste streams.* ***PT 1***

Interviewees operating pre-treatment facilities consistently reported around 10% of the appliances collected directly from households or retailers were suitable for reuse as whole machines with a further 20% by weight suitable for component reuse (the rest was recycled). Components were either used in the refurbishment process or sold as spare parts. This high rate of reuse is thought to be due to care in handling. By comparison the products that arrive via local municipal recycling centres only yield a 1% reuse potential. The appliances arrive at a reception point, are assessed for reuse, stored until space is available for refurbishment, tested for functionality and electrics, refurbished and sold on, either directly through online platforms or through trusted sellers or charity retail. The same process as highlight above, is used for other large household appliances, IT equipment and TVs. Similar processes were seen at all the facilities visited.

Plates 3 – 8 taken at site visit 3 show the various steps of this refurbishment process for washing machines.

Plate 3 Appliances arrive at the reception area

Plate 4 Appliances are assessed for refurbishment potential.

Plate 5 Appliances are stored awaiting refurbishment.

Plate 6 Testing washing machines.

Plate 7 Refurbishment of Appliances.

Plate 8 Harvesting of spare parts.

OEM 4 stated that in the USA they set up and fund collaborations with national schemes to collect used EEE. Similarly, these schemes adopt a refurbishment CEBM through which refurbished products are sold directly to the public.

In the UK a percentage of the products collected by Dixons/DHL via take-back schemes is made available to social enterprises via the ARC scheme, a collaboration between Dixons/DHL and the Reuse Network.

> *With regards to the WEEE we get access through various sites from Manchester, Dixons DHL site, because we are an ARC member of the Reuse Network. Which basically allows us the access to go on site and cherry pick on certain days and certain times all the white goods and cold appliances.* ***RF 1***

The potential for reuse of appliances through this system, is much higher than was seen with PT 1 and PT 3, as the EEE is handpicked by the social enterprise up to 90% of appliances are suitable for refurbished. Plate 9 shows an example of refurbished appliances taken during the site visit to RF 1.

Plate 9 Refurbished appliances on sale at a UK social enterprise

RF1, RF2, PT 1, PT 2 and PT 4 all report an uplift in the past few years in interest in reused products from consumers, not just as source of affordable products, but from an increasing environmental awareness of the benefits of reuse in resource reduction. Two of the OEMs interviewed stated that whilst they were aware of reuse happening, they had lower knowledge of the amount it was happening as it is complex to track reuse of products especially in the B2C world. For interviewees delivering CEBM refurbishment models from WEEE, such as RF1, RF2, PT 1, PT 2 and PT 4, refurbishment and reuse are seen as a key factor for economic sustainability and transition to a circular economy.

Concerns were raised by some interviewees regarding the variability in methodology and internal standards within Europe in preparing for reuse. Specifically, for OEMS and EPR schemes interviewed, this included the liability of producers for reused appliances that may not reach quality standards and may pose a hazard to second life users.

"We highlight the issues that producers are talking to us about: product safety, directive, liability, indemnity" ***EPR 3***

The solution was felt to be the development of a high-quality standard for methodology in preparing for reuse or the use of established trustworthy partners. For example, PT1 and PT 2 both have partnership contracts with large retailers.

6.2.3.3 Sub-Theme 7.3 Social benefits of Remanufacture/Reuse

The social benefits of the potential for reuse were highlighted during interviews, with several interviewees participating directly or via partners. Many interviewees recognised the social benefits in providing good quality affordable second life appliances, and the valuable skills and employability benefits provided for those working in the reuse sector. Donations of EEE to social enterprises are made directly by the public and sold on-line or in store, generating important revenue for charities to carry out their social activities.

> *There are certain things that we don't sell in-store but we do sell white goods, display TVs, refrigeration and small electricals, household appliances and IT. And we carry out tests, - a function test and the PAT test in store. And then if they pass those tests, we'll put them on sale and if we can sell them, we will, and if not we'll recycle them. There is one sort of slightly different process which is in terms of data bearing devices. They go into our eBay facility where the data is safely erased.* ***RF 2***

6.3 Part 3 –Closing the loop CEBMs - Materials Capture

The ReValue model is the capture of materials from WEEE. Materials are treated and reprocessed to become secondary raw materials that can be incorporated into new products.

Interviewees are looking to develop the ReValue model by:

- expanding their current activities geographically
- working with end users to produce a greater quality and quantity of useable raw materials
- increasing products containing recycled content

- increasing the amount of recycled content within those products currently already using recycled content.

Part 3 looks at the themes that emerged from the findings relating to the capture of post consumer plastic recyclate (PCR) materials at end of life and their reintegration back into products as recycled content. Recovery of materials can come via other CEBMs or directly from the consumer, this is seen by the EEE value chain as a closing the loop CEBM model. The ReValue model works with the current traditional linear business models. The main contribututors were interviewees from the EPR schemes, pre-treatment operators, compounders and the OEMs as users of the PCR.

6.3.1 Theme 8 – Collection Systems

Collection systems discussed by the interviewees include WEEE collected via European EPR schemes in Ireland, Italy, France and the UK as well as systems in the USA. As has been already covered in Part 2 slowing the loop CEBMs will all ultimately generate material at the end of their extended life and result in takeback systems to capture the products for materials recovery at the end of their in-use phase. Business products are collected either through takeback schemes provided by the OEMS or by specialist WEEE waste collectors. Household WEEE is covered by the WEEE legislation as covered detailed in Chapter 3.

> *Obligations in the UK for waste electricals fall into two areas. One is in the lap of producers, the people who manufacture these goods or the people who import them and place them onto the market. The other is through distributors who are the people who place them on the market themselves. So primarily retailers, and increasingly a significance of online sellers of various types.* ***EPR 1***

Targets for recovery of WEEE are legislated by national governments based on the WEEE Directive (2012/19/EU). These targets are calculated as a percentage of the EEE placed on the market and are overseen by EPR schemes as explained by a UK EPR scheme.

> *So basically, how it works in the UK is obviously we have members of, they put on the market, EEE per year. We discharge their obligations in terms of gathering information from them about how much EEE they put on the market in the*

different reporting categories. Because we understand what they're putting on the market and we have the UK targets, we then go out and make arrangements with local authorities, with retailers, with other third parties to get WEEE collected and then sent for recycling through and reuse through AATFs. So that we can generate the correct amount of evidence to discharge our members obligation. ***EPR 4***

6.3.1.1 Sub Theme 8.1 – Take back Systems/Reverse Logistics

OEMs providing these services stated that they work directly with consumers, retailers or EPR schemes, and third-party specialist providers to provide the infrastructure necessary to maximise collection of products by making the process as simple as possible. Some OEMs provide the opportunity to directly return used products to them.

Regular takeback programme for our customers in Europe where we provide free shipping labels for anybody that wants to return any phone, and we are now trying to figure out if we can give some extra economic incentive for that. ***OEM 8***

Some of the largest retailers of EEE, as part of their WEEE obligations, offer takeback schemes to their customers collaborating with partners such PT 1 and PT 2 as discussed under theme.

The takeback systems work in basically the same way. If you're gonna send a truck out to deliver me a washing machine, you've then got an empty truck that has to go somewhere else, so the idea is, use that space on the truck to take away the old items, take them back to a retail distribution centre, and from there move them on to the recycling structure that we have. **EPR 1**

6.3.1.1 Sub-Theme 8.2 Collection via Designated Collection Facilities (DCF)

The other main route is via DCF's which are run by Local Authorities under an EPR scheme. The products are sorted according to category of WEEE and then moved on to an Authorised Treatment Facility where they are processed.

So, we've got 19 contracts that will have a number of recycling centres I think it's over 150, so we need to move the five streams listed in the current practice. So large, small, TVs fridges and tubes from those 150+ sites to an AATF. ***EPR 2***

As was discussed in Sub – theme 7.2, the quality of the appliances is not as good as the appliances processed through a take back scheme due to the handling. Plate 10 shows the state of appliances collected through DCF. RF 2 explained during their interview that often value parts such as compressors are removed.

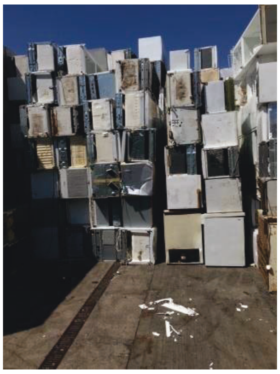

Plate 10 Fridges delivered to an AATF from a Local Authority site visit 2

6.3.2 Theme 9 Recycling processes

6.3.2.1 Sub Theme 9.1 WEEE Reprocessing

The first step in WEEE reprocessing is to break things down to generic streams, resulting in materials such as steel, aluminium, copper, plastics, compressors and printed circuit boards (PCBs) as shown in plates 11-14 taken on site visit 1 and 6. PCBs have a high value and are segregated into different grades.

Plate 11 – Plastic Cables from site visit 6

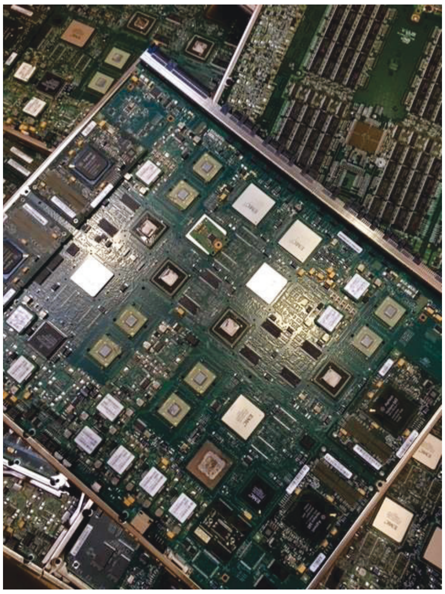

Plate 12- Printed Circuit Boards (PCBs) at site visit 6

The complexity of WEEE was seen as a major challenge when segregating materials out. Extraction of metals is seen as the main economic benefit as can be seen in Plates 13 and 14, but plastics are increasingly seen as an important material to recover.

if you've specialized your plant for 15 years to recover all the metals and somebody comes and tells you: "Well, this is not enough, you need to be able to recover more mass", then of course you start looking into plastics recycling – and this is really what we've seen happening. ***Other 3***

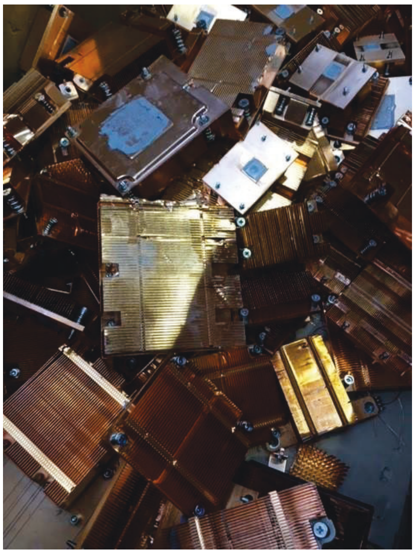

Plate 13 -Copper heating elements at site visit 1.

Plate 14 Metals from fridges at site visit 1.

EU and UK legislation requires fridges to be processed separately and de-gassed to remove harmful gases via specialist processing plants. High Impact Polystyrene (HIPS) is one of the main products that comes out of this process. HIPS were identified by several interviewees as one of the most valuable plastic streams produced by the WEEE pre-treatment plants. Plate 15 shows an example of this materials from this process.

HIPS are our easiest stream to sell of plastic. Halfway through 2017 when the entire plastics industry went through its meltdown, then everything stopped for a couple of weeks. Since then, fridge plastic has been the most sought-after of the plastics. Certainly, its price is nowhere near where it was two or three years ago. ***PT 2***

Plate 15 HIPS from a fridge reprocessing plant -site visit 2.

Large investments have been made by re-processors into shredding machines which means in order to get return on investment that this will continue to be a key process in reprocessing plastics from WEEE. PT 2,3 and all explained in their interviews, that originally these shredding plants were built to supply the Chinese market, to a particular specification, however, import of waste plastics has now been banned by China by "Operation National Sword" a policy initiative launched in 2017 by the Chinese government. In the short-term the Chinese ban has resulted in the markets for lower grade plastics from WEEE reducing and the higher grades such as HIPs from fridges having a lower market value (up to 50% less). The Chinese ban on importing of plastics was seen as an important driver in stimulating the market to invest in new technologies to be able to access higher value markets. However, several interviewees cited that for the European market investment needs to be made in density separation lines to produce the quality needed, and it's difficult to justify this investment based on current markets for plastics. This will be key in the future in ensuring both quality and quantity of materials.

> *To put up a density separation line which copes with WEEE would be around £750,000. Then, electrostatic I would look at probably another £400,000. So just in equipment alone you're in for 1.1 / 1.5 million. Historically, there's been no justification for business cases in support of that because you just ship it all to China.* ***PT 2***

The other key element is in pre-sorting prior to shredding, this is seen as increasingly important with economic investment taking place to remove contaminants such as wood and appliances known to contain hazardous materials. The best sources of PCR plastics were identified as coming from products such as vacuum cleaners, fridges and ICT equipment such as monitors and all-in-ones, as they have larger plastic housings, and their design is unlikely to change rapidly. The light weighting and slim lining of mobile products was seen as potentially challenging as less plastic is being used.

Several important technical barriers to using recycled polymers, were identified by interviewees, examples cited included brittleness due to the recycled plastic having been exposed to heat previously, and the risk of presence of potential hazardous substances such as brominated fire retardants (BFR). BFR pose a challenge for effective polymer sorting, as they come under Regulation of chemical substances REACH and RoHS. The presence of BFR is further complicated by the possibility of the levels of certain persistent organic pollutants (POPs) such as decaBDE potentially having lower than current acceptable threshold levels, could lead to a substantial reduction in the future ability of WEEE plastics to be recycled. Removal of BFR containing plastics accounts for up to of 40% of the total plastics in the WEEE stream.

> *We have a machine in the company to comply with legislation, which can tell whether a product contains bromine up to 2000ppm and sort those plastics (above and under 2000ppm of bromine). This enables us to recycle one type of plastics and eliminate the other type. Over the years, we'll manage to decrease the quantity of bromine in the products.* ***PT 5***

6.3.3.2 Sub Theme 9.2 Design for Recycling

The view from the pre-treatment operators is that from an end-of-life perspective there is a need for designers to consider end of life of products when they are being developed to increase the potential for recycling. Interviewees from the reprocessing part of the value chain identified that reducing the complexity of the types of plastics being currently used in

EEE would be beneficial.

> *if the brand owners are made to be much more responsible in the true meaning of the word in the waste stream by actually being engaged in that reprocessing loop, then that starts to push the behaviour in the direction of understanding and realising the relationship between their original new product design decisions and what the mixture and complexities are of their products when they arrive at end of life.* ***PT3***

Difficulty in being able to dismantle products and separate materials out was identified as a barrier to maximising the plastics stream. OEMs were identified as being key in facilitating this by considering design for recycling.

