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Regulating and Designing Electrical and Electronic Equipment

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BY
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AALBORG UNIVERSITY
DENMARK

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ENGLISH SUMMARY

The Earth is a closed system and, with the exception of energy, the resources available to us are finite. The economic system as well as consumption and production patterns are not designed to take this fact into consideration. Instead, they are characterised as linear take-make-dispose systems. The consequences are environmental degradation and, in the long term, resource scarcity. A circular economy is proposed as an alternative to the linear take-make-dispose system. A circular economy is defined in this study as a consumption and production system based on closed loops that minimises resources, energy flows and environmental degradation without restricting economic, social or technical progress. The loops in the circular economy model can be closed using five strategies: (1) reducing consumption of energy and resources, (2) maintenance and repair, (3) reuse, (4) reconditioning and remanufacturing, and (5) recycling.

In this PhD thesis both resource efficiency and the circular economy are examined. Resource efficiency is defined as using the limited resources on Earth in a sustainable way and minimising their environmental impact. The same five strategies which can close the material loops in the circular economy are also used in this study to improve resource efficiency. Therefore, a broad definition of resource efficiency is applied in this study. The material loops in the circular economy can be closed in different ways using different concepts and tools. This study examines

> How can ecodesign close the material loops in the circular economy for electrical and electronic equipment?

Ecodesign is a concept used to improve the environmental performance of products and can be defined as the implementation of environmental issues in the design process taking the entire lifecycle of the product into consideration. The main research question was examined through the following two sub-questions:

> How have the EU product policies covering electrical and electronic equipment integrated resource efficiency aspects and what is the role of the Ecodesign Directive?

> How to design electrical and electronic equipment for closed material loops in the circular economy using ecodesign and what are the drivers and barriers?

A qualitative research strategy was applied and the research was designed as a series of case studies examining different research objects. The main methods applied were qualitative research interviews and document reviews. Furthermore, a workshop was conducted at one of the case companies.

The study of the regulations revealed that EU environmental product policies can improve resource efficiency and that the tools cover different strategies for resource efficiency and for closing material loops. The WEEE Directive primarily ensures the recovery and recycling of waste electrical and electronic equipment in Europe by establishing collection systems and setting requirements for recovery as well as a combined target for recycling and preparation for reuse. The RoHS Directive improves recyclability by restricting hazardous substances, thus remove from the market the worst products with regard to hazardous substances. The EU Energy Labelling and the EU Energy Star Regulation target the reduce strategy by setting mandatory requirements for information on the energy efficiency of the product and thus help drive the existing market towards improved energy efficiency during use. The EU Ecolabel and the EU guidelines on green public procurement can set criteria for all five strategies to close the material loops because they apply a lifecycle perspective. These instruments provide the purchaser (private or public) with information, which makes it possible for them to select the environmentally best performing products. Thus they encourage the development of more environmentally friendly products.

The Ecodesign Directive can set minimum requirements for all five strategies to close the material loops because it also applies a lifecycle perspective. The Ecodesign Directive plays an important role as it is the sole mandatory policy instrument which can set minimum requirements for all the five strategies to close the material loops in the circular economy. The actual uptake of specific requirements in the Ecodesign Directive targeting resources other than energy is still limited. In 2013, 21 implementing measures were adopted and two voluntary agreements were recognised, however only five implementing measures and one voluntary agreement included specific requirements targeting resources other than energy. To understand what made it possible to include resource efficiency requirements in the Ecodesign Directive, two product categories which succeeded in integrating resource efficiency were selected for further study. An analysis was therefore preformed of the processes and stakeholder interactions which formed a basis for the development of the implementing measure for vacuum cleaners and the voluntary agreement for imaging equipment. Based on the analysis, recommendations were made on how to improve the uptake of further requirements for resource efficiency targeting other resources than energy.

The voluntary instruments can support the integration of resource efficiency requirements into the Ecodesign Directive and have indeed already done so. A review was made of resource efficiency criteria in four voluntary instruments, namely the Nordic Ecolabel, the EU Ecolabel, EU guidelines for green public procurement (GPP) and electronic product environmental assessment tool (EPEAT), for three product categories, namely computers and servers, imaging equipment and windows. The review showed that the voluntary instruments already set a wide range of resource efficiency criteria and that these criteria can support the uptake of further requirements targeting resource efficiency in the Ecodesign Directive.

The study of how companies can close the material loops in the circular economy through ecodesign was examined through the two case studies of Bang & Olufsen and Tier1Asset, examining two of the five strategies to close the material loops that is recyclability and reconditioning. Bang & Olufsen is a producer of high-end audio and visual equipment and Tier1Asset reconditions computers, tablets and smartphones. The case studies showed that the two examined ecodesign guidelines, the Ecodesign Pilot and the ECMA 341 standard, did provide design recommendations, which could improve recyclability and the reconditioning potential of the examined product categories. However, the recommendations for reconditioning could be further developed in the two guidelines. The two case studies disclosed design recommendations which were not included in or only partly covered by the guidelines. These recommendations were more detailed and product or even company specific. A conclusion is that the general design recommendations in the existing guidelines are useful for designing products for closed material loops, but it is also relevant to develop design recommendations that are more detailed and product specific and even company specific. The workshop at Bang & Olufsen revealed that it is possible to create a knowledge exchange between the recycler and the producer through a workshop that includes disassembling products from the producers and developing more product and company specific design recommendations.

The study revealed a link between the core characteristics of luxury products and circular activities and circular product attributes including aspects such as the rarity and scarcity of luxury products, high quality, durability, service schemes, extended warranties and large aftermarkets. Some of these links were also evident in the case study of Bang & Olufsen. Bang & Olufsen's core products have a long lifespan, extended warranties, repair and service schemes, spare part availability for eight years, an aftermarket and leasing schemes, all of which are characteristics that could be linked to Bang & Olufsen's focus on design and quality and the fact that their core products are luxury products. Bang & Olufsen also had circular activities and circular product attributes which were driven by stock and cost optimisations, such as the reconditioning of components for their repair loop. Finally, Bang & Olufsen had circular activities which were driven by an environmental agenda and environmental regulation. This included aspects such as the marking of plastic components, a negative list and disassembly tests. By 2016, many of the circular activities driven by the environmental agenda had been included in the EU environmental product policies and Bang & Olufsen has not developed new proactive environmental requirements. Therefore, circular activities and circular product attributes may not solely be improved through ecodesign, especially in a company where environmental aspects are not used to differentiate themselves from their competitors.