> *The question was how we could increase the recycling of plastics in EEE again to be used in another part of the electrical industry. The outcome was that this was down to the OEMs, as the OEMs set the material requirements, whether it is primary or secondary material, for their products and product parts.* ***Other 1***

6.3.3.3 Sub Theme 9.3 Compounding

The compounding step involves the processing of the output of mixed plastics from waste electrical and electronic equipment (WEEE) pre-processing as outlined in Theme 2 to produce high-quality Post-Consumer-Recycled (PCR) polymers. Compounders stressed that they need to be able to offer their customers a sustainable and consistent supply of PCR. As OEMs start to move to incorporating recycled content into their products this demand is growing and is expanded on in Theme 4. On average the compounders interviewed were treating around 50,000 tonnes of material. A considerable percentage (between 15-50%) of this material doesn’t make it into the final product due to the presence of material containing brominated flame retardants and processing losses. The key differences in procurement, processing and selling of virgin polymers products versus recycled polymers are outlined in figure 6.5.

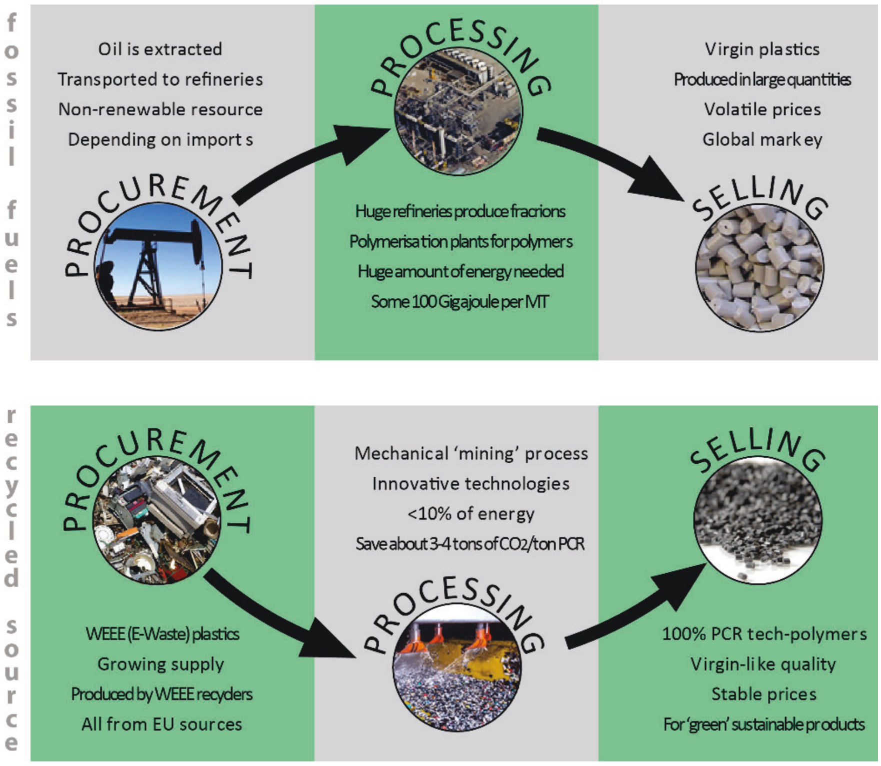

Figure 6-5 Comparison of virgin vs fossil sources of polymers derived from data supplied by reprocessing interviews.

Compounders interviewed were either stand-alone reprocessors or part of a larger organisation which included the pre-treatment process. In one instance the OEM had purchased a compounder to ensure quality and quantity of supply.

The circular business model for re-processors presents several challenges. The main issue is around controlling quality using as much recycled polymer in the mix as possible.

> *What we saw a lot in compounding was people blending away recycled material and virgin material, but what we wanted to do from the beginning on was, if possible, sell with 100% recycled content but that's not always possible because we have to use additives, but at least the goal was to go as high as possible all the time.* ***Conv 3***

consistency is also a key issue due to the complexity of the input feedstock, as there is no standard regulating quality of the feedstock. This results in compounders having to source material from different suppliers as even when material is sourced from one supplier quality between batches can vary. Poorer quality feedstock will mean less material being suitable for included in the compounded material and higher disposal costs for the compounder.

Legislative barriers identified by interviewees centre around the large amounts of bureaucracy involved in moving collected WEEE plastics through the recycling supply chain across Europe.

We have to cross borders and these borders are almost brick walls to go through. And that has to do with notifications of waste transport, it has to do with huge bureaucracy with regards to the paperwork linked to these shipments. But it also has to do with all sorts of rules and regulations that make our work almost impossible. ***Conv 1***

Once it becomes a compounded material is free to move as if it were a virgin material as it is no longer considered waste. The technology required to produce high-tech recycled polymers is complex and requires major investment.

I think --- being in those conversations helps motive the kinds of investment. They recognise that the compounders that have got a steady demand from ---, which allowed both the compounder and the recycler to make the investments, needed to get the materials into the proper form. ***OEM 3***

6.3.2 Theme 9 - Use of Recycled PCR

All of the OEMs interviewed were investigating incorporating increased percentages of recycled PCR plastic into a greater range of products. The amount of recycled material that could be incorporated varied depending on the product. For some OEMs increasing the percentage in certain targeted products was identified as a priority whereas other OEMS were more interested in increasing the number of products that contained PCR plastics.

What we want is to use recycled plastic whatever the %. So, we are now measuring % of products that contain recycled plastic. ***OEM 9***

6.3.2.1 Sub Theme 10.1 Quality and Quantity of Recycled PCR

Any PCR plastic developed needs to meet functionality and performance criteria and be cost-effective. From an OEM perspective the supply chain having the ability to supply both quality and quantity of different types of plastics was a key factor. This was reflected in the EEE sector survey where material availability and improved supplier relationships was identified as being an extremely/very important enabler of the ReValue model as seen in figure 6-6.

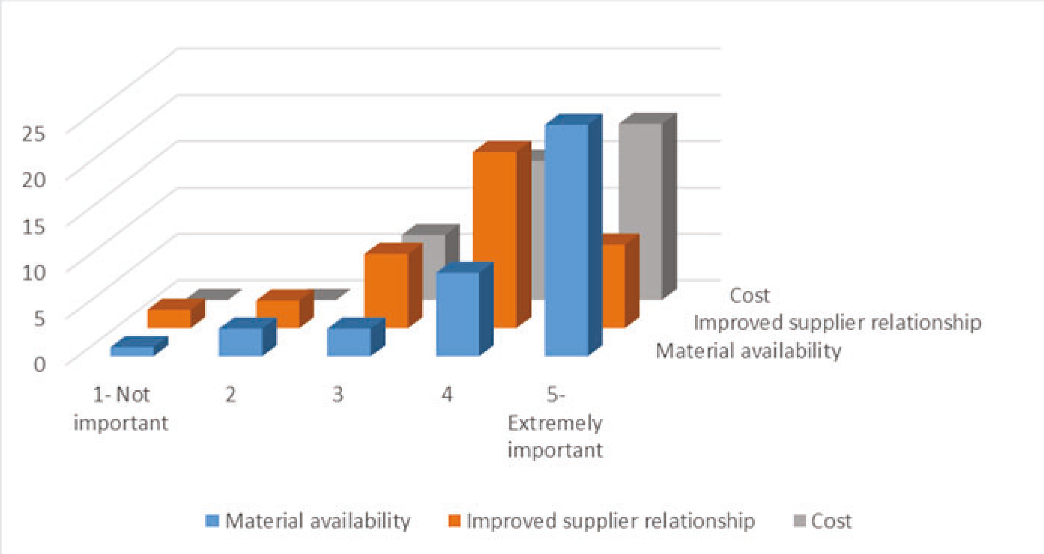

Figure 6-6 Most Important drivers for adoption of CEBMs

There is perception by the OEMs of a huge variance in supply of different types of PCR plastics depending on investments made by the pre-treatment and compounding actors in the value chain. OEMs felt that the infrastructure for supply of the quantity that would be needed to meet quality specifications was not yet in place and that this would be detrimental to the industry.

> *we think that doesn't make the situation better because you have to have the technical possibilities, you have to have the material in the quality which is high enough. If you say a limit value of 50% of recycled plastic content, where should that come from? And in a quality which is sufficient to meet the needs.* ***OEM 3***

Conversely the reprocessors interviewed felt that recycled content targets would stimulate demand for PCR plastics and provide the confidence to invest in reprocessing to increase quality. However, concern was raised about products manufactured in other countries and the ability to prove that they contained recycled content.

Current quality barriers, identified from the interviews and surveys, to increasing recycled content are around aesthetics such as colour and visible imperfections. Odour from previous use and the processing system were also identified as a key barrier to using PCR plastics. Other barriers included the end use and achieving the quality appropriate for skin contact, or food grade applications.

> *Often what still restricts how much you can use is food contact, skin contact and colours. Colour can even when its black, for deep black could also be an issue.* ***OEM 1***

However, it was felt PCR solutions for products at the quality and quantity needed were possible through close partnerships with suppliers.

> *it's very necessary to make a long-term relation with a supplier, which can supply you with your correct material that you need but be aware you have to create that relationship.* ***D1***

For OEM such as OEM 9, the solution has been to buy compounders to ensure both quality and quantity of supply.

> *The second difficulty was that it was really difficult to understand each other. They were recyclers we were manufacturers, and we obviously didn't use the same words to say the same thing. So, we spent hours in meetings just trying to understand each other.* ***OEM 9***

6.3.2.2 Sub Theme 10.2 Collaboration and Supply Chain

Many of the OEMs interviewed have developed a trusted supplier list which is carefully vetted and ensures long term consistent supply. The successful application of the ReValue model was shown to be facilitated by the adoption of a collaborative approach along the value chain. Each part of the value chain is inevitably interrelated, and a relationship of trust needs to be established in all directions for all CEBMs but especially for recycled PCR.

For some of the re-processors accessing supply chains was a lengthy process, they highlighted that becoming a trusted supplier is a long process and getting on to the supplier list is not straight forward.

Whereas selling to electrical and automotive companies, the selling period seems to be a year, up to two, even three years of painful, slow, really difficult meetings that always at the risk of something coming up which puts a complete blocker on it. ***PT 3***

Improvement in collaboration along the value chain was also identified as important by the respondents of the EEE sector survey. Both material flows and information flow, need to be enhanced, 51% of respondents consider that greater awareness of the supply chain would help to develop a circular economy approach (figure 6.7).

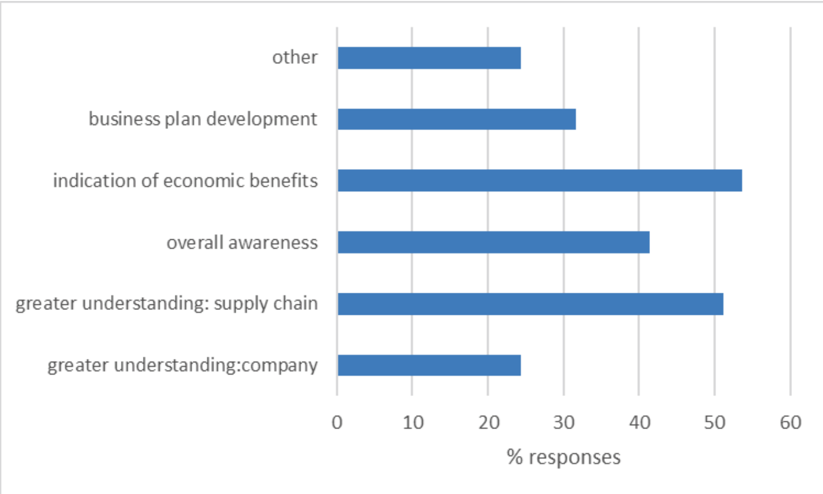

Figure 6-7 Q22: Which of the following would help your organisation to prepare for, or develop, a circular economy approach within your organisation?

I think it's a good learning for everyone, that you create a robust supply chain and closing the loop, because in fact a lot of that material wasn't' going back into original products, it was going back into clothing hangers and lower value items. And steadying up the processes regionally that allow you to recover and put it back into original products is just a much smarter approach. ***OEM 3***

6.3.2.3 Sub Theme 10.3 Design from recycling

In general, there is a move by OEMs to incorporate more post-consumer recyclates but as mentioned previously the main criteria is performance quality and health and safety requirements such as compliant levels of POP. In general designers, pre-treatment operators and compounders considered that the use of PCR is determined by OEMs, as the OEMs specify material requirements, whether it is primary or secondary material, for their products and product parts. This was corroborated by the OEMS.

What we've done is get the entire supply chain in a room, talk about where we want to end up and make sure that we're developing as much as possible collaborative and strategic relationships rather than strictly transactional. And we have found that to be for us the key to cracking the code on the use of recycled plastics. ***OEM 9***

Often recycled plastics are contained in parts of the product where aesthetics are not as important such as in internal parts of small household appliances or the backs of monitors. For external applications colour and performance are important, so it is less likely that recycled content will be used.

We're trying to expand into both areas, both external, cosmetic, case parts as we refer to them. Or internal functional parts and proving to folks that recycled content can be successful in both. ***OEM 3***

Where recycled content is used, OEMs suggested that this constitutes around 35% on average, however they stressed that this is dependent on the product type and the type of polymer being used. Incorporation of either higher percentage of PCR into products or incorporation of PCR into new products was seen by both designers and OEMS as being easier in products with a larger plastic component. Examples cited by OEMS and designers, included static products like a monitors or desktop computers, due to them having lower requirements around properties such as drop testing, rather than products that require a higher performing resin. Designers such as D1 advice that OEMs adopt a step approach to incorporating PCR plastics by taking a drop in approach where the use of recycled material as a replacement for virgin material is experimented with to understand the difference in the behaviour of the material. The drop in approach allows the OEM to build confidence in the material through experience. The drop in approach is a look and learn process, as the manufacturer becomes comfortable with the material.

> *The effort has been flipped to the material that it must be a drop-in replacement. That certainly has made the effort more difficult because you have to mimic existing materials.* ***OEM 3***

Chapter Summary

This chapter has explored the ten emergent themes and fourteen sub-themes from the data collected through the interviews, surveys and site visits. The themes will be discussed and analysed in context of the findings from the literature review in the next chapter.

Chapter 7 Discussion

The overall aim of the research was to identify the enabling and inhibiting factors for effectively applying Circular Economy Business Models (CEBMs) within the EEE sector. The discussion chapter is split into the three parts aligning with the three circles as seen in Fig 7-1. The strategic management process is the mechanism that enables an organisation to take stock of its current situation and plan for its future development when identifying how it will adopt a circular approach (Aspara *et al.*, 2011).

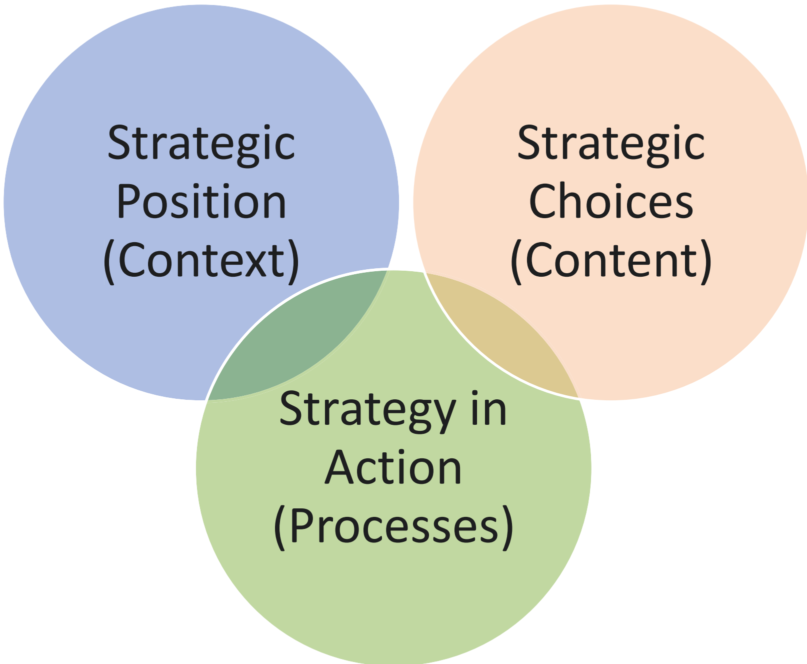

Figure 7-1 Strategy model (adapted from Johnson *et al.*, 2020)

The data from the findings suggested that adoption of CEBMs is determined by an organisation's overall strategy which is influenced by both external and internal factors. This chapter will therefore evaluate these factors through a strategy lens. The strategic position, choices, and actions of the selected businesses within the EEE sector will be evaluated considering the key factors identified from the value chain case study research. A key finding identified is the relationship between sustainability and economic feasibility. Externally the data suggests that the adoption of CEBMs is influenced by the response to climate change measures, resource resilience, technical considerations, and policy. The data suggests that the internal culture of the organisation has an important part to play in which circular strategies are adopted by the different organisations studied.

7.1 Strategic Position

The thematic analysis in chapter 6 identified that the context or environment that an organisation operates in creates opportunities and threats. The changing and complex environment that EEE organisations operate in and the way that these organisations respond to this changing environment by adopting CEBMs is examined. The different layers that influence EEE organisations are shown in Figure 7-2. For each layer an analytical tool has been identified to assess the different factors, utilising data drawn from the case study findings and literature.

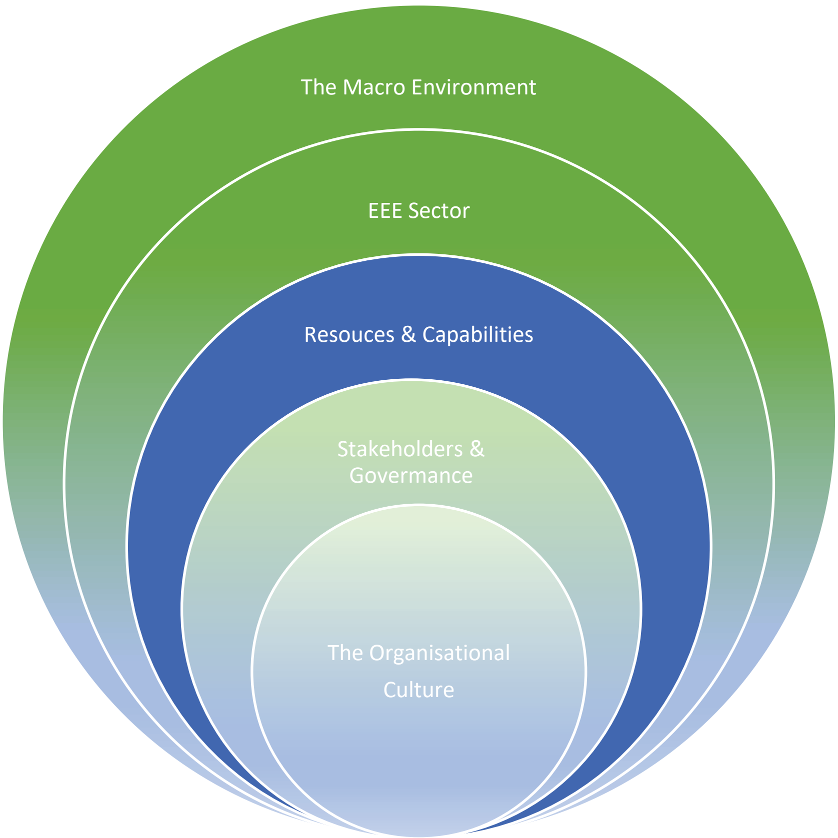

Figure 7-2 The different layers of an organisation's environment (Adapted from Johnson, *et al.*, 2020)

7.1.1 The Macro- Environment

The PESTEL framework, was identified in Chapter 5 as a key part of the conceptual framework for assessing adoption of CEBMs. The themes identified in chapter 6 from the interviews, have allowed an understanding of how the macro-environments, which are the broad external influences impact on business' strategy and success. Understanding how the external influences in the PESTEL analysis are working together, has been an important factor when interpreting the key external drivers and barriers to change within the EEE sector. The key factors considered in PESTEL analysis are shown in figure 7-3.

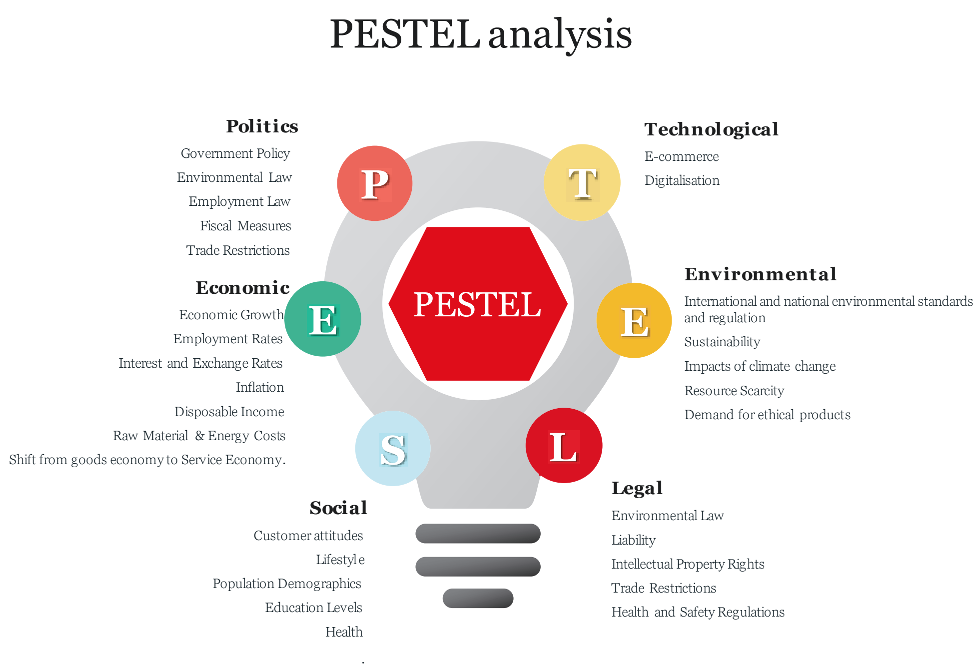

Figure 7-3 PESTEL Analysis influencing the EEE value chain.

7.1.1.1 Political Factors

Political factors will determine how governmental policies and governments through policy interventions influence the EEE value chain. This section examines how the key policy interventions have influenced transition to a circular economy strategy for the EEE sector. As was discussed in the literature review in chapter 2, circular economy CE) is high on the political agenda globally, and is the focus of EU policy, (WBCSD, 2019, McDowall *et al.*, 2017; Winans *et al.*, 2017; Ghisellini *et al.*, 2016) . The emergence of theme 4 – transition to CEBMs shows that CE is well understood by all of the organisations interviewed and surveyed and is already having an impact on company strategies.

From the analysis of the interviews, working towards SDG 12 was seen to form a fundamental part of OEMs' circular economy strategies. There is a push towards CE through CEBMs from organisations such as the UN, OECD and World Economic Forum and the EU as it is a mechanism to achieve Sustainable Development Goals (SDG) specifically SDG goal 12 centred around sustainable resource use.

Focusing on Europe, the area that this research has concentrated on, there has been a response from the EEE sector to adopt circular strategies, following the presentation of the European Commission 's first Circular Economy Action Plan (CEAP) in December 2015 (European Commission 2015). As was described in chapter 2 the purpose of the CEAP was to facilitate the transition of the European economy from linear to circular by closing the loop of product lifecycles through more sustainable production, distribution, consumption, and waste management. In theme 4 which explores the transition to CEBMs, it is demonstrated that companies are aligning their business strategies to meet CEAP policy timelines.

The European Strategy for Plastics published in January 2018 aims to push the EU towards a circular plastic economy, to support more sustainable production patterns for plastics, to promote reuse, repair and recycling of products as well as to reduce marine litter, greenhouse gas emissions and dependence on imported fossil fuels (European Commission 2018).

As a result of the Circular Economy Package and the Plastics Strategy, tangible changes are happening in progressing CEBMs at a faster pace than in the past. The theme resource efficiency and circular economy shows that, whilst companies were aware of CE previously, they were reluctant to implement the required changes due to not understanding the full extent of potential disruptions to their core business operations. Once organisations interviewed, had been able to evaluate the potential impact to their business, they began gradually the transition to CE, this was also highlighted in the literature (OECD, 2019a, UNEP, 2016, UNEP, 2019, Circle Economy, 2022, Dobbs *et al.*, 2013).

> *We were talking about integrated product policy and then that turned into eco design and it then there was sustainable consumption production and resource efficiency and so it feels like we've been progressing on this whole thing which is now called circular economy. For me it doesn't feel like a new thing it feels like a rebranding and a bigger political push, maybe. None of the concepts are really new. We've all been working on this for ages now.* ***EPR 1***

50% of the organisations from all parts of the value chain, interviewed during this research are members of the Circular Plastics Alliance (CPA), either directly or via their trade associations. Interviewees saw it as an important commitment by them, to help EEE/WEEE plastics value chains boost the EU market for recycled plastics to 10 million tonnes by 2025. The interviewees detailed how the EEE sector are working within the CPA, to identify limitations in existing standards that restrict the incorporation of high value recycled products being used in manufacture of new products, via the EEE Working Group. The CPA was launched by the European Commission in December 2018 (European Commission,2018), as part of Annex III of the plastics strategy relating the voluntary pledges by industry. Currently 272 signatories have made voluntary pledges to produce or use more recycled plastics; among them there are several EEE producers and WEEE plastic recyclers. Figure 7-4 shows the key areas where the CPA are developing and reviewing standards to increase the amounts of recycled polymer that can be used in products (CPA, 2022).

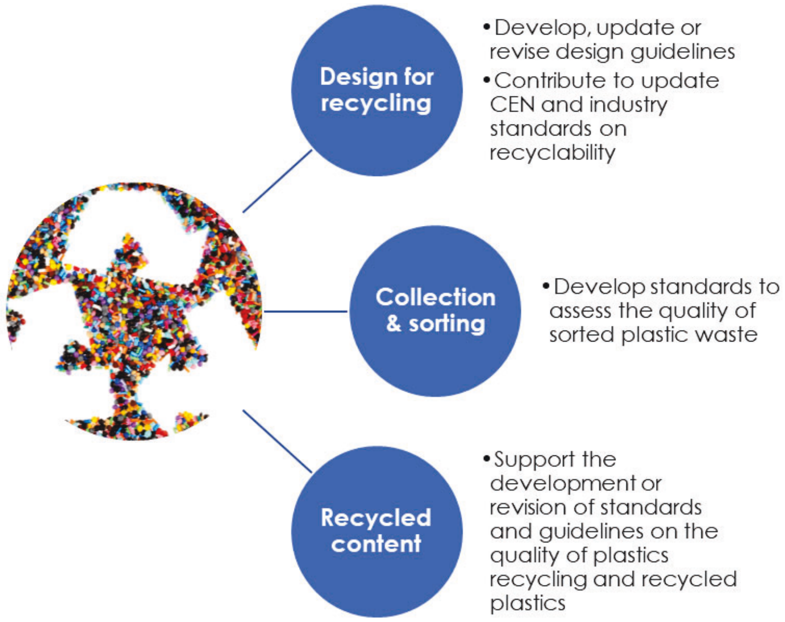

Figure 7-4 Areas covered by standards work of the CPA, (Reproduced courtesy of CPA, 2022)

One of the strategies identified and developed in theme 9 use of PCR, as key to increasing the uptake of recycled plastics, was the potential for a mandatory requirement for minimum recycled content in new products. For example, in the UK this is being applied to packaging via the plastic packaging tax (Plastic Packaging Tax (General) Regulations 2022). Currently for the EEE sector this remains a voluntary commitment, and companies have addressed this by joining the CPA and committing to voluntary pledges. OEMs in general during the interviews preferred the voluntary approach offered by the CPA, as they didn't believe there was the required infrastructure in place currently to provide the quality and quantity of recycled plastics to support a mandatory target.

> *I don't think there is enough volume, we need high quality grades of plastics. If suddenly it becomes law, then a lot of other companies will also need to use it, and I don't think there is actually the process and capacity in place to do that. You would immediately run into shortages which would immediately raise the price.* ***OEM 1***

OEMs felt that the positive benefit of the voluntary approach is that is gives organisations time to work with their supply chain and do any necessary research and development, thus reducing risk. The emergence of sub theme 10.2 in chapter 6, specifically highlights the need for collaboration throughout the value chain and has been clearly recognised by the EEE sector. OEM 9 demonstrated how they have implemented a collaborative value chain strategy when designing products to improve the potential for incorporating recycled content:

What we've done is get the entire supply chain in a room, talk about where we want to end up and make sure that we're developing as much as possible collaborative and strategic relationships rather than strictly transactional. And we have found that to be for us the key to cracking the code on the use of recycled plastics. ***OEM 9***

Additionally, other issues with mandatory recycled content were concerned with the ability to test products for recycled content. Currently the ability to test for recycled content is not widely available and therefore could lead to false claims, particularly for products being manufactured outside the EU.

You cannot check on the product to see if it contains recycled content. You can make it a law, but you can't enforce it. ***OEM 1***

However, if the gap between the pledges and the target by voluntary means is not met then the next step could be mandatory recycled content. The mechanism for this will be discussed in more detail later in this chapter. Whilst it is understandable that mandatory recycled content may be problematic in terms of securing the right materials, recyclers in the value chain would welcome mandatory levels. Recyclers such as PT 1 believe that mandatory recycled content would create stability in the market and make investment into sorting equipment more certain.