The case study of Bang & Olufsen also revealed drivers and barriers, which can facilitate or hinder the integration of ecodesign into the company and thereby the use of ecodesign to close the material loops in the circular economy. Quality, design and luxury seemed to be the main drivers of Bang & Olufsen's activities within the inner circles of the circular economy, whereas the activities in the outer circles were mainly driven by environmental regulations or stock and cost optimisations. Furthermore, the specific design recommendations for the improved recyclability of Bang & Olufsen's products could also help drive their circular activities. One of the identified barriers is that Bang & Olufsen is in a financial recession. Therefore, activities are not prioritised unless they can provide value for the company in the short term. Ecodesign is not considered an aspect with which they can differentiate their products from their competitors and is thus not part of the core values of the company. Another potential barrier is that Bang & Olufsen has no activities to support their goal on product environment. Finally, Bang & Olufsen is not experiencing any demand from the consumer market for sustainable or more environmentally friendly products.

Non-technical barriers hindering reconditioning were identified in the case study of Tier1Asset. Lack of consumer trust was one of these non-technical barriers. The purchaser of reconditioned products should trust the quality of these products and thus also needs to trust the reconditioner. Lack of trust from the seller of the used equipment was another non-technical barrier. The used equipment handled by Tier1Asset can potentially contain sensitive information, therefore it is important that the seller trusts that Tier1Asset will delete all the data. Other potential barrier is that it can be too expensive to recondition the product in comparison to the resale price. Potential barriers also include that Tier1Asset needs a certain quantity and quality of used products in order to have a viable business with standardised and efficient processes. A finial barrier is that products are not designed for reconditioning and that the producers have little or no motivation to change the design for this purpose.

The study has shown that regulation can support the closure of the material loops in the circular economy by setting requirements to reduce resources or energy consumption and by improving the possibilities for maintenance, repair, reuse, reconditioning, remanufacturing and recycling. However, regulation can also hinder some of the strategies to close the material loop in the circular economy. An example is Bang & Olufsen's remanufacturing of components for their repair loops, which was hampered by the introduction of the RoHS Directive. Bang & Olufsen could not use components for repair, which did not comply with the RoHS Directive in products which did comply with the RoHS Directive, and therefore they had to either discard the components or have two repair loops. To avoid these negative side effects, new product regulations should not hinder the resale, reuse, reconditioning and remanufacturing of old products unless health issues or environmental benefits from banning the products exceeds those gained from prolonging the life of the products. Moreover, regulations should provide clear guidance on how the requirements cover resale, reuse, reconditioning and remanufacturing.

DANSK RESUME

Jorden er et lukket system og når man ser bort fra energi, er alle de tilgængelige ressourcer begrænsede. Hverken det overordnede økonomiske system eller vore forbrugs- og produktionsmønstre, er indrettede på en sådanne måde at de tager hensyn til dette faktum. Derimod er disse karakterisereret ved et lineæret ”tag-brug-smid væk” system. Konsekvenserne er miljøproblemer og i det lidt længere perspektiv, ressourceknaphed. Cirkulær økonomi er et alternativ til dette ”tag-brug-smid væk” system. I denne afhandling defineres cirkulær økonomi som et produktions- og forbrugssystem baseret på lukkede kredsløb, der minimerer ressource- og energiforbruget, og dermed miljøpåvirkningerne, men uden at sætte begrænsninger for økonomiske, sociale eller tekniske fremskridt. Ressource kredsløbene kan lukkes gennem fem strategier: (1) reduktion af forbrug af energi og ressourcer, (2) vedligeholdelse og reparation, (3) genbrug, (4) istandsættelse og genfremstilling, og (5) genanvendelse.

I Ph.d. afhandling er både ressourceeffektivitet og cirkulære økonomi nærmere undersøgelse. Her defineres ressourceeffektivitet som det at bruge de begrænsede ressourcer på jorden på en bæredygtig måde, samt at minimere den miljømæssige påvirkning. De fem strategier, som i den cirkulære økonomi kan anvendes til at lukke materialekredsløbene, bruges i denne afhandling også til at forbedre ressourceeffektivitet. Der anvendes dermed en bred definition af ressourceeffektivitet. Materialekredsløbene i den cirkulære økonomi kan lukkes med anvendelse af forskellige koncepter og værktøjer. Denne Ph.d. afhandling undersøger

> Hvordan ecodesign kan lukke materialekredsløb i den cirkulære økonomi specifikt for elektroniske og elektriske produkter.

Ecodesign er et koncept der kan anvendes til at forbedre produkters miljøprofil, og kan defineres som implementeringen af miljøhensyn i designfasen under hensyntagen til hele produktets livscyklus. Det primære forskningsspørgsmål blev undersøgt ved hjælp af de følgende to underspørgsmål:

> Hvordan har EU's miljølovgivning som dækker elektrisk og elektronisk udstyr implementeret ressourceeffektivitet aspekter og hvad er Ecodesign Direktivets rolle?

> Hvordan kan ecodesign anvendes til at designe elektrisk og elektronisk udstyr der kan indgå i lukkede materialekredsløb, og hvilke barrierer og drivkræfter eksisterer der i forhold til dette?

I studiet er der blevet anvendt en kvalitativ forskningsstrategi og undersøgelsen blev tilrettelagt som en række casestudier, med hver deres undersøgelsesformål. De

primært anvendte metoder er kvalitative forskningsinterviews og dokumentanalyse. Derudover blev der gennemført en workshop hos en af de involverede case-virksomheder.

Studiet af EU's miljølovgivningen som dækker elektrisk og elektronisk udstyr viste at lovgivningen har og kan forbedre ressourceeffektiviteten og at de undersøgte direktiver og forordninger dækker forskellige aspekter af ressourceeffektivtiet. WEEE Direktivet sikrer primært indsamling og genanvendelse af elektrisk og elektronisk affald i Europa ved at etablere indsamlingssystemer og opstille krav til indsamlingen og et samlet krav for genanvendelse og forberedelse til genbrug. RoHS Direktivet forbedrer muligheden for genanvendelse af materialerne i elektrisk og elektronisk affald ved at begrænse brugen af farlige stoffer og fjerner på den måde de værste produkter med hensyn til farlige stoffer, fra markedet. EU's Energimærkeordning og EU Energi Star forordning hjælper med at reducere primært energiforbruget i brugsfasen ved at opstille obligatoriske krav til information om produktets energieffektivitet og andre relevante aspekter og bidrager derved til at bringe det pågældende marked mod et forbedret energiforbrug i brugsfasen. EU's miljømærkeordning og EU's guides til offentlig grønne indkøb kan sætte kriterier til alle fem strategier til at lukke materialekredsløbene, idet de anvender et livscyklusperspektiv. Disse politiske instrumenter giver køberen (offentlig eller privat) adgang til information, der gør det muligt at vælge de miljømæssigt set bedst produkter. På den måde tilskynder de til udviklingen af mere miljøvenlige produkter.