The question was how we could increase the recycling of plastics in EEE again to be used in another part of the electrical industry. The outcome was that this was down to the OEMS, as the OEMs set the material requirements, whether it is primary or secondary material, for their products and product parts. ***O1***

Theme 1 circular economy and sustainability in chapter 6, established that several OEMs such as OEM 1 and OEM 4, are looking to decouple growth from consumption. These OEMs through adopting a more circular approach and by keeping materials in use at their highest value, align with the European Green Deal (European Commission 2019), which aims for the EU to develop a resource efficient and competitive economy which is climate neutral by 2050.

> *And then if we go to circular economy it's, as I said, the decoupling of growth from consumption. That means keep materials in use at the highest state of value, reduce Having a greater percentage revenue from sustainable products helps to mitigate these risks.* ***OEM 4***

As discussed in chapter 2, one of the main blocks of the Green Deal is the second Circular Economy Action Plan which was published in March 2020 and provides a future-oriented agenda for achieving a cleaner and more competitive Europe (European Commission 2020). This shift is reflected in that OEMs and refurbishment organisations are practically progressing from primarily offering CEBMs that close material loops such as recycling, traditionally associated with linear business models, to narrowing and slowing business models such the service models offered by OEM 3, refurbishment models as facilitated by RF3 and durable products being designed by OEM 8 Often these are working in parallel with each other, so as is explored in chapter 6, and evidenced in the literature in chapter 4, (Bocken *et al*.,2021). many of the OEMs are adopting several CEBM strategies. For example, OEM 4 delivers service models (a slowing the loop strategy), where the products contain recycled content (closing the loop strategy).

7.1.1.2 Economic factors

In Theme 3 - resource efficiency and circular economy, interviewees such as OEM 7 demonstrated that for them, CE has grown as an increasingly attractive business proposition, as in addition to ensuring environmental sustainability it is also seen as responding to the business needs of price stability and as a mechanism for secure access to raw materials.

In other words, it's risk mitigation. Its more and more frequent in our industry, not only for us but for everyone dealing with a lot of raw material consumption that we face a crisis, because of some shortages of materials on the market. We know that in the future this might increase, the situation will not improve so we need to be ready with backup solutions. ***OEM 7***

The potential for growth of all the CEBMs is significant, according to the OECD, circular business models make up no more that 5-10% of current business practices (OECD, 2019a). OEMs have clearly recognised this and is evidenced in chapter 6 by OEMs such as OEM 4, 5 and 6 trialling different types of CEBMs such as remanufacturing. Currently CEBMs such remanufacturing offers a significant opportunity for value retention (IRP,2018). In the EU remanufacturing accounts for only 1.9% of production and is similar in the US at 2%.

It's basically an innovation challenge with our suppliers but we focused it on circular economy this year to say we kind of went out to our consumer suppliers and said, 'Bring us your circular economy innovations,' and did a bit of training with them about what that meant, and then we had about eight of the suppliers enter, in the end. Some of them were mobile phone suppliers and a lot of those focused on refurbished phone opportunities. ***OEM 5***

Considering the results and analyses presented in Chapter 6 there is evidence that the demand for quality recyclates is increasing. In theory this will drive the value chain to collect sort and produce more recycled polymers, from both an economic perspective as well as an environmental perspective. Interviewees such as OEM 7 and F2 acknowledged that legislation and fiscal changes are vital in order to fully realise the potential for recycled polymers.

Potential economic factors that could boost circular use in the EEE sector in the next years are presented below:

Economic Incentives from the Circular Finance Sector: Increasingly circular finance is being recognised as an important driver by financial institutions and internally within organisations as outlined in theme 1, section 6.1.1. Institutions such as F1, see circular finance, as a critical factor in contributing to more sustainable consumption and production.

> *the role of financiers is, basically, to provide the financial means needed to conduct circular business. So, circular businesses need financial capital. And especially the product-as-a-service mode,* ***F1***

Internally OEMs such as OEM 1 are using financial mechanisms such as Circular Finance Green Bonds which are ringfenced for green investment, as they recognise that substantial financial resources are needed to induce structural change in production and consumption alongside technology changes, to enhance economic efficiency and optimise use of financial capital.

This aligns with the literature, which shows a steep increase in activity in the past 2 years (EMF 2020), and the funding of initiatives such as Homie, a B2C service model for home appliances a by banks such as ABM Amro (Bocken *et al*., 2018).

Financial Risk: In chapter 6, section 6.1.1., F1 and F2 highlighted that external risks such as environmental, social and governance (ESG) criteria are becoming an increasingly important criterion for investors.

> *So, it is true that the financial sector underestimates the risks related to linear models. So, for example, the Dutch Central Bank has recently published the risks related to biodiversity loss, and I think that financial institutions overlook these types of environmental risks.* ***F1***

The emphasis has shifted from whether they matter to how they will be addressed, and the circular economy provides a crucial part of the solution. F2, highlights that ESG criteria can include measurement of circular elements such as product stewardship, eco-design and revenues from sustainable products.

> *"While we do not have a particular indicator that looks at how a company implements circular economy, we have three different indicators, one that looks at the revenues that the company is deriving from sustainable products, i.e. also products that incorporate sustainable features or are looking at closing the loop in life cycle analysis, then we're looking at eco-design—so, how a company is looking into incorporating recyclable or sustainable raw materials in its final product—and product stewardship, which is sort of at the end of the lifecycle, namely how a company is making sure that it's taking back its product, it's limiting its waste footprint, and how it's closing the loop when you're looking at a circular model."* **F2**

Investment from EU/National Governments: EU H2020 programme funds innovative business models to be trialled through projects such as PolyCE. OEMs such as OEM 1 and 7 who were partners in PolyCE were clear that being part of a research and development project and being able to collaborate with the value chain and experiment with demonstrators, had significantly progressed their ability to deliver CEBMs. Several products containing recycled content were launched commercially by OEM 1 and 7 as a result. Other sources of funding such as the European Investment plan has provided almost EUR 2.5 billion in lending for circular projects over the past 5 years (EMF 2020).

Fiscal Measures: interviewees from across the value chain such as EPR 1 and 4, analysed in theme 8 – collection systems, believe that extended producer responsibility such as the WEEE Directive (2012/19/EU) has stimulated collection of materials through funding of infrastructure. Improved collection systems have provided the materials needed to address the demand for recycled plastics. However, as was identified in the literature review in chapter 2, there is great potential for expansion as of these, and plastics taxes are increasingly likely to be implemented on national level and European level.

Cost of Recycled plastics: OEMs need a stable supply of material terms of volumes, quality and properties however this can be difficult to achieve from recycled sources of materials as reported in 6.3.2.1 Sub Theme 10.1 Quality and Quantity of Recycled PCR. For pre-treatment organisations such as PT2 and Conv 1**,** securing investment, to provide this quality whether externally or internally, will require the recyclers to demonstrate their return on investment. Expensive equipment such as density separators needed to achieve the quality requires access to capital, whether internal, by persuading their board of the need, or investment from financial institutions.

> *To put up a density separation line which copes with WEEE would be around £750,000. Then, electrostatic I would look at probably another £400,000. So just in equipment alone you're in for 1.1 / 1.5-million. Historically, there's been no justification for business cases in support of that because you just ship it all to China.* ***PT2***

From the literature review the advantage for using PCR plastics is a more stable market price with lower fluctuations. The monthly data from "Kunstoff Information" over the past four years shows less fluctuation in recycled plastics when compared to virgin plastics and that recycled plastic equivalents had a market price around 30-50 % below the price of primary plastics (KunststoffWeb 2021). It remains to be seen whether a future increase in demand for plastic recyclates would result in rising prices, although recent drops in oil prices, during the pandemic, didn't change price advantages of recycled material.

7.1.1.3 Social Factors

Sustainable development requires the consideration of the interaction of economic, social, environmental and technological aspects of a sector (Ren et al., 2013). The underlying rationale (environmental, political, economic and business) of the CE attempts to reconcile all these elements (EMF, 2012). The very concept of the CE promotes the efficient and environmentally sound use of resources, new business models and innovative employment opportunities as well as improved wellbeing and positive impacts on future generations. For OEMs such as OEM 8 social considerations are a key principle in the circular strategy

Most relevant is the origin of materials. We work with several parties and several supply chains to improve the working conditions across the supply chain, not only in mining. So there, we work with component manufacturers and our assembler
OEM 8

In the EU between 2012 and 2018 the number of jobs with a direct link to circular economy grew by 5% (EU 2020). Practical evidence of this was also presented in the case studies, for example in the refurbishment of appliances with RF 1 employing ex-employees from a closed down manufacturing plant and utilising their skills, as well as PT1 who through their reuse activities have created apprenticeships, providing training and skills development needed for future growth. Indirectly social enterprises such as RF 1 use the revenue created from sales of appliances, to get unemployed people back into work.

The provision of affordable appliances which raises standards of living, is also an important impact and reuse organisations such as RF1, RF2 and RF3 have seen an uplift in the past few years, in interest in reused products from all consumers, as environmental awareness as well as affordability influences purchasing decisions.

The EU Strategy on Corporate Social Responsibility (CSR) defines as “the responsibility of enterprises for their impact on society” (European Commission, 2011). CSR goes beyond legal requirements and includes aspects such as environmentally responsible production and procurement (Fortunati *et al.*, 2020)The uptake of recycled plastics into new electronic products is not only a choice for sustainability but could provide a company with a competitive advantage over market players who remain linear. On a B2C level the advantage was shown from the results of the consumer survey which indicated that recycled content would play a positive part in their purchase decisions. In theme 2 on circular economy and climate change OEM 3 highlights that on a B2B level, the use of recycled content is also an advantage, as it contributes to the business customers environmental credentials too, as it is used for Net Zero scope 3 calculations.

The promotion of the CE and consumer responsibility/ awareness is vital in driving the development, purchase and use of more sustainable products and services (Ghisellini *et al*., 2016). The sector survey highlighted in theme 4 found that many EU consumers claim to frequently engage with CEBMs in terms of recycling, retaining, and repairing possessions but engagement with CEBMs such as leasing, is dependent on the type of product, for example 80% would consider leasing of large household appliances, which is consistent with the findings evidenced by the emergence of new services for B2C such as Homie ((Bocken *et al*., 2018).

7.1.1.4 Technological factors

All actors in the value chain are very aware that by investing in new innovations and technologies in the long term, current barriers and challenges to implementing CEBMs can be overcome, leading to systemic change in how things are done and an increase in resource efficiency.

Digitalisation is seen as a key enabler, providing the means to digitally track assets and materials (Tonelli and Cristoni 2019). This is being used in several ways depending on the types of business model. The evidence shown in Themes 3 and sub theme 6,1 shows that for OEMs engaged in service models such as managed IT systems and photocopiers, digitalisation provides the means to assess usage so that consumables such as ink cartridges can be sent and also provides the ability to diagnose faults and repair systems remotely. Replacement parts can be 3D printed allowing more effective repair options.

> *We are digitising supply chains and production. That's what we do for example, with our 3D printing technology, which means transform the product design, manufacture, and distribution, disrupt the traditional supply chain and also create products and services in a more efficient and environmentally sound way.* **OEM 3**

Important technical challenges for closing the loop strategies such as recycling are the aesthetics, functional properties, colour or odour specifications in order to integrate PCR-plastics into new EEE products. All OEMS interviewed have their own specification requirements for each product and PCR plastics must meet these technical requirements in order to enable its future uptake (Mbarek *et al*., 2019). For OEMs a visual appearance is seen as a key priority in driving sales for electric and electronic goods and they have seen little feedback from customers that would show that this has changed. Desired aesthetics include colour and surface properties (gloss, matt, transparency, etc.) and this poses some of the major challenges for manufacturers and designers working with recycled plastics. The small range of coloured PCR plastics available on the market is a limiting factor for specific colour requirements as outlined by OEM1. Even when black is available it is often not the deep black required by the OEM.

> *Often what still restricts how much you can use is food contact, skin contact and colours. Even when the colour needed is black, deep black could be an issue.* ***OEM 1***

It was demonstrated during the PolyCE project demonstrators that recyclers can produce a broad spectrum of coloured and high gloss products with recycled materials however, this is currently prohibitively expensive and is only possible from post-industrial sources of recycled polymer.

7.1.1.5 Environmental factors

CEBMs are seen by OEMs as a mechanism to achieve resource efficiency and many of them are using CEBMs to build on sustainability strategies that they have been implementing for several years. Often the approach has come from the top with founders and CEO's recognising the importance of environmental sustainability to the success of the business.

CEBMs are being viewed as a mechanism for achieving sustainability, resource efficiency and climate change goals such as Net Zero. For OEM 6 this is a key driver to adoption of CEBMs.

> *Our big marketing focus is net-zero, and that will be the big story for the next ten years. I would like to think, as customers become more educated in this, we can push our stories about the circular economic model and demonstrate that it is reducing our CO_2.* ***OEM 6***

OEM 7 recognised that CEBMs as a key advantage by providing the opportunity for business to manage their material flows better and overall framework to deliver resource efficiency for those businesses implementing them.

> *I always say the CE is not the what but the how, the big what is resource efficiency and the CE is a way, its probably the best or most level way to reach or to optimise resource efficiency.* ***OEM 7***

Organisations see the implementation of CEBMs as a way of delivering a sustainable value proposition to customers who are becoming more aware of the need for sustainable consumption. As B2B suppliers' OEMs such as OEM 3 are being asked to provide data to help their customers achieve their own sustainability objectives.

> *we help our big customers doing their own sustainability impact reports. So, we do the calculation, for example, for their printer fleet. So, we know what they have, if they have it from --, of course, and then we do the calculation, how many metric tonnes of CO_2 they saved, how much electricity and water consumption they saved and all kinds of other environmental factors.* ***OEM3***

The financial sector recognises that linear model of production doesn't include external risks such as security of supply of raw materials and loss of biodiversity as was seen in chapter 6, however they cannot yet estimate these risks. For OEMs such as OEM 8 a secure and an ethical raw material supply chain, is a prime consideration.

Compared to virgin plastics, the recycling of plastics can save large amounts of CO_2 emission and energy (EERA, 2018) with an estimated CO_2 reduction around 2.5 million mega tonnes per year based on compliant recycling of all plastics from WEEE in Europe according to the standard EN 50615-1 (EERA, 2018). However, OEMs such as OEM 7, are currently not prepared to pay extra for it, financial institutions believe that this is a situation that needs to change, and the externality costs need to be built in to cost models in future in order for companies to be more resilient to environmental risk.