Ecodesign Direktivet kan opstille minimumskrav til alle fem strategier til at lukke materialekredsløbene fordi også det, anvender et livscyklusperspektiv. Ecodesign Direktivet spiller derfor en vigtig rolle. Antallet af specifikke minimumskrav til ressourceeffektivitet udover energi i Ecodesign Direktivet er dog begrænset. I 2013 var der 21 vedtaget gennemførelsesforanstaltninger og to anerkendte frivillige aftaler, men kun fem gennemførelsesforanstaltninger og én frivillig aftale indeholdt specifikke krav til andre ressourcer end energi. For at forstå hvad der har gjorde det muligt at inkludere krav til ressourceeffektivitet i Ecodesign Direktivet, blev to produktkategorier udvalgt om havde integreret krav til ressourceeffektivitet udover energieffektivitet. Der blev derfor lavet en analyse af processerne og interessenternes interaktioner under udviklingen der udgjorde grundlaget for udviklingen af gennemførelesforanstaltninger for støvsugere og den frivillige aftale for printer. Baseret på denne analyse, var det muligt at fremsætte en række anbefalinger som kan øge optaget af specifikke ressourcekrav til andre ressourcer end energi.

De frivillige ordninger kan understøtte integreringen af krav til ressourceeffektivitet i Ecodesign Direktivet, hvilket også allerede er sket. En analyse er gennemført af ressourceeffektivitetskriterier i fire frivillige ordninger, det nordisk miljømærke, EU miljømærkordningen, EU's guides for grønne offentlige indkøb og EPEAT, for tre produktkategorier, computere og servere, printer og vinduer. Undersøgelsen viste, at de frivillige ordninger allerede indeholdt en række kriterier for ressourceeffektivitet og at disse kriterier kan understøtte optaget af yderligere krav til ressourceeffektivitet i Ecodesign Direktivet.

Casestudierne af Bang & Olufsen og Tier1Asset undersøgte hvordan virksomheder kan lukke materialekredsløbene i den cirkulære økonomi gennem brugen af ecodesign. Bang & Olufsen producerer højkvalitets lyd- og billedeudstyr og Tier1Asset istandsætter computere, tablets og smartphones. To af de fem strategier til at lukke materialekredsløb blev undersøgt, nemlig genanvendelse og istandsættelse. Casestudierne viste, at de to undersøgte ecodesign vejledninger, nemlig Ecodesign Pilot og ECMA 314 standarden, faktisk gav designanbefalinger, der kunne forbedre genanvendeligheden og muligheden for at istandsætte de undersøgte produktkategorier. Dog kunne anbefalingerne til istandsættelse udvikles yderligere i de to vejledninger. De to casestudier afdækkede designanbefalinger, der enten ikke, eller kun delvist, var dækkede af de to vejledninger. Én konklusion fra de to casestudier er derfor, at de generelle designanbefalinger i de eksisterende vejledninger er brugbare i forhold til at designe produkter til lukkede materialekredsløb, men det er samtidigt også nødvendigt, at udvikle designanbefalinger, der er mere detaljerede, produktspecifikke, og endda virksomhedsspecifikke. Workshoppen hos Bang & Olufsen viste også, at det er muligt at skabe videns udveksling mellem repræsentanter fra affaldssektoren og producenter gennem en workshop, hvor producentens produkter adskilles og analyseres, og hvor der på denne baggrund udvikles produkt- og virksomhedsspecifikke designanbefalinger.

Afhandlingen undersøgte gennem et litteraturstudie sammenhænge mellem luksusprodukters karakteristika og de produkt egenskaber og aktiviteter som er afgørende for at lukke materiale kredsløbene i den cirkulære økonomi. Her fandtes overlap i litteraturen såsom begrænset udbud, høj kvalitet, levetid, mulighed for serviceydelser, udvidede garantiordninger og store markeder for brugte produkter. Et udvalg af disse sammenhænge kunne også dokumenteres i casestudiet af Bang & Olufsen. Bang & Olufsens kerneprodukter har en lang forventet levetid, udvidede garantier, reparations- og serviceydelser, adgang til reservedele i otte år, et marked for brugt udstyr, samt leasingydelser, hvilket i alle tilfælde er karakteristika der kan knyttes til Bang & Olufsens fokus på design, kvalitet og luksus. Bang & Olufsen havde også cirkulære aktiviteter og cirkulære produktegenskaber der var drevet af lager- og omkostningsoptimering, såsom renovering af delkomponenter i deres reparationssløjfe. Slutteligt havde Bang & Olufsen cirkulære aktiviteter der var drevet af en miljødagsorden og miljølovgivningen. Dette indbefattede aspekter såsom mærkning af plastickomponenter, en "negativ-liste" og tests ift. at skille produkterne ad. Det kan derfor konkluderes at det ikke udelukkende er gennem ecodesign eller en miljødagsorden, at cirkulære aktiviteter og cirkulære produktegenskaber udvikles.

Casestudiet af Bang & Olufsen afdækkede drivkræfter og barrierer, der enten kan facilitere eller forhindre integreringen af ecodesign i virksomheden, og dermed anvendelsen af ecodesign til at lukke materialekredsløbene i den cirkulære økonomi. Kvalitet, design og luksus, syntes at være de primære drivkræfter for Bang & Olufsens aktiviteter og produkt egenskaber i de indre cirkler i den cirkulære økonomi, hvorimod aktiviteterne i de ydre cirkler primært blev ansporet af miljølovgivningen eller lager- og omkostningsoptimering. Derudover kunne de specifikke designanbefalinger til at forbedre genanvendeligheden af Bang & Olufsens produkter udviklet under workshopen understøtte deres arbejde med lukning af de ydre cirkler. Én af de identificerede barrierer er Bang & Olufsens økonomiske udfordringer. Som følge af de økonomiske udfordringer, prioriteres kun de umiddelbart lønsomme aktiviteter. Ecodesign vurderes ikke af Bang & Olufsen, som et aspekt der kan anvendes til at differentiere virksomhedens produkter fra konkurrenternes, og er af samme grund ikke en kerneværdi for virksomheden. En anden potentiel barriere er at Bang & Olufsen ikke har nogen aktiviteter til at støtte op om deres mål i forhold til produktmiljø. Afslutningsvist oplever Bang & Olufsen ikke nogen efterspørgsel fra afsætningsmarkedet i forhold til bæredygtige eller mere miljøvenlige produkter.

Ikke-tekniske barrierer, der hindrer istandsættelse, blev identificeret i casestudiet af Tier1Asset. En af disse ikke-tekniske barrierer var manglende tillid fra forbrugeren. Køberne af istandsatte produkter skal kunne stole på disse produkters kvalitet og derfor kunne stole på sælgeren. En anden ikke-teknisk barriere var manglende tillid fra sælgeren af det brugte produkt. Det brugte produkt, som Tier1Asset opkøber, kan indeholde følsomt data og det er derfor vigtigt at sælger af det brugte produkt har tillid til al data slettes inden videresalg. En anden potentiel barriere er, at det kan være for dyrt at istandsætte produktet sammenlignet med nyprisen for et lignende produkt på markedet. Mængden og kvaliteten af det brugte udstyr kan også være en potential barrierer for Tier1Assets istandsættelse af udstyret. Tier1Asset behøver en vis mængde og kvalitet af brugte produkter førend de kan have en levedygtig forretning med standardiserede og effektive processer. En sidste barriere er at produkter ikke er designet til at kunne restaureres, og at producenterne intet incitament har til at designe dem med dette formål.

Afhandlingen har dokumenteret, at lovgivning kan hjælpe til lukningen af materialekredsløbene og forbedre ressourceeffektiviteten ved at opstille krav til nedbringelsen af ressource- og energiforbruget, og ved at forbedre mulighederne for vedligeholdelse, reparation, genbrug, genfremstilling og genanvendelse. Lovgivning kan dog også hindre lukningen af materialekredsløbene. Et eksempel er Bang & Olufsens genfremstilling af komponenter til deres reparationssløjfe, som blev besværliggjort ved indførelsen af RoHS direktivet. Efter RoHS Direktivet trådte i kraft måtte Bang & Olufsen ikke bruge komponenter der ikke overholdt RoHS direktivet, til reparationer af produkter der overholdt direktivet, og derfor skulle de enten skaffe sig af med de pågældende komponenter eller have to separate reparationssløjfer. For at undgå disse negative følgevirkninger, bør ny produktlovgivning ikke hindre gensalg, genbrug, istandsættelse og genfremstilling af brugte produkter, medmindre de sundheds- og/eller miljømæssige fordele overstiger fordelene ved at forlænge produktets levetid. Desuden bør lovgivningen vejlede tydeligt i forhold til, hvordan kravene dækker gensalg, genbrug, istandsættelse og genfremstilling

PREFACE AND ACKNOWLEDGEMENTS

This PhD thesis is the result of a three-year PhD fellowship at the Sustainability Innovation and Policy research group at the Department of Development and Planning at Aalborg University. I began my PhD studies in February 2013 and finalised the thesis in October 2016. In between, I had a 10-month maternity leave lasting from February 2015 to December 2015.

The subject of the PhD is how ecodesign can close the material loops in the circular economy while examining how environmental product policies and companies can support a circular economy. My interest in environmental product policies began during my 8th semester of my M.Sc. in Environmental Management and Sustainability Science. In collaboration with a fellow student, we examined the synergies between the different environmental product polices covering household washing machines. Here, we found that there was a mismatch between the requirements in the Ecodesign Directive and the Nordic Ecolabelling. This mismatch between the intended synergies and the actual synergies encouraged my interest in the subject. This initial interest in environmental product policies led to an interest both in ecodesign more generally and in what the companies could do to support a circular economy.

The thesis is partly article based and partly consists of chapters written solely for the purpose of the PhD thesis. Chapters 5 and 10 comprise two papers one is accepted with minor revisions and one is under review at the Journal of Cleaner Production. Chapter 6 consists of a chapter from a report published by the Danish Environmental Protection Agency. Chapters 1-4, 7-9 and 11-15 are solely written for and published in this PhD thesis.

The PhD research project was financed through two projects, namely Designing out Waste and Ecodesign Directive 2.0: From Energy Efficiency towards Resource Efficiency. Both projects were financed by the Danish Environmental Protection Agency. The report developed in connection with the Ecodesign Directive 2.0 projects. I would therefore like to thank the Danish Environmental Protection Agency for making this PhD thesis possible. I would also like to thank the two case companies who participated in the project Designing out Waste, Tier1Asset and Bang & Olufsen, for allowing me insight into their companies. I would also like to thank all interviewees who participated in the study.

I would like to thank my two supervisors, Professor Arne Remmen and Dr Mette A. Mosgaard, for their comments and support and for encouraging me to apply for the PhD position.

Lastly, I would like to thank my family and friends for their love and support. I especially would like to thank my husband, my parents and my sister for their help and support while finalising this PhD thesis. It would not have been possible without them.

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CHAPTER 1 THE PROBLEM FIELD AND RESEARCH QUESTIONS

1.1 INTRODUCTION TO THE PROBLEM FIELD

The Earth is a closed system and, with the exception of energy, the resources available are constant (Boulding 1966). However, our economic system does not consider this fact (Boulding 1966). Both consumption and production are characterised by a linear take-make-waste economy (Boulding 1966). The natural environment has a certain assimilative capacity to handle waste, however we greatly exceed this capacity (Boulding 1966). Therefore, a circular economy has been proposed as an alternative. The idea of a closed looped system is not new, but it gained renewed attention in the 2000s when the world experienced increasing raw material prices and again in 2010 with the establishment of the Ellen MacArthur Foundation (Ellen MacArthur Foundation 2012). The idea of a circular economy has its roots in different schools of thought including ecological economics (Georgescu-Roegen 1975, Boulding 1966, Daly 2008), environmental economics (Pearce, Turner 1990) and industrial ecology (Stahel 1982, McDonough, Braungart 2010, Allenby, Graedel 1993).

The industrial ecologist Stahel (1982) defines a circular economy as one based on a spiral loop system founded on reuse, repair, reconditioning and recycling while the Ellen MacArthur foundation (2012) defines a circular economy as a system that is intentionally restorative (Ellen MacArthur Foundation 2012). Particularly within the contributions from industrial ecologists, design is assigned an important role in closing the material loops in the circular economy. The introduction of environmental aspects into the design process dates back to the 1970s (Papanek 1971) and since then it has developed, introducing concepts such as green design (Mackenzie 1997, Burall 1991), ecodesign (Tischner et al. 2000, Karlsson, Luttropp 2006, Luttropp, Lagerstedt 2006a), design for the environment (Allenby, Graedel 2003) and design for sustainability (Spangenberg et al. 2010). The starting point of this PhD thesis is ecodesign, whereby ecodesign can be defined as the implementation of environmental issues in the design process while taking the entire life cycle into account.

The effects of this take-make-waste consumption and production system can be seen in many places in the physical world, such as the occurrence of micro-plastics in our oceans (Barnes et al. 2009), the leaking of hazardous substances into soils and water from old and new dump sites (Ahmed, Sulaiman 2001), pollution by dioxins from the burning of waste (McKay 2002) and contamination with hazardous substances due to improper waste treatment (Huang et al. 2009). These problems are also evident in the volatile raw material prices which have been experienced over the last few years (European Commission 2008d). These problems are particularly relevant for the product group of electrical and electronic equipment as these often contain hazardous substances as well as valuable or scarce raw materials (Widmer et al. 2005, Chancerel et al. 2009) and because the consumption and production of this product group is on the increase (Achabou, Dekhili 2013).