> *Financial institutions are not yet organised to finance the circular economy, but I think that the main obstacles are that externalities are not priced in and that circular businesses … The costs of conducting circular businesses are, in general, higher than the linear alternatives. They are used to calculating financial risks and they have their instruments to do so, but we do not yet, as society, understand what the risks to the environmental … What the environment risks mean in financial terms—what they do with financial profitability on the long-term. So, we need to invest in developing these types of instruments to be able to estimate environmental risks.* ***F1***

OEMs 1 and 7 and Conv 1 investigated through the PolyCE project, the life cycle assessment (LCA) of virgin and recycled plastics. The environmental performance of post-consumer recycling of PP and PS from WEEE was compared with a respective conventional approach. The environmental performance of the resulting PCR PP and PCR PS from PCR approach showed that the GWP of 1 kg PCR PP is 75 % lower than virgin PP. Fig 7-5 shows for that circularity needs less water for production and so strengthens resilience to climate change, water requirements to produce PCR equivalent is 53 % lower and the abiotic resource depletion potentials (ADP) is 91 % lower than the virgin production. (PolyCE, 2022). Compounders and recyclers interviewed see this as a benefit to users of recycled polymers and that it should be factored in when considering the use of PCR as it can contribute to Net zero goals. Some of the compounders and recyclers are reducing their water consumption further by recirculating water used in their processes, thus using a narrowing the loops CEBM (Konietzko *et al.*, 2020a)

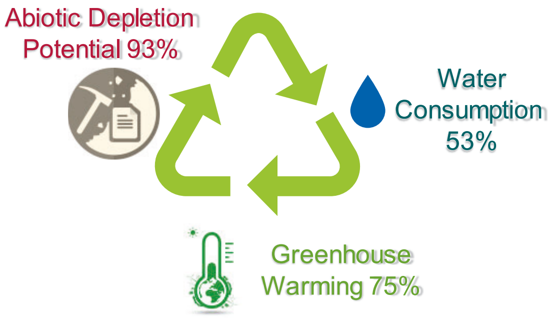

Figure 7-5 Saving potential of using recycled instead of virgin plastics from WEEE (Adapted from PolyCE 2022)

7.1.1.5 Legal factors

Chapter 3 highlighted that the EEE and WEEE sectors are highly regulated due to their complex and potentially hazardous nature. Theme 9.3- the recycling process in chapter 6 showed that the legislation can impact on the ability of organisations in the EEE sector to adopt closing the loop CEBMs. For organisations such as OEM 3 and OEM 4 different legal aspects in the different countries that they operate impact on the circular business models they adopt which demonstrates that policy both within national and European/ global context is important in the facilitation of CE. For example, OEM 4 in the US has a collaboration with a US wide social enterprise and recycler based in Texas, however whilst they could access materials from Europe, transport costs make this prohibitively expensive, and the system would not work as well under EU WEEE regulations.

> *Currently the Closed Loop is a US only option. We are focusing on resourcing materials from more than just the US and we are really focusing on the EU. In part because CE is such a hot topic there, we really want to get materials from there. One of the problems we have found in the past isn't necessarily on the legal barriers of transferring the materials, but rather the cost of transportation, connecting potential recyclers with our*

current partners. We just haven't been able to make the prices match and that's mainly because of logistics. **OEM 4**

In Europe EEE producers and retailers are subject to extended producer responsibility via the WEEE Directive (2012/19/EU) which provides an incentive to shift to more circular business models. Article 4 of the WEEE Directive (2012/19/EU) encourages the "*cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials*" The impact of the WEEE Directive (2012/19/EU) can be seen in practice with OEMs such as OEM 1, 3 and 9 actively collaborating with recyclers to facilitate recycling however, this is currently limited to a few pioneers and there is a lot of scope for this collaboration to be expanded.

The European Commission has set increasing collection and recycling targets to increase the amount of WEEE to be treated, therefore, from 2019 the minimum collection rate rose from 45% to 65% this will in theory mean that more WEEE plastics are available for recycling.

Postconsumer plastic recyclate (PCR) need to comply with defined limit values for harmful substances (e.g., RoHS, REACH as outlined in chapter 3). Due to these regulatory requirements, WEEE recycling facilities and EEE manufacturers are often faced with difficulties like dealing with plastics parts that contain brominated flame retardants (BFR), this situation is exacerbated by uncertainty on POPs regulation as seen in the literature review in chapter 3 and theme 9 in chapter 6. Recycling technologies today are increasingly being developed to detect and remove substances of concern (SOC) from the plastic waste streams, followed by a secure elimination to remove SOC from the value chain. Furthermore, pre-processors and recyclers are widely aware of the waste stream categories and even the plastic parts that need special handling to avoid SOC entering the mix of materials to be recycled. It is critical that there is a balanced interface between EU chemical and waste legislation.

OEMs 1 and 7 have several food contact plastics and use of food contact PCR is currently not an option. Food contact approval remains a challenge for recyclers such as Conv 1 for materials other than PET. PCR WEEE plastics could contain certain impurities including a low percentage of substances of concern, applications for food contact, toys or medical devices which are not suited for PCR plastic uptake. Within the PolyCE project tests were done on food-grade HIPS recycled material from refrigerators as OEM 7 was keen to investigate the potential. The technical performance was demonstrated to be equal to virgin material, however, the material cannot be considered as food-grade qualified as it has no certification. If this regulatory issue could be overcome, it could boost recycling as food contact materials have a higher value. There is potential that for some PCR polymers that the challenge to using food contact PCR could be addressed by the new amendments to the food contact regulation. The amendments to the food contact legislation could potentially provide a pathway, with the introduction of piloting novel technologies for non-PET polymers (EU 2021). The ability to sell food contact non-PET polymers at a higher price could further stimulate investment in WEEE plastic recycling with the objective of increasing quality and quantity of the available materials.

OEMs such as OEM 4 and 7 currently prioritise designing for perspective energy efficiency rather than recycled materials due to the current Ecodesign Directive (2009/125/EC) which focuses on minimum mandatory requirements for the energy efficiency of the household appliances and ICT products rather than materials. The EU recognised this limitation and addressed it through the development of an Eco-design Working plan as part of the CEAP (European Commission 2016). The Eco-design Working Plan was written to explore product-specific elements including durability, reparability upgradeability, design for disassembly, and information and ease of reuse and recycling in order to further establish the scientific basis for developing corresponding criteria that meet the requirements to deliver circularity. The new Sustainable Products Initiative (SPI) launched in March 2022 (European Commission, 2022)will repeal the Ecodesign Directive (2009/125/EC) making it regulatory rather than a framework to ensure harmonisation across EU member states. This will include material efficiency and design requirements for EEE products, which should stimulate greater adoption of CEBMs in the future.

Respondents of the consumer survey indicated that they were willing to engage in sustainable consumption driven by their environmental concerns and that they frequently looked for information about sustainability on products but often that information was difficult to find. Lack of knowledge, awareness and communication could potentially become a major barrier, resulting in a low demand for EEE containing recycled plastics in electronic devices. The use of mandatory ecolabels could be used to mitigate this.

Introduction of mandatory recycled content targets was very much supported by the parts of the value chain that produce recycled plastics as they believe this will improve confidence for investment into the technology needed to produce material of a high quality. There was a consensus from the interviewees from all parts of the value chain, that it might only be a matter of time before minimum recycled content is implemented for new EEE products and the repeal of the Ecodesign Directive (2009/125/EC) would probably be the vehicle to do this. Companies interviewed were keen to trial the integration of PCR plastics in new products as they believed that if a policy change regarding mandatory recycled content was coming then they would be well prepared for this change and to implement the new recommendations more easily and quickly.

Legislation around transboundary movement of materials such as the Basel Convention (BRS 2022) was not necessarily seen as a barrier by interviewees, but the cost of transportation; connecting potential recyclers with partners can be challenging and complex, which can act as an economic barrier. One of the suggestions put forward by convertors and pre-treatment organisations interviewed was the regulation of quality of export plastics to increase stability in developing better quality recyclate. Pre-treatment organisations such as PT1 and 3 believe that if the plastics previously going to Chinese markets are simply diverted to Thailand, Vietnam, Taiwan and Malaysia this will stop investment by processors in Europe.

7.1.2 The EEE sector

The industry sector forms the next layer of influence on the environment that organisations operate in, a grouping of organisations producing the same products and services in this case the EEE sector. Porter's five forces shown figure 4.2, Chapter 4 can be used to evaluate how circular strategies work within the EEE sector and how circular strategies might lead to competitive advantage and therefore increased profitability (Porter, 2008).

7.1.2.1 Bargaining power of suppliers

In the EEE value chain, there are limited concentration of suppliers of PCR polymers therefore the potential bargaining power of suppliers is high. As demand for circular materials increases suppliers could potentially raise prices or insist on other more favourable terms as there are few alternative sources. In addition, downstream suppliers of WEEE recycled plastics will need to invest to produce the quality and quantity of materials needed which could lead to price increases which will have to be passed on to the EEE manufacturer.

However, it is easy for OEMs to switch back to suppliers of virgin materials, so there is a mutual need to create value between the supplier and buyer which is gained by the collaborative approach taken by the OEMs. The relationship between OEM 1 and Conv 1 has allowed Conv 1 to invest in technologies, in the knowledge that the materials will be purchased by OEM1, for OEM 1 they have the confidence that the recycled polymers will meet their quality specifications. Another way that OEMs implementing circular strategies are reducing this bargaining power is by forward integration through purchasing supplier companies as in the case of OEM 9 who purchased a compounding company to guarantee a quality supply of material. What is clear is that trusted suppliers are valued, and it takes time to establish these supply chains for both parties. Those OEMs highlighted above that are implementing circular strategies are well informed about circular practices and can properly rank suppliers on their capabilities.

7.1.2.2 Threat of substitute products

Substitute products to circular EEE products represent an immediate high threat as linear products are the dominant method of consumption; however, current and future policy developments and financial incentives will mitigate this to a certain extent. Companies transitioning to circular business strategies are provided with a buffer as customers generally have the choice of opting for a circular business model or not. As many of the CEBMs are unique to specific products rather than the whole range, customer loyalty will reduce the potential for switching between suppliers of products. The value proposition is greater than the product itself, especially for service models as it includes maintenance and repair which make it unique and more difficult to find substitutions.

7.1.2.3 Bargaining power of buyers

The bargaining power of buyers is medium/low, this however depends on whether they are B2B or B2C. As many of the CEBMs offered to businesses by OEMs in this research, are bespoke and involve long-term contracts and commitment, switching cost for buyers would be high in this context. From a B2C perspective currently there is a low concentration of buyers that would buy a circular alternative. Market penetration for B2C is increasing as consumer awareness of circular alternatives increases, the success of circular alternatives will however be determined by the value proposition offered to the consumer in switching to a CEBM. The consumer survey indicated an increased consumer willingness to consider CEBMs such as refurbished products and those containing recycled content. OEM 1 delivered a successful B2C subscription model with their laser hair removal product, which indicated a change in consumer attitude to what OEM 1 had previously experienced and expected. However, this will depend on the product, and it seems likely that this will work better for high value products such as high-cost personal health products where leasing reduces the risk of not liking a high-cost item. OEM 3 has also been successful in penetrating this market with their ink subscription service by making it very accessible and easy to use, thus developing a successful business model.

7.1.2.4 Threat of new entrants

The threat of new entrants offering circular CEBMs could currently be considered medium/low. The investment needed to enter the EEE sector is high. OEMs active in the EEE sector, as demonstrated in chapter 6, have had to invest significant time and finance in developing these CEBMs and therefore have a cost advantage. However. as policy pushes other companies into offering circular strategies this threat could increase in the future. Those companies who have already invested in circular strategies will be better placed than those yet to invest, to expand the scope of their products that are circular, building on their successes from circular ventures and being able to demonstrate a proven track record of effective delivery. For large companies implementing CEBMs, economies of scale offer these companies a competitive advantage over new competitors, considering their global manufacturing and distribution network. However new entrants would have the agility to start offering innovative new CEBMs from the start without having the burden of transitioning to circular economy business models from linear, so could be a high threat for new products. For example, OEMs such as OEM 1 have had to implement new financial mechanisms to deliver their subscription CEBM, which is disruptive and incurs a cost, whereas a new entrant would put that in from the beginning.

7.1.2.5 Rivalry among existing competitors

The level of competition in the EEE industry is strong, for example in the IT sector many more organisations such as OEM 3 are offering CEBMs particularly on a B2B case. Differentiation is high for those organisations such as OEM 3, when offering CEBMs compared to linear models. OEM3 has seen that the value to the customer is evident and larger business customers can see the advantage in the offer and are making conscious decisions to choose CEBMs over linear ones.

7.2 Strategic Choices

Strategic choices are the choices an organisation makes in terms of its circular strategy in this case, and the methods that it will use to pursue that strategy. An overview to the approach to adoption of CEBMs in terms of the categories outlined in figure 7-6 by each of the OEMs will be evaluated from the findings ((Konietzko *et al.*, 2020).

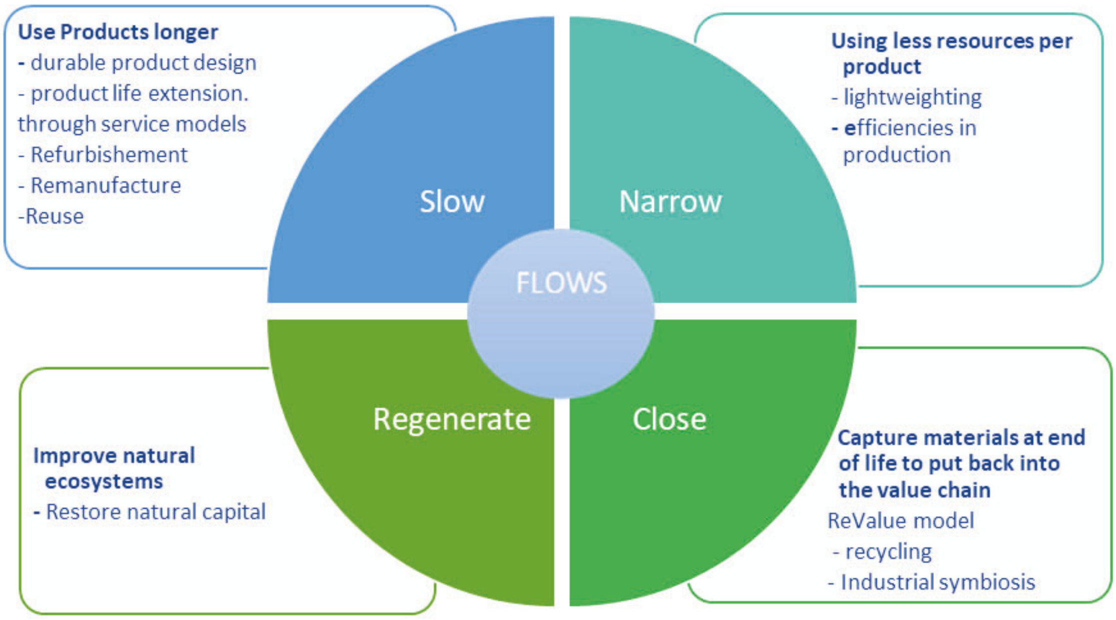

Figure 7-6 Business models strategies (Adapted from Bocken *et al*., 2016; Konietzko *et al*., 2020)

7.2.1 OEM 1 circular strategy

OEM 1 has adopted several different CEBM strategies, predominantly in the slowing and closing loops, they see sustainability as an important part of their future business strategy and CEBMs as a key mechanism for delivering on their sustainability goals. OEM1 was interviewed twice (2017 and 2020) as they were a partner in the PolyCE project, and this enabled a reflection on how being part of a research and development project had impacted on their progress in their circular strategy. They now have clear goals of what they want to achieve, for example 25% percent of their overall revenue should be generated from CEBMs by 2025. In the original interview, the goal was only 15% which was already achieved by 2020. The continuous improvement reflects on how the importance of CEBMs has grown and reflects the opportunity via European funding to undertake research and development to demonstrate what was possible.