1.1.1 ELECTRICAL AND ELECTRONIC EQUIPMENT

During the last three decades, electrical and electronic waste has increased rapidly because more products are being produced and consumed by an increasingly large consumer group (Amankwah-Amoah 2016). Furthermore, many electrical and electronic products have a relatively short lifespan (Prakash et al. 2015). The global generation of electrical and electronic equipment was assessed at 41.8 MT in 2014 (Baldé et al. 2015). The definition of electrical and electronic equipment applied in this study is in line with the definition provided in the Waste Electrical and Electronic Equipment Directive (WEEE Directive) and the Restriction of Hazardous Substances Directive (RoHS Directive) and is defined thus:

> "Electrical and electronic equipment or EEE means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1.000 volts for alternating current and 1.500 for direct current" (European Commission 2008g, article 3, 1.(a))

This definition includes a broad selection of different types of equipment such as large and small household appliances, IT and telecommunications equipment, consumer electronics, lighting equipment, electrical and electronic tools, toys, medical devices, monitoring and control instruments and automatic dispensers (European Commission 2008f).

The life expectancy of electrical and electronic equipment varies significantly (Robinson 2009). Table 1-1 provides and overview of the life expectancy of some of the more common categories of electrical and electronic equipment. Changes in technology and shorter innovation cycles of hardware have resulted in shorter life spans of electrical and electronic equipment due to technological obsolescence (Robinson 2009). For example, the lifespan of central processing units in computers was reduced from 4-6 years in 1997 to 2 years in 2007 (Robinson 2009).

Product group	**Typical life (years)**
Computers	3
Mobile telephone	2
Television	5
Dish washer	10
Freezer	10
Kettle	3
Vacuum cleaner	10
Washing machine	8
Refrigerator	10

Table 1-1: Typical life of selected electrical and electronic equipment categories (Robinson 2009: 184).

A recent German study examining a selection of large and small household appliances, information and communication technology devices and consumer electronics also documented relatively short useful lifetimes of the product groups examined (Prakash et al. 2015). However, for some product groups, such as televisions, the first useful service life increased from 2.0 years in 2006 to 5.6 years in 2012 (Prakash et al. 2015). This may be the result of a slowdown in technological development. The study also revealed that a large proportion of the replaced products were still functioning (Prakash et al. 2015). For large household appliances, 30.5% of the products which were replaced were still working while in the category flat screen televisions 60% were still functional when replaced (Prakash et al. 2015). This also indicates that psychological obsolescence plays a part in the relatively short lifespan of electrical and electronic equipment. Hence, there is great potential for improvement in increasing the life span of electrical and electronic equipment through maintenance, repair, reuse, reconditioning and remanufacturing.

According to the Basel Convention, waste electrical and electronic equipment (WEEE) is categorised as hazardous waste as it contains toxic materials such as lead, mercury and brominated flame retardants (UNEP 2011) as well as precious metals such as gold, copper, nickel and rare earth elements such as indium and palladium (Chancerel et al. 2009). Hence, the proper recycling of WEEE is important to limit the impact on both humans and the environment. The waste treatment of electronics and electrical equipment depends on the geographical context and the composition of the WEEE. It is therefore not possible to predict with certainty how the recycling of a certain product will proceed. In Europe, mechanical, and increasingly technological, solutions are typically chosen to treat WEEE (Gmünder 2007). WEEE is generally pre-processed mechanically using destructive methods combined with different sorting techniques and the resulting fractions are processed in refineries with high standards (Gmünder 2007). Typically, the main steps in the recycling of WEEE are (1) collection, (2) sorting, dismantling and pre-processing (including processes such as mechanical treatment, sorting and dismantling) and (3) end-processing (Schluep et al. 2009, Tanskanen, Takala 2006). The technological requirements and investment costs associated with the two first steps, namely collection and pre-processing, are considerably less than the investment costs of end-processing. Therefore, collection and pre-processing is typically carried out in a regional context whereas end-processing happens in a global context (Schluep et al. 2009).

1.2 RESEARCH QUESTION

Electrical and electronic equipment presents an ever-growing environmental problem due to the increasing waste streams resulting from the increase in consumption and production as well as short lifespans. Furthermore, electrical and electronic equipment contains both hazardous substances and precious metals and rare earth elements. Therefore, it is important to reduce the consumption of resources and close the material loops. This PhD thesis examines how ecodesign can be used to close the material loops through five strategies (1) reduction, (2) maintenance and repair, (3) reuse, (4) reconditioning and remanufacturing and (5) recycling. The research question is as follows:

> How can ecodesign close the material loops in the circular economy for electrical and electronic equipment?

Closing the material loops in the circular economy requires innovative solutions. Rennings (2000) and Rubik (2005) have developed a model describing the factors effecting eco-innovation. In their model, eco-innovation can be encouraged through a regulatory push/pull mechanism, a technological push, business aspects or market demand. In the case of electrical and electronic equipment, the regulatory push could be through the Ecodesign Directive or the WEEE Directive and the regulatory pull could be through green public procurements. The technology push can be both through technological improvements in the waste treatment process or through design changes of products encouraging resource efficiency. Business aspects could be companies applying and developing ecodesign guidelines to use in their design process or self-regulation such as voluntary agreements. Finally, market demand for more resource efficient products could be encouraged. In this PhD thesis, the main focus will be on two of these aspects: the business and the regulatory push/pull mechanism. Hence, the thesis focuses both on how companies can work with ecodesign and on how authorities can regulate to improve the resource efficiency of electrical and electronic equipment.

1.2.1 PART ONE: REGULATING RESOURCE EFFICIENCY

One of the challenges faced by the circular economy is that the prices of materials and natural resources do not reflect the cost of depletion or environmental degradation (Andersen 2007, Sauvé et al. 2015). Therefore, only a limited number of circular solutions are economically viable from the perspective of a company (Andersen 2007). For example, it is often more expensive to produce a long-lasting product than a quick and disposable product (Sauvé et al. 2015). Furthermore, it can be argued that if a company were to act in a rational way, they would already have utilised those recycling and reuse options that were economically viable (Andersen 2007). For this reason, recycling and reuse are only undertaken when they are desirable from the producer's economic standpoint (Andersen 2007) Therefore, the decision-makers have a vital role in ensuring recycling and reuse not only when it is viable from the narrow perspective of the private economy, but also when it is socially desirable and efficient (Andersen 2007).

Part one of this PhD thesis will examine the European environmental product policies covering electrical and electronic equipment, including the Ecodesign Directive, the WEEE Directive, the RoHS Directive, the EU Energy Label, the EU Energy Star Regulation, the Ecolabels and the EU guidelines for Green Public Procurement (GPP). A specific focus will be on the Ecodesign Directive as it has a specific focus on design, applies a life cycle perspective and sets minimum performance requirements. The research question and sub-questions are as follows:

> How have the EU product policies covering electrical and electronic equipment integrated resource efficiency aspects and what is the role of the Ecodesign Directive?

- How have the environmental product policy evolved in the European Union?
- Which environmental policy instruments regulate the resource efficiency of electrical and electronic equipment
- What made it possible to integrate resource efficiency requirements into the implementing measure for vacuum cleaners and the voluntary agreement for imaging equipment? Based on this experience, how could the focus on resource efficiency be further strengthened in the Ecodesign Directive
- How are resource efficiency parameters integrated into the Nordic Ecolabel, the EU Ecolabel, the EU guidelines for Green Public Procurement (EU GPP) and the American Electronic Product Environmental Assessment Tool (EPEAT)? And how can these experiences be applied when integrating resource efficiency requirements into the Ecodesign Directive?

1.2.2 PART TWO: DESIGNING FOR A CIRCULAR ECONOMY IN COMPANIES

The second part of this thesis focuses on how to design products for closed material loops and what can drive and has been driving closed loop activities. Three different aspects relevant for closing the material loops are presented through two case companies. The first case presented concerns Bang & Olufsen, a producer of consumer electronics. This case study illustrates how the company's core values and consumer segments have been driving their closed loop activities and product attributes. Furthermore, the case study illustrates how a company can work with design for recycling through a workshop. The final case study is Tier1Asset, a company reconditioning computers, laptops, tablets and smartphones. This case demonstrates the non-technical and design barriers faced when reconditioning computer. The overarching research question and the sub-questions are:

> How to design electrical and electronic equipment for closed material loops in the circular economy using ecodesign and what are the drivers and barriers?

- How can luxury products support a circular economy? Examined through a case study of Bang & Olufsen.
- How can the recyclability of B&O's products be improved with the current recycling processes and how can a workshop be used to facilitate knowledge exchange between the waste treatment sector and the producers?
- Which non-technical and design barriers experiences Tier1Asset when reconditioning computers?

CHAPTER 2 CONCEPTUAL FRAMEWORK: CIRCULAR ECONOMY AND ECODESIGN

This chapter presents the conceptual framework applied in the study. The chapter begins with a historical outline of the circular economy with outset in ecological economics, environmental economics and industrial ecology. Then the definitions of circular economy and resource efficiency applied in the study and the model describing the different strategies to create a circular economy and improve resource efficiency are presented. Finally an introduction to ecodesign is presented providing insight into the integration of ecodesign into companies, ecodesign tools and ecodesign recommendations which can help closing the material loops in the circular economy.

2.1 CIRCULAR ECONOMY AND RESOURCE EFFICIENCY

The following section will introduce the circular economy. It begins by introducing how circular economy has developed as a concept. The focus is on three schools of thought, namely ecological economics, environmental economics and industrial ecology. This is followed by an introduction to how the European Commission is working with circular economy and resource efficiency. The section concludes with my understanding and definition of circular economy and resource efficiency.

2.1.1 CIRCULAR ECONOMY - A HISTORICAL OUTLINE

The concept of the circular economy has its roots in different schools of thought. The following section introduces some of the main schools of thought and the thinkers who have provided insights into the ideas behind the circular economy. The focus is on the roots of the circular economy within ecological economics, environmental economics and industrial ecology. Environmental economics are a subfield of economics focusing on environmental aspects, particularly the economic analysis of the environment. The ecological economics, on the other hand, considers the economy as a subsystem of the ecosystem and focuses on strong sustainability. There are different conceptual and theoretical understandings of the circular economy within environmental economics, ecological economics and industrial ecology (Andersen 2007). From the environmental economics perspective, circular economy is based on a material balance perspective whereby all material flows should be accounted for. It is the economic values of these flows that guide their management (Andersen 2007). In industrial ecology, on the other hand it is the physical flow (materials and energy) which guides the management, and the product design and manufacturing process are in focus (Lifset, Graedel 2002). The following section is not a full account of how the concept has developed over time, however the more important contributions have been highlighted. Among the first to theorise about the underlying idea behind the circular economy were the ecological economists Nicholas Georgescu-Roegen, Kenneth E. Boulding and Herman Daly.

Roots in Ecological Economics

Nicholas Georgescu-Roegen's main contribution was to link the laws of thermodynamics to economics (Georgescu-Roegen 1975). He argued that the economy needs to function within the framework of the natural world and its limitations (Georgescu-Roegen 1975). The natural world is a closed system. In the thermodynamic understanding, this means that the world exchanges energy, but not matter, with the rest of the universe (figure 2-1) (Georgescu-Roegen 1975). Therefore, the laws of thermodynamics also apply to the economic system (Georgescu-Roegen 1975). In a somewhat simplified manner, the first law of thermodynamics states that energy and matter are constant in a closed system (Pearce, Turner 1990). Theoretically, resources could be used repeatedly with no limitations if it were not for the second law of thermodynamics (Pearce, Turner 1990). The second law states that the entropy of a closed system will never decrease, but will increase towards thermodynamic equilibrium (Pearce, Turner 1990). Hence, materials and energy are dissipated in the system and are thereby more difficult or even impossible to recycle when entering into the economy. Energy is provided as an example of a resource that is impossible to recycle (Pearce, Turner 1990). After burning fossil fuels, it is difficult, if not impossible, to collect the resulting carbon dioxide (Pearce, Turner 1990). Further, if it were captured it would be impossible to use it as a new energy source (Pearce, Turner 1990). Entropy thereby limits to what extent we can recycle resources (Pearce, Turner 1990). If the two laws were embedded into the perception of the economy, a link would be created between the environment and the economy (Pearce, Turner 1990).

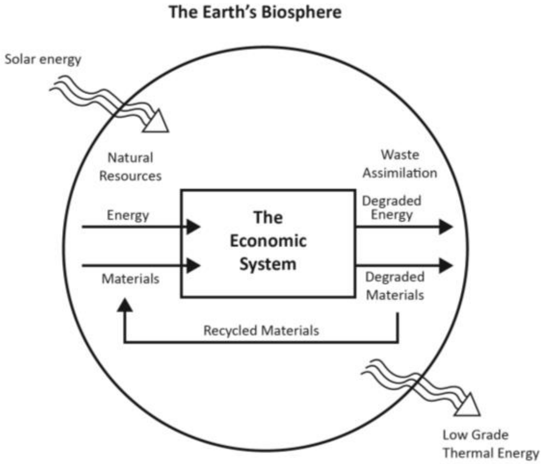

Figure 2-1 The thermodynamic understanding of the world as a closed system, based on (Gaeanautes 2015)

Kenneth E. Boulding was also inspired by the ideas of Georgescu-Roegen when he published his essay *The Economics of the Coming Spaceship Earth* in 1966 (Boulding 1966). Here, Boulding argued that we need to change our current way of perceiving the Earth as an illimitable plane (Boulding 1966). Instead, we need to acknowledge that we are living in a closed sphere (Boulding 1966). We need to stop behaving as if there were no limits to resource extraction and to nature's ability to receive and treat the waste and pollution we produce (Boulding 1966). The issue of pollution in particular has shown the importance of this change (Boulding 1966). Boulding (1966) defines a closed system as a system where all the output of all parts of the system are linked to the input of other parts of the system. There is no input from the outside and no output to the outside. In fact, there is no outside at all in a closed system(Boulding 1966). According to Boulding (1966), we are far from having made the moral, political and psychological changes necessary in the transition from perceiving the world as an illimitable plane to considering it a closed sphere. In particular, the majority of economists have failed to come to grips with the ultimate consequences of the transition from the concept of an open Earth to that of a closed one (Boulding 1966). Moreover, in order to facilitate the transition, the economic principles should be different from those currently applied (Boulding 1966).