The initial strategy concentrated on developing slowing their business loop strategies such as product service models, for their large-scale healthcare equipment aiming for all this equipment to be delivered via this model by 2025. Having achieved success in they have now revised that goal and extended it to all professional medical equipment including smaller appliances.

By 2017 they had started a small-scale pilot delivering a personal healthcare device as a product service model to assess feasibility. The success of which they were surprised by, having believed that consumers would prefer to buy rather than subscribe to a leasing model. Having demonstrated the attractiveness of the value proposition to customers, they had to set up the financial infrastructure to be able to deliver the CEBM. This service is now offered as a subscription and CEBM are now looking at other products that could be delivered this way. The reason that OEM1 believe that this model has worked, it that it is a high-cost item and consumers want to know if it works for them, thus it minimises financial risk for the consumer. A consequence of scaling up the model is that OEM 1 has had to re design the product so that it is easier to refurbish. Delivering this product via a subscription model (calculated by an internal LCA) achieves around a 40% reduction in environmental impacts.

Closing the loop strategies taken by OEM 1 have been around incorporating more recycled content into their appliance. As part of PolyCE they trialled several demonstrators including a coffee machine, vacuum cleaner and internal parts for shavers. All three items are now in commercial production. OEM 1 has successfully incorporated 70% recycled content into their popular coffee machine.

7.2.2 OEM 2 circular strategy

OEM 2 adopt a partial closing the loops strategy by capturing materials at end of life. In the country where their headquarters is based, located outside the EU, they operate a partial closing the loop system, collecting WEEE products at end of life and ensuring it is processed correctly. Currently they are not incorporating recycled WEEE plastics back into their appliances as legislation in the country of manufacture makes this an issue, thus highlighting the need for a push in policy at national as well as global/ European level. Whilst a closed loop system using WEEE PCR is not possible, they are however using non WEEE recycled PET in their washing machine drums. OEM 3 are also piloting a slowing the loop strategy, working with a housing association to offer an affordable leasing option for home appliances.

7.2.3 OEM 3 circular strategy

OEM 3 is investigating CEBMs by reinventing the way its products are designed, manufactured, used and recovered as it moves business models and operations towards a material- and energy-efficient circular economy approach. OEM 3 sees a business opportunity in designing products and services that meet and enable circular economy applications for its customers by adopting closing, slowing, narrowing and regeneration strategies.

OEM 3 has well established, product service models for business to business offering managed print and IT services, however business to consumer service models is a more difficult model to implement. OEM 3's ink subscription service is an example of a business to consumer product as a service model and has more than 1 million subscribers in six countries (Strandberg 2017). Compared with conventional business models' printers using this service consume up to 67 percent less materials per printed page (Strandberg 2017). Through the service, an internet-connected printer notifies OEM 3 when it is running low on ink, and a replacement cartridge is automatically despatched. The value proposition of this CEBM for customers is that they never run out of ink when they need it, and that they can recycle used cartridges more efficiently (returned cartridges are fed into OEM 3's closed loop recycling program). An LCA study of the process suggests that using this system as opposed to the traditional purchase and recycle system, decreases the carbon footprint by 73%, reduces energy use by 69% and water consumption by 70% (HP 2020).

OEM 3 has a comprehensive closed loop strategy as more than 80% of their ink cartridges, and 100% of their LaserJet toner cartridges are now manufactured with recycled content, a total of 60,000 tonnes in the past 15 years (HP 2020).

7.2.4 OEM 4 circular strategy

OEM 4 operate close, narrow, and slow circular strategies. OEM 4's slowing strategy revolves around a refurbishment CEBM which is run in partnership with a social enterprise in the US. OEM 4 collect electronics from 11 states, which are dropped off at their social enterprise facilities.

For their closing the loop strategy OEM 4 has been using recycled content since 2008 and in 2012 set a series of goals to use sustainable materials including recycled plastics. OEM 4 see an added value in developing a closed loop supply chain, in order to recycle their own material and material from their industry. Products collected via their refurbishment CEBM, that can't be reused or refurbished are fed into their closing the loop system and shipped into one electronics recycler, who recover the plastics which are then used in new computers. The added environmental benefits of using a closed loop source rather than just a recycled source, are measured as their impact on Natural Capital, this describes the non-market value of the environmental resources that businesses depend on to grow revenue. OEM 4 commissioned a study to assess the net environmental benefit of closed-loop recycled plastic in terms of lower pollution, reduced greenhouse gas emissions, and improved human health compared to using traditional plastic. The study quantified positive and negative environmental impacts and putting a monetary value on the results of the environmental improvements (Trucost, 2015).

7.2.5 OEM 5 and 6 circular strategies

OEM 5 and 6 are telecommunications and entertainment organisations and have developed similar slowing circularity strategies centred around a results-focused service CEBM so these will be considered together. For both organisations the EEE equipment that they produce is a tool to deliver their services. and significant investment has been made in designing devices that can deliver their services effectively. Their equipment is all designed to be refurbished, remanufactured or repaired through a modular design. Both organisations see adoption of this CEBM to achieve their net-zero goals and an important way to build resilience into their supply chains. In 2020 OEM 5 introduced a contractual obligation on the service user to return equipment at the end of their service contract or they will be charged. This financial incentive has resulted in a greater return of equipment, this process is designed to be easy for the customer.

7.2.6 OEM 7 circular strategy

OEM 7 adopts both closing the loop and slowing the loop strategies. Their closing the loop strategy is centred around incorporation of recycled metals, however through the PolyCE project they successfully trialled using recycled mineral filled polypropylene (the filling of the PP provides stiffness) in their washing machine drums. Following the success of the recycled polymer they investigated the ability to secure recycled filled polypropylene commercially in the quantities and quality they need as discussed earlier in the PESTEL analysis. In terms of slowing the loop strategy, OEM 7 adopts a refurbishment CEBM. OEM 7 participates in over forty-five appliance takeback schemes via trade, consumer, and internal returns. These goods are returned to their facility in the UK and refurbished and sold as a second-life appliance with a warranty.

7.2.7 OEM 8 circular strategy

OEM 8 are both an SME and a social enterprise. They set up as a company to deliver a circular strategy for mobile phones. They adopt slow, narrow, regenerate and closed loops as part of their circular strategy. Social economic impact forms a core part of their ethos as a company, concentrating on regeneration and narrowing loops through ethical supply chains. OEM8's slowing the loop strategy revolves around modularity and long-life CEBMs, their phones are designed to be repaired, refurbished and upgraded. Their phones have an IFixit repairability score of 100%. The limiting factor is software updates for which they are investigating a solution. At end-of-life customers are encouraged to return phones to the company, forming part of OEM 8's closed loop strategy. The other aspect of OEM 8's closed loop strategy is to maximise the amount of recycled content possible without impairing the functionality of the phone.

7.2.8 OEM 9 circular strategy

OEM 9 adopts a closed loop circular strategy incorporating recycled content into a wide range of products. Their goal is to incorporate recycled plastics into all their products. Part of their strategy, after an initial trial, was to purchase a compounder. The purchase of the compounder gives them a competitive advantage as they have control over the quality of the recycled plastic being produced.

7.3 Strategy in Action Impacts

7.3.1 Examples of strategy in action

Many of the organisations that were interviewed during the PolyCE project have a long history of embedded sustainability and resource efficiency goals. An interpretation of best practice from the EEE value chain using examples from companies interviewed is shown in Figure 7-7.

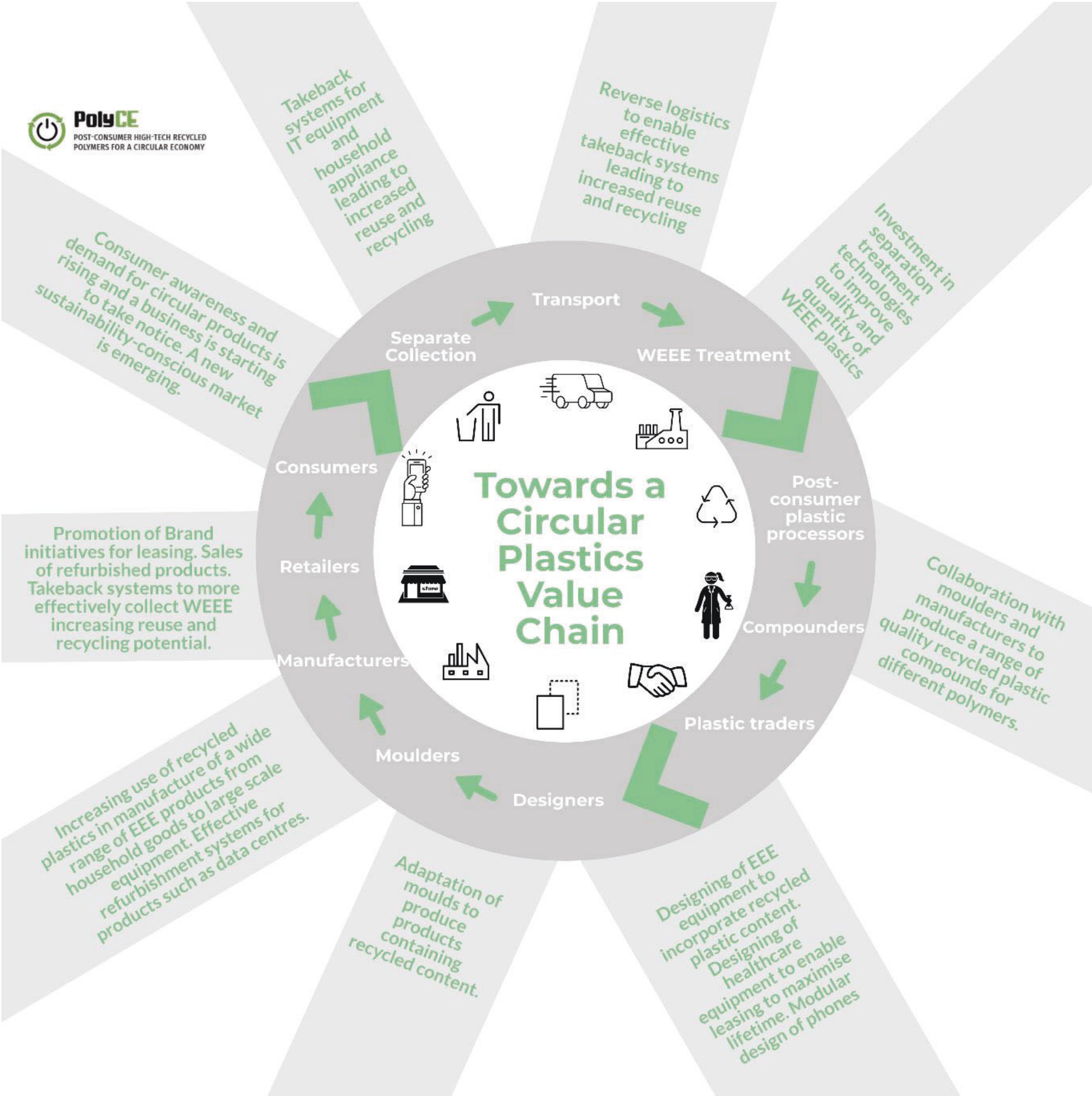

Figure 7-7 Strategies in action from the case study developed by the author for the PolyCE project (PolyCE 2022).

7.3.2 Measuring Impact

A review of indicators used by OEMS to measure environmental/ circularity performance show that there is a range of methods to calculate environmental or circularity employed. While companies are encouraged to come together in a pre-competitive environment to share best practices for movement towards a circular economy it is clear that each organisation's journey towards circularity is unique and therefore comparison can only be done in a meaningful context and in careful consideration. Companies such as OEM3 and OEM4, focus on the environmental impact of the company with OEM 4 reporting "net benefits” (in terms of natural capital) and OEM 3 aligning itself with “three pillars of sustainability”. All OEMS report on circularity in terms of improvements or goals achieved, set against pledges and internal benchmarks, and in relation to OEM 1 and OEM 7 are keen to report in terms of individual products as well as looking at the company as a whole, as this advantageous when marketing products. It is noted that none report in terms of economic benefits and tend to cite the impact, in terms of benefits to sustainability. OEM 3 identify as aligning and progressing towards the following UN Sustainable Development Goals (SDGs) 3,4, 5, 7, 8,9,10,11,12,13 and 17. There is no consensus as to how companies should measure their effectiveness in moving towards more circular business models. Some of the OEMs interviewed such as OEM 1, are active in collaborating to develop overarching Circular Transition Indicators (WBCSD 2022) which aims to provide an objective, quantitative and flexible framework (Van Brunschot, 2020) and compliment a company’s existing sustainability efforts.

An interpretation of best practice gathered from all the OEMs interviewed (Figure 7-8) shows the potential steps to be considered by OEMs, when developing the case for, and monitoring the development of a circular product.