Boulding (1966) explains and compares the economic principles in open and closed systems, applying the narrative of a cowboy economy and a spaceship economy. The cowboy economy is the illimitable plane, where we use resources and dump waste without considering future generations (Boulding 1966). This economy is characterised by reckless, exploitative, romantic and violent behaviour (Boulding 1966). On the contrary, in the spaceship economy, the Earth is a spaceship with a fixed stock of resources and with radiation from the sun as the only external input (Boulding 1966). It is a cyclical ecological system where materials should be continuously reproduced and recycled instead of wasted (Boulding 1966). The two economic models build on very different perceptions of consumption and production (Boulding 1966). In the cowboy economy, consumption and production are considered a good thing and success is measured by the amount of throughput according to the gross national product, among others (Boulding 1966). This economic model requires the extraction of raw materials for the production of goods (Boulding 1966) and when the goods are no longer useful, they are deposited in the environment (Boulding 1966). The model could be plausible if there were infinite reserves of materials and infinite sinks for residuals (Boulding 1966). However, in a closed sphere resources and sinks are limited (Boulding 1966). In the spaceship economy, on the other hand, consumption and production are not considered a good thing (Boulding 1966). Here, the main concern is to maintain resources and energy (Boulding 1966). Technological change is a gain given that it maintains the stock of resources and reduces throughput, thereby lessening consumption and production (Boulding 1966). This understanding deviates from the current economic system, which depends on growth and throughput; therefore, economists might find coming to terms with it difficult.

Another ecological economist who has contributed to the ideas of a circular economy is Herman Daly and his steady state economy. Daly was a student of Georgescu-Roegen and was therefore also influenced by his ideas and thoughts about entropy (Røpke 2004). Daly similarly argued that the Earth is a finite and non-growing ecosystem but that the economy is operating as an open system, taking matter and energy from nature with a low level of entropy and transforming it into goods that eventually end up as high entropy waste and pollution in the environment (Daly 2008). The resources can be recycled and transformed, however this requires new energy and new resources (Daly 2008). Daly (2008) argues that the closer the scale of the economy comes to the scale of the Earth, the more it needs to follow the same principles as the Earth.

Daly has proposed a steady state economy (Daly 2008). A steady state economy can be defined as "*an economy with constant population and constant stock of capital, maintained by a low rate of throughput that is within the regenerative and assimilative capacities of the ecosystems*" (Daly 2008, 3). According to Daly (2008), reaching a steady state economy requires low birth rates equal to death rates as well as low product rates and low depreciation rates. However, he also proposes an alternative approach whereby a steady state economy can be reached by "*a constant flow of throughput at a sustainable (low) level, with population and capital stock free to adjust to whatever size can maintained by the constant throughput beginning with depletion and ending with pollution*" (Daly 2008, 3). Thus, he is also a representative of the degrowth movement and he does not believe that we can overcome resource scarcity only through price mechanisms or technological development. Daly does not believe that a steady state economy will happen naturally and thus he differs from other classical economists. Instead, he proposes that governments permanently regulate the economy to reach this state (Daly 2008).

Environmental Economics

In the beginning of the 1990s, the environmental economists David W. Pearce and R. Kerry Turner (1990) further developed the concept and introduced the term circular economy. They developed a theoretical model describing the interactions between the economy and the environment. If we do not give any consideration to the environment, then the economy appears as a linear system where consumer goods and capital goods are produced and consumed to create "utility" or welfare (Pearce, Turner 1990). However, in their model, Pearce and Turner include four welfare economic functions of the environment. Firstly, the environment provides resources as an input for the production of consumer and capital goods. Secondly, the environment is also a major recipient of waste products from the economy but also from nature itself. Thirdly, the environment also provides value to the economic system through amenity value. Finally, and encompassing the three previous functions, the environment is the basis condition for life.

In line with the ecological economists, Pearce and Turner argue that we also need to acknowledge that the economy is a closed system (Pearce, Turner 1990). They arrive at this conclusion based on the first law of thermodynamics, which states, "*that we cannot create or destroy matter and energy*" (Pearce, Turner 1990). This implies that all the resources that go into the production system will at some point end up in the environmental system. In Pearce and Turner (1990), an illustration of such a system is presented (figure 2-2). Here, resources are still extracted and go into the production of consumer goods; however, matter is recycled as a new resource re-entering the system, instead of ending up in the environment (Pearce, Turner 1990). Still, a fraction ends up in the environment as waste; this is linked to the second law (Pearce, Turner 1990). In contrast to Daly, Pearce and Turner (1990) believe in the market mechanisms and that part of the solution is to internalise the externalities. They developed several valuation techniques for obtaining the price of environmental services and proposed market-based instruments such as pollution taxes and tradable permits (Pearce, Turner 1990).

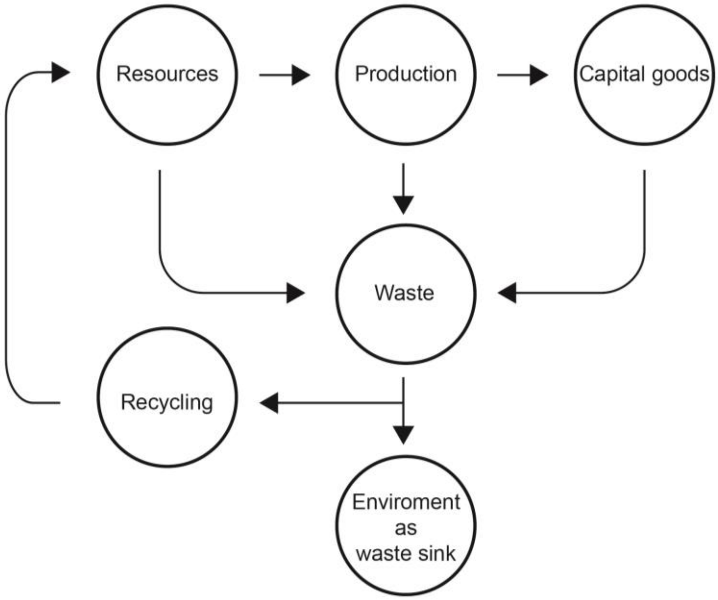

Figure 2-2 Circular economy, based on (Pearce, Turner 1990)

Roots in Industrial Ecology

The idea of a closed system or circular economy has not only developed within the fields of ecological or environmental economics. These ideas of considering the world as a closed system where resources should continue to circulate are also prevalent within industrial ecology and circular economy is also strongly rooted within this line of thinking (Andersen 2007).