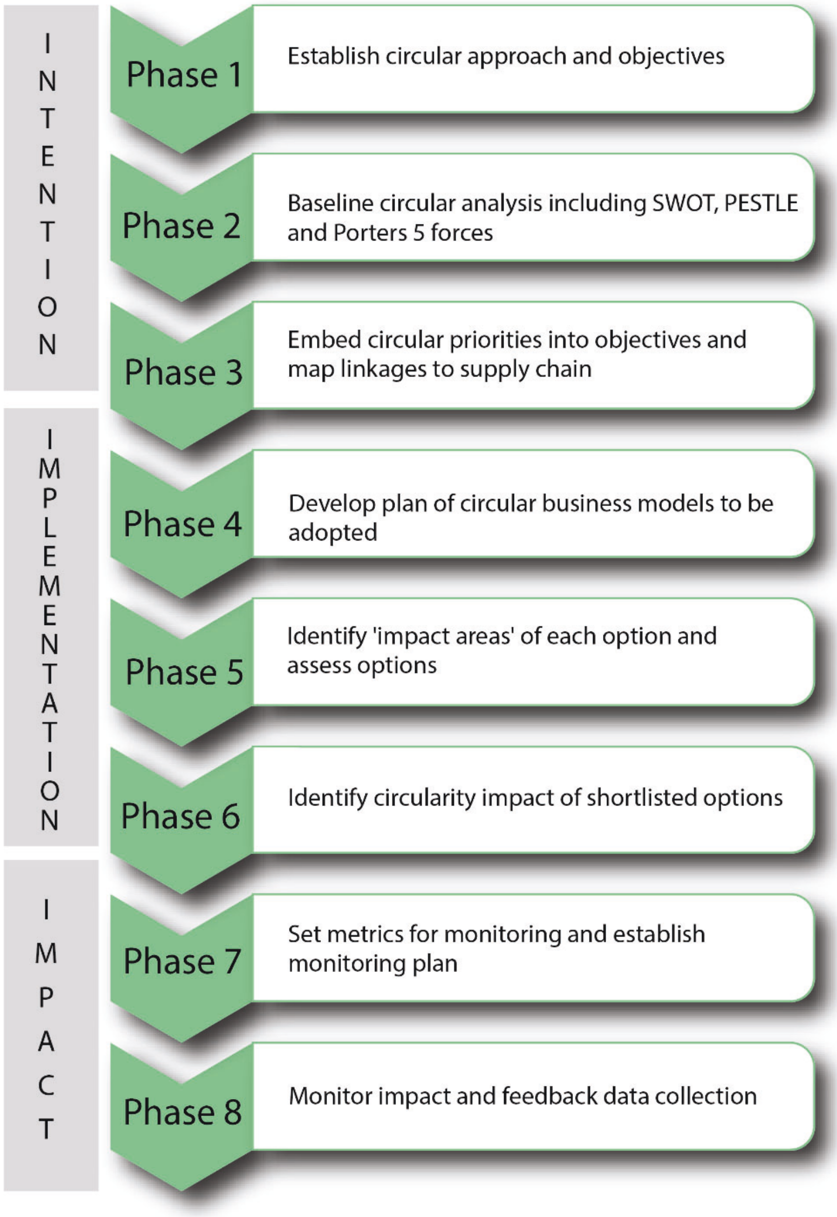

Figure 7-8 Phases of developing and implementing a CEBM

Chapter Summary

This chapter has explored how the themes from Chapter 6, combined with the findings from the literature in chapters 2-4 have shaped the use of CEBMs as part of organisational strategy. PESTEL analysis and Porters 5 forces have been used to evaluate why different circular strategies are adopted by OEMS. This has demonstrated that the developing of circular strategies and implementing them through the adoption of CEBMs can create an effective business strategy for the EEE manufacturing sector.

Chapter 8 Conclusions

8.1 Introduction

This concluding chapter presents the research's contribution to circular economy strategy and business model (CEBM) literature. The aim of the research was to investigate how production and consumption of EEE can be undertaken in a more sustainable way through transitioning to a circular economy. The chapter brings together the conclusions from the literature review, findings and discussion chapters and answers the research questions and objectives. It also evidences the future opportunities for advancing the research and practical applications of circular strategies and CEBMs in this research area.

8.2 Originality and contribution

This thesis is original in investigating the practical application of CEBMs focusing solely on the Electrical Electronic Equipment sector, with a specific focus on plastics. Despite the growing interest and theoretical discussion around circular strategies and CEBMs found in the literature, there are few studies on the practical application of CEBMs within EEE sector and use of WEEE plastics back into EEE products. While metals and electronic components are prioritized during recycling, plastics are often left in the background. Plastics represent a significant portion of EEE at around 25% by weight, and therefore present an important contribution in the reduction in the need for virgin resources.

The following research questions have guided this study:

RQ 1 *How are Circular Economy practices and models being adopted currently within the EEE value chain?*

RQ 2 *Where are the potential opportunities for intervention to apply new CEBMS in order to retain value of products and materials?*

RQ 3 *How do external and internal factors pose challenges and barriers to adoption of CEBMS by businesses?*

RQ 4 *How do external and internal factors present opportunities that could be provided by adoption of CEBMS by businesses?*

The following objectives were set in Chapter 1 in order to achieve the research aim of identifies influencing external and internal factors, that can affect the uptake and application of circular business models (CEBMs) by the Electrical and Electronic Equipment sector and the mechanisms available to enable adoption.

1. **Critically evaluate and identify key CEBMs being adopted by the EEE sector operating within the EU**.

The literature review in chapters 4 provided a theoretical understanding of different types of CEBMs and the types of circular business strategies that they support. The reality of how these theoretical CEBMs are being practically applied currently within the EEE value chain was achieved through the case study research methods which allowed for research under real world conditions, within the context of supply chains, answering the how and why (Yin, Robert K., 2013).

2. **Critically evaluate the opportunities to apply different CEBMs within the value chain from representative electrical/electronic product groups and their constituent main plastic components.**

The literature review in chapter 3 provided a theoretical understanding of the EEE sector and the constituent plastics that make up different EEE products. This data was supplemented by the case study research and by data from the PolyCE project to evaluate specific product groups and their plastic components by interviewing the pre-treatment and compounder part of the value chain to gain knowledge on the quantity of plastic constituents of products is being collected and processed from WEEE and the markets that they currently supply.

3. **Analyse the challenges, risks and barriers to adopting Circular Economy business models (CEBM) in the EEE sector operating in the EU.**

Several barriers, risks and challenges were identified through the literature and findings.

The case study approach enabled a greater understanding of these and the impact that they have on the EEE value chain. External factors identified in the PESTEL analysis in Chapter 7 and the industry analysis highlighted the potential risks of adopting CEBMs, however this analysis also highlighted the risks of not adopting CEBMs particularly the issues of value chain resilience. As EEE and WEEE contains hazardous materials, valuable data was also gathered to understand the losses incurred due to hazardous substance in some of the plastics and the risk this poses to the viability of closed loop circular business strategies.

4. **Determine the economic, environmental, and social opportunities to use CEBMs as when developing and implementing business strategies within the EEE sector operating within the EU.**

Material extraction processing of the materials and consequently waste generation to satisfy the growth in EEE production demand places pressure on the resource base and has environmental consequences such as greenhouse gas emissions, air pollution and toxic effects on ecosystems. The literature review in Chapters 2 and 4 highlighted the opportunities that circular strategies through adopting CEBMs can provide a viable alternative to linear models. Circular strategies were demonstrated by the findings to be having real impact on tackling environmental issues created by unsustainable linear practices as well as creating positive economic and social impacts. The research identified the opportunities arising to increase the value proposition across the supply chain for stakeholders in the EEE value chain.

8.3 Research Conclusions

CEBMs are being increasingly adopted by OEMs as part of their circular business strategies for a wide variety of applications. CEBMs are seen as being a viable alternative solution to linear business models. Often, once they have been adopted successfully for a specific product the OEM will assess other products in their range to determine their suitability.

The OEMs control the flow of materials through adopting slowing, narrowing, closing and regenerating CEBMs as part of their business strategy. The success of these CEBMs adopted however, is determined by collaboration and support from the whole EEE value chain. Circular strategies adopted by the OEMs were demonstrated to be having real impact on tackling environmental issues created by unsustainable linear practices as well as creating positive economic and social impacts. The research identified the opportunities arising to increase the value proposition across the supply chain for stakeholders in the EEE value chain. The following key factors influence the adoption of CEBMs.

- The pace of transition to CEBMs will be determined by both the legislative framework and the commercial attitude to change. Currently it is simpler for business to be conducted in a linear way, and the adoption of CEBMs will need to run in parallel with linear business practice before a paradigm shift is achieved.
- Design is a critical factor, by designing for specific types of CEBMs the potential for reducing resource consumption is maximised.
- Design of CEBMs including the product and systems need to be desirable to the customer, economically and practically feasible, and deliverable by the producer.
- Effective delivery of CEBMs needs the value chain to work as a system. Collaboration with both suppliers and customers is critical in ensuring the circular flow of materials.
- Controlling the flow of materials retains the value of products, components and plastic materials for longer. Ideally therefore, products should be kept in use either intact or as component parts, for their designed lifetimes.
- Well-designed value propositions offering users of EEE easy ways of accessing products can be successful from both B2B and B2C perspectives.
- There is considerable scope for organisations to offer subscription services for high-value products directly to consumers, which provides the opportunity to significantly reduce environmental impacts (up to 40%) of these products.
- Effective preparation for reuse can be maximised by using takeback systems as this

leads to the highest levels of reuse of whole products or product parts, including plastics.

- Once a product reaches end-of-life the materials need to be captured effectively and reprocessed back into new products, ideally within a closed loop or a high value application. Essential to this is designing systems to capture more of each type of waste streams and by defining appropriate product clusters.
- Incorporating recycled content once a process has already been designed requires more investment in time and financial investment, than if it had been designed to incorporate recycled content at the concept stage.
- Increased capture of small household appliances would increase both the total amount of plastics captured, specifically of ABS and PP which can be incorporated back into new EEE products.
- The recycling industry can meet quality requirements for many electronic applications, and certain plastic components can be replaced by PCR polymers.
- There is a need for manufacturers to better understand the challenges and possibilities of PCR plastics for their specific products. Overcoming these challenges will require close collaboration between recyclers, compounders, designers and OEMS.
- WEEE pre-treatment operators must improve their treatment procedures in order to provide suitable quality plastics to recyclers. Recyclers and converters can then subsequently improve the performance of the plastic compounded according to the manufacturer’s specifications.

8.4 Limitations

The case study approach whilst giving rich and detailed data, was limited by context and time so it would be difficult to apply it in a different context, such as a different value chain and it is open to interpretation.

The organisations interviewed and surveyed were assumed to be representative, however they may or may not reflect what would occur in similar organisations, as each organisation's individual strategy will determine the direction that they take. Therefore, the case study approach can only suggest that in similar organisations, similar behaviour would be observed.

Information given by the organisations was reliant on the individual interviewed, whilst steps were taken to reduce bias by triangulating data, to establish the participants accurately reflected the organisation, this only reduces the risk.

CEBMs are always progressing and since the interviews there have been a number of key policy changes such as the launch of the Sustainable Products Initiative (SPI) in March 2022 which will have implications on areas such as design and recycled contented. Circular economy theory is also developing and new examples of CEBMs are emerging, and learnings from these will offer new insights and potential for research.

8.5 Recommendations for future research

This research did one longitudinal study with a two-year gap which was insightful as it shows the impact of research and development funding. There are opportunities to do further detailed longitudinal studies of the EEE value chain. Specifically, studies with the participants engaged in this study, would enable an evaluation of the impact of pending legislation and changing consumer attitudes.

Net Zero emerged during the interviews as becoming a key metric for organisations in the EEE value change, a focused study on the impact of this on the uptake of CEBMs in the future would be informative.

EU Directives such as the WEEE Directive (2012/19/EU) are a framework, and each country adopts a different approach to implementing the legislation in their respective countries. There is the potential to investigate the impact of these different approaches on determining the availability and quality of recaptured plastics.

This study also took place pre-Brexit so the UK might well adopt different legislative approaches going forward. The impact of this on this on material flows within the EEE value chain would provide valuable insights.

Circularity metrics are becoming an increasing area of research and may well influence the EEE sectors strategies in adoption of different CEBMs as it will potentially become easier to compare different organisations.

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Annex A Semi Structured Interview Guideline

Interview guideline:
Confirm that they give their consent to be interviewed and that they are free to stop the interview at any time. Remind them of the purpose of the interview, tell them about the research being conducted.

- Ask for permission to record
  - Recording not public
  - the recordings will be saved on a secure server
  - → record interview if allowed
- Note:
  - Name:
  - Company Name, Country:
  - Size of company:
  - Job position:
  - Product or WEEE category / Customers:
  - Type of stakeholder (equipment manufacturers, pre-processors, plastic recyclers):
  - Date of interview:

- Take notes from interview or directly write down the answers to the questions during the interview. Questions are a guide only.
- After interview: Transcribe interview
- Inform the interviewee that you will send transcription for feedback

Coordination of stakeholder interview from

Short	Stakeholders	Circular business models (n stakeholders)	Material flows	Pre-sorting	WEEE pre-treatment	PCR Market
OEM	Equipment manufacturer					
Other	Trade Association/Lab					
D	Designer					
EPR	EPR Compliance schemes / collection					
PT	Pre-processors					
RF	Refurbishment/Reuse					
Conv	Compounder					

Row	Questions
CEBMS/CE 1	How do you think that CE differs from previous “sustainability” and resource efficiency initiatives
2	Has your company incorporate CE into their business strategy (or does it plan to) Is “environment” featured in your marketing? If yes what aspects and how
3	What do you think are the most important/ relevant to you CEBM in the EEE and plastics sectors (only ask relevant sector)
4	Of those CEBM which have you considered? Have you adopted any? Specify which
5	What was your main motivation/ justification and what criteria did you use in considering CEBM
6	What specific metrics do you use – how were they determined / developed
7	What results were you expecting and what results did you get?
8	What were the biggest challenges and barriers to adopting CEBM and are they internal or external. Were these technical, cultural, economic, legal etc
9	What impact have the results had on your business activities ie considering new CEBM,
10	What methods tools etc do you use to communicate about your CEBM? Within company, with customers, with supply chain?
11	Do you have any supply chain blockages preventing adoption of CEBM?
12	Do you think certain sections of the value chain, or aspects of the company are more accepting than others to CEBM
13	If you could do one thing to make your business more circular / sustainable what would it be?
WEEE Plastics 1	What do you think needs to be done to raise awareness of the value of plastics in WEEE?
2	As reuse and recycling figures are combined to meet WEEE targets, what do you think would be the incentive to encourage reuse of whole products or component parts?
3	Do you use PCR? If so what polymers/ source and percentage
4	Is there a particular plastic stream that is seen as problematic?
5	Do you think certain product types or value propositions are more suitable for PCR than others
6	What are your barriers to using PCR
7	What would encourage greater use of PCR
8	Can you think of any organisation with logistical or other best practices in CE in WEEE plastics? If yes, please name and justify?
9	Do you have any good, or bad, examples of using PCR plastics

10	What is the role of legislation in use of PCR plastics
11	Do you think that there is a role for standards eg minimum recycled content *ignore if standards mentioned in previous answers*
12	Do you personally believe that compared more plastic types will be recycled in the future than is the case today? Why?
13	Do you believe technological improvements will substantially increase the recycling efficiency of plastics from WEEE in the next 5 years? And collection improvements? And sorting improvements?
14	Do you already identified some improvement to increase the recycling rate of plastic or to increase the use of PCR but there are technical/legislative/economic barriers to implement it?
15	Do you believe increasing connectivity and data sharing amongst supply chain actors can improve the quality of plastics received from upstream suppliers? How?
16	Which output streams achieve the highest purity and which lowest?
17	Which is the share in % of plastic fraction obtained from WEEE treatment activities per WEEE stream? Do you know the rate of the plastic that is incinerated, recycled, landfilled?
18	Did you identify some correlation between brands of products and the plastics they use?
19	Do you test or analyse the plastics/plastic fractions? Which parameters are measured? With which measurement methods?
20	Do you treat the collection categories or other mixes separately? Do you pre-sort the input before treatment?
21	What are the main logistical constraints that hinder you in using WEEE plastics?

Annex B EEE sector Survey

Copy of PolyCE

PolyCE circular business survey

This survey should take no longer than 15 minutes to complete. All responses are confidential and any personal data will remain anonymous.

The questionnaire is split into four sections:

Your Organisation
Opportunities and Barriers
Circular Economy Business Models
Support

At the end of the survey you have the opportunity to join PolyCE's expert network panel.

Copy of PolyCE

Your Organisation

1. Please state the name of your Company/Organisation.

2. Please state the geographical focus of your business activities.

3. Approximately how many employees work at your organisation?

4. Within which sector do you operate? Tick all that apply:

- ☐ a. Consumer Electronics
- ☐ b. Information and Communication Technologies (ICT)
- ☐ c. Large household appliances
- ☐ d. Cooling and freezing equipment
- ☐ e. Television and monitors
- ☐ f. Small household appliances - Kitchen appliances
- ☐ g. Small household appliances - Body care appliances
- ☐ h. Small household appliances - Other
- ☐ i. Electrical and electronic tools
- ☐ j. Toys, leisure and sports equipment
- ☐ k. Lighting equipment
- ☐ l. Other (please specify)

5. How familiar do you feel with the term circular economy?

- ☐ a. Excellent knowledge
- ☐ b. Understanding of the principles
- ☐ c. Vague understanding of concept
- ☐ d. Heard of it but don't know what it means
- ☐ e. Never heard of it
- ☐ f. Other (please specify)

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Opportunities and Barriers

6. What does circular economy mean to you?

- ☐ a. A new way of doing business more sustainably
- ☐ b. Greater ownership and control of supply chain
- ☐ c. Greater ownership and control of products
- ☐ d. Access to new markets
- ☐ e. Environmental marketing
- ☐ f. I don't know
- ☐ g. Other (please specify)

7. On a scale from 1 (not at all) to 5 (major shift), please rate to what extent you think the circular economy represents a major / radical shift change for YOUR business sector?

1. Not at all	2	3	4	5. Major shift
○	○	○	○	○

8. Do you think that the concept of circular economy can be easily applied to your organisation through a circular economy business model (CEBM)?

CEBMs include:

Longlife Model: retains the value of a product after use so that reuse or refurbishment is likely.

Modularity Model: increase in product lifetime by encouraged repair via replacement of faulty components.

Re-Value Model: extends the lifespan of products or materials by giving them new value as the same or an alternative product after the first phase, via redistribution, refurbishment or recycling.

Access Model: describes businesses which, instead of selling a product, offer a rental or a leasing service.

Service Model: describes businesses which provide a service rather than sell a product.

- [ ] Yes
- [ ] No

9. What do you think are the biggest barriers to adoption of CEBMs for your organisation.

- [ ] a. Cultural change
- [ ] b. Management support
- [ ] c. Lack of understanding within company
- [ ] d. Lack of understanding by customers
- [ ] e. Product range unsuitable
- [ ] f. Supply chain resistance
- [ ] g. Technical feasibility
- [ ] h. Data protection
- [ ] i. Legislation
- [ ] j. I don't know
- [ ] k. Other (please specify)

10. What would be the biggest benefits to adoption of CEBMs for your organisation

- [ ] a. Greater engagement with customers
- [ ] b. Carbon reduction
- [ ] c. Decoupling of materials from profit
- [ ] d. Greater supply chain engagement
- [ ] e. Environmental image / marketing
- [ ] f. Company sustainability / future proofing
- [ ] g. I don't know
- [ ] h. Other (please specify)

11. What do you think are the measurable benefits of adopting CEBMs for your organisation?

- [ ] a. Economic
- [ ] b. Jobs
- [ ] c. Carbon savings
- [ ] d. Material savings
- [ ] i. Other (please specify)
- [ ] Customer loyalty
- [ ] f. Better client relationships
- [ ] h. I don't know

12. Do you think there are measurable 'social benefits' of adopting CEBMs for your organisation?

- [ ] No
- [ ] Yes. Please specify

13. Do you consider that you adopt circular business model?

	No - but future CEBM plans may consider the following model/s	**Yes** - we have adopted a CEBM in the following model/s
a. Long Life Model (retains the value of a product after use, so that reuse, or refurbishment, is likely).	☐	☐
b. Modularity Model (increase in product lifetime by encouraging repair through replacement of faulty components).	☐	☐
c. Re Value Model (extends the lifespan of products, or materials, by giving them new value as the same, or an alternative, product after the first phase, via redistribution, refurbishment or recycling).	☐	☐
d. Access Model (describes businesses which, instead of selling a product, offer a rental or a leasing service).	☐	☐
e. Service Model (describes businesses which provide a service rather than sell a product).	☐	☐
f. Blend of the above models	☐	☐

g. Other (please specify)

14. When considering the adoption of CEBMs in your organisation which of the following drivers are important. Please rate on a scale of 1 (Not important) to 5 (Extremely important).

	1. Not important	2.	3.	4.	5. Extremely important
a. Material availability	○	○	○	○	○
b. Improved supplier relationship	○	○	○	○	○
c. Cost	○	○	○	○	○

d. Other (please specify)

[ ]

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Circular Economy Business Models

15. If you have adopted a CEBM which of the following does your current CEBM involve:

- [ ] a. Whole products
- [ ] c. Specific materials
- [ ] b. Individual components
- [ ] d. No CEBM adopted
- [ ] d. Other (please specify)

[ ]

16. Do you incorporate any of the following post-consumer metal recyclates into your products?

- [ ] a. No
- [ ] b. Ferrous
- [ ] c. Non ferrous please specify

[ ]

17. Do you incorporate any of the following post-consumer plastics recyclate into your products?

- [ ] a. Plastic ABS
- [ ] c. Plastic PP
- [ ] b. Plastic HIPS
- [ ] d. None.
- [ ] e. Other (please specify)

[ ]

18. If you don't use post-consumer plastic please rate the importance of the following production issues associated with PCR use on a scale of 1 (Not important) and 5 (Very important).

	1. Not at all	2.	3.	4.	5. Very important
a. compliance with regulations	○	○	○	○	○
b. increase the final price of the product	○	○	○	○	○
c. quality of the final product	○	○	○	○	○
d. adjust the product design	○	○	○	○	○
e. adjust the product function	○	○	○	○	○
f. customers' acceptability	○	○	○	○	○

g. Other (please specify)

19. Please specify the content (in percentage) of post-consumer plastic in your products.

- ☐ a. We use plastic but only from virgin supply
- ☐ b. Less than 10%
- ☐ c. Between 10% and 30%
- ☐ d. More than 30% but less than 50%
- ☐ e. Between 50% and 100%
- ☐ f. None
- ☐ g. Other (please specify)

20. Which of the following describes your approach for procuring post-consumer plastic materials?

- ☐ a. Direct selling (company-to-company) not related to a specific plastic index
- ☐ b. Direct selling (company-to-company) related to a specific plastic index
- ☐ c. Online platform for trading (buying or selling)
- ☐ d. We don't procure any post-consumer plastics.
- ☐ Other (please specify)

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Support

21. If your organisation had access to an online platform or website for PCR which of the following tools/functionality would be useful:

- [ ] a. A European wide marketplace for buyers and sellers of virgin and recycled plastics material
- [ ] c. Reference standards (methodologies) to test PCR material properties
- [ ] b. A "quality indicator" that classifies every bale of PCR material offered on the marketplace, the origin of the waste stream, the processes performed on the materials
- [ ] d. Market reports
- [ ] f. Other (please specify)

22. Which of the following would help your organisation to prepare for, or develop, a circular economy approach within your organisation?

- [ ] a. Greater understanding in company
- [ ] d. Clearer indication of economic benefits
- [ ] b. Greater understanding in supply chain
- [ ] e. Business plan development
- [ ] c. Overall awareness
- [ ] f. Other (please specify)

23. If you are interested in further support/help please tell us which methods you would prefer.

- [ ] a. Seminars
- [ ] d. Case studies
- [ ] b. Webinars
- [ ] e. One to one support
- [ ] c. Telephone support

24. If you are willing to be used as a case study please provide details below.

Name

Company

Address

Address 2

City/Town

State/Province

ZIP/Postal Code

Country

Email Address

Phone Number

Annex C PolyCE Consumer Awareness Survey

PolyCE Consumer Survey

PolyCE Consumer Survey

Here is how YOU can help put huge amounts of waste plastics to good use. By dedicating less than 10 minutes of your time to completing this survey, you will provide valuable input into a major research and innovation effort aiming to make it easier and more affordable to reuse plastics in new electronic products. PolyCE, a EU funded project is showcasing the value within plastics found in electronic waste – a real circular economy solution making a positive difference to help tackle the impending plastic waste crisis. Behind PolyCE are 20 expert organisations, among which major manufacturers, Philips and Whirlpool. Read more about the PolyCE project here: https://polyce-project.eu/.

1. Please indicate your age group:

- ◯ 15-24
- ◯ 25-44
- ◯ 45-64
- ◯ 65+

2. What is your gender? (Optional)

- ◯ Male
- ◯ Female
- ◯ I prefer not to answer

3. How many people does your household consist of?

- ☐ 1
- ☐ 2-5
- ☐ 6-10
- ☐ Other (please specify)

4. What is your household's yearly income ?

- ☐ Less than EUR 20.000
- ☐ EUR 20.000 to 50.000
- ☐ EUR 50.000 to 80.000
- ☐ EUR 80.000 to 110.000
- ☐ EUR 110.000 to 140.000
- ☐ EUR 140.000 to 200.000
- ☐ EUR 200.000 and more

5. What is your educational level

- ◯ Primary
- ◯ High school
- ◯ Bachelor or similar
- ◯ Master or similar
- ◯ Doctor

6. Where do you currently live (city, country)?

7. Are you familiar with the term "Circular Economy"?

- ☐ Very familiar
- ☐ Somewhat familiar
- ☐ Not at all familiar

PolyCE Consumer Survey

8. Please provide your definition of the "Circular Economy"

9. State your level of agreement with the following claim: The improper treatment of electronic waste has a negative impact on the environment and human health.

Disagree Not sure Agree

10. Below are some examples of circular consumption models. Please select all that apply to you.

- ☐ I purchase new products only when absolutely necessary.
- ☐ I repair the products I own, rather than buy new ones.
- ☐ I sort my waste.
- ☐ I choose to purchase products containing eco-labels.
- ☐ Other (please specify)
- ☐ I pursuade others to make sustainable choices.
- ☐ I share or trade goods rather than buy new ones.
- ☐ None apply to me.

11. What did you choose to do with your old tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) that you no longer use? Select all that apply.

- [ ] Repair
- [ ] Donate
- [ ] Discard in a dedicated e-waste collection point
- [ ] Discard in general waste bin
- [ ] Re-sell
- [ ] Keep at home
- [ ] Other (please specify)

PolyCE Consumer Survey

12. Why did you choose to discard your old tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) in a dedicated e-waste collection point? Multiple choices are possible.

- [ ] Organising / decluttering my home.
- [ ] It is the right thing to do for myself and for the planet.
- [ ] Receiving a discount voucher or other reward from collector.
- [ ] Other (please specify)

13. Why did you choose **not** to discard your old tech tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) in a dedicated e-waste collection point? Please rank in order of relevance (1 being most relevant):

	Lack of knowledge or information regarding appropriate method.	☐ N/A
	Lack of collecting facilities.	☐ N/A
	Concern regarding privacy of my data.	☐ N/A
	Sentimental attachment to device.	☐ N/A
	Distance between my home and the recycling facility is too big (lack of transport / time)	☐ N/A

14. When purchasing a new tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) , how important is it to you that the product and its components are environmentally-friendly?

Not important at all. Somewhat important. Very important.

15. When planning to purchase a new tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) , what role do the following aspects play in your purchasing decision? Please rate in order of importance (1 being most important).

	1	2	3	4	5
Appealing design	☐	☐	☐	☐	☐
Attractive color	☐	☐	☐	☐	☐
Upgrade-able (an upgrade is a new version of or addition to a hardware or, more often, software product that is already installed or in use)	☐	☐	☐	☐	☐
Repairable	☐	☐	☐	☐	☐
Latest model	☐	☐	☐	☐	☐
Critical acclaim	☐	☐	☐	☐	☐
Refurbished	☐	☐	☐	☐	☐
Contains recycled plastics	☐	☐	☐	☐	☐
Long-lasting	☐	☐	☐	☐	☐
Green (has sustainability claims, i.e. eco-label)	☐	☐	☐	☐	☐
Modular (can be dissembled allowing for part replacement)	☐	☐	☐	☐	☐
Favorite brand	☐	☐	☐	☐	☐
Possibility to borrow under a service agreement, and replace after one year	☐	☐	☐	☐	☐

Other (please specify)

16. Have you ever purchased a tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) containing recycled plastics?

- [ ] Yes
- [ ] No
- [ ] I don't know.
- [ ] Other (please specify)

PolyCE Consumer Survey

17. Were you aware that the product contained recycled plastics?

- [ ] Yes
- [ ] No

18. Have you noticed any issues with your product in terms of quality, performance or appearance?

- [ ] Yes
- [ ] No
- [ ] Other (please specify)

19. Would you consider buying a tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) if it were clearly labelled that it contains recycled plastics?

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

20. If a tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) contained recycled plastics, and performed in the same way as a brand new tech device, how would that influence your purchasing decision?

- [ ] I would prefer purchasing the tech device containing recycled plastics.
- [ ] I would prefer purchasing the tech device containing **NO** recycled plastics.

21. In your view, a tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) containing recycled plastics has:

Poorer quality compared to device containing brand new plastics	Same quality as device containing brand new plastics	Superior quality compared to a device containing brand new plastics

22. Would you consider purchasing a tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) containing recycled plastics in the future?

No	Maybe	Yes

23. Have you ever rented a tech product in the past (car, tools, household devices)?

- [ ] Yes
- [ ] No

PolyCE Consumer Survey

24. Please clarify your reasoning:

- I prefer purchasing a brand new device.
- I was not aware of such a service.
- I have concerns regarding reliability of such schemes.
- I am not interested.
- Other (Please specify)

25. Could you imagine to rent a tech product (including, but not limited to smartphone, computer, TV, vacuum cleaner, coffee machine, washing machine, etc) for a monthly fee in the future instead of purchasing it?

- [ ] Yes
- [ ] No

PolyCE Consumer Survey

26. Yes for the following categories (Multiple choice is possible):

- [ ] Large household appliances (refrigerator, washing machine, oven, dishwasher, drier, etc)
- [ ] Consumer electronics (phone, laptop, tablet, headphones, etc)
- [ ] Smaller household appliances (microwave, coffee machine, toaster, iron, etc)
- [ ] Other (please specify)

27. In your opinion, why would people avoid buying products containing recycled plastics?

28. In your opinion, why would people prefer buying products containing recycled plastics?

Thank you for your feedback. To learn more about the PolyCE Project, please visit: https://www.polyce-project.eu/.