Industrial ecology emerged during the 1980s and 1990s as a new approach to handling the increasing problems concerning pollution and waste from industrial systems (Frosch 1992). The idea was that industrial systems should resemble natural ecological systems (Frosch 1992). In nature, organisms within an ecosystem live on and consume each other and each other's waste (Frosch 1992). Waste is not waste but an input into new processes and neither energy nor material is lost (Frosch 1992). The idea of industrial ecology is that industrial processes should be designed in a way that resembles natural ecosystems processes (Frosch 1992). Waste from industrial processes and products at the end of their useful lives should be considered not only as output that should be prevented but also as part of a new product stream (Frosch 1992). One of the earliest definitions of industrial ecology was provided by Braden R. Allenby and Deanna J. Richards (1994) and states that industrial ecology is "*the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the* *influence of economic, political, regulatory and social factors on the flow, use and transformation of resources*" (Allenby, Richards 1994). A very famous example of its practical implementation is the Kalundborg case of industrial symbioses (Ehrenfeld, Gertler 1997). The idea of industrial symbioses is strongly linked to that of a circular economy as it strives to close the material loops of the industrial system and utilise waste from one industrial process as a material input in another industrial process (Ehrenfeld, Gertler 1997). Therefore, industrial symbioses can be seen as one of the possible solutions towards reaching a circular economy.

Allenby and Graedel (1993) have developed three typologies of ecosystems (see figure 2-3) according to how linear or circular the system is. The type I ecosystem has a linear material flow where unlimited resources enter the ecosystem component and unlimited waste exits (Lifset, Graedel 2002). The type II ecosystem has a quasi-cyclic material flow where energy and limited resources enter the system of ecosystem components and limited waste exits (Lifset, Graedel 2002). Within the system of ecosystem components, energy and resources are exchanged (Lifset, Graedel 2002). The final ecosystem, type III, is a cyclic material flow where only energy enters the system of ecosystem components and no resources enter the system and no waste exits (Lifset, Graedel 2002). Type III has the greatest degree of resource recycling and the least reliance on using the environment as a sink for waste (Lifset, Graedel 2002). Hence, type III is the end goal and emphasises one of the important aspects of industrial ecology, namely the importance of closing the material loops (Lifset, Graedel 2002)

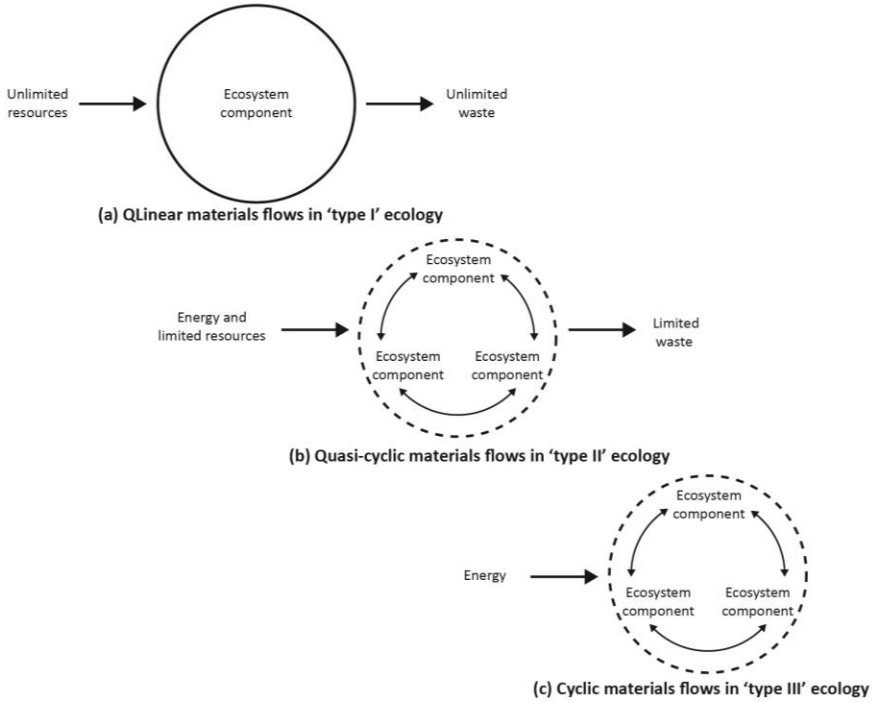

Figure 2-3 The three types of ecosystems, based on Lifset and Graedel (2002)

According to Lifset and Graedel (2002), moving from a type I to a type II or a type III ecosystem not only requires that the loops are closed but also that fewer resources are used to produce the same service. This can be obtained through concepts such as dematerialisation and eco-efficiency (Lifset, Graedel 2002), whereby dematerialisation is defined as the reduction of materials needed to provide a certain output and eco-efficiency is defined as producing a certain output with reduced environmental resources or environmental impacts (Lifset, Graedel 2002). These ideas are linked to the IPAT equation (Allenby, Graedel 2003). The IPAT equation is used to describe the drivers of environmental impacts:

environmental impact = population x affluence (GDP/person) x technology

The main idea is that we can reduce the environmental impact by reducing either population or affluence or by improving technology (Allenby, Graedel 2003). This is again linked to the idea of decoupling (Allenby, Graedel 2003), whereby the idea is that if technology can improve sufficiently then both population and affluence can increase without an increase in environmental impacts or even with a reduction in environmental impacts (Allenby, Graedel 2003). Therefore, technological change is an important aspect in industrial ecology for reducing the environmental impact

(Allenby, Graedel 2003). An important tool in reducing environmental impact from services and products is ecodesign or design for the environment, which covers the incorporation of environmental considerations into the design process (Lifset, Graedel 2002). Other key aspects in industrial ecology are: the lifecycle perspective, materials and energy flow analyses, systems modelling and interdisciplinary research (Lifset, Graedel 2002). Applying a life cycle perspective implies considering the environmental impact of a product or service throughout its entire life cycle from raw material extraction to production, use and final disposal, also known as a cradle-to-grave perspective (Lifset, Graedel 2002). Related concepts and tools applying the life cycle perspective are life cycle management (Remmen et al. 2007) and life cycle assessments (LCAs) (International Standard 2006).

Another industrial ecologist who has theorised regarding a spiral-loop economy system is Walter R. Stahel (Stahel 1982). He denotes this system as the self-replenishing system, which is proposed as an alternative to the existing fast-replacement system or linear consumption and production system (Stahel 1982). The self-replenishing system, or product-lift extension system, would create an economy based on a spiral-loop system instead of the current linear model based on a fast-replacement system (Stahel 1982). This system would reduce matter, energy flow and environmental degradation without restricting economic growth or technological and social progress. This system introduces three loops in addition to the recycling loop (Stahel 1982), namely reuse (loop 1), repair (loop 2) and reconditioning (loop 3) and finally recycling (loop 4) (figure 2-4) (Stahel 1982). Stahel (1982) also enhances the importance of keeping the loops as small as possible, implying that products or components that could be reused should not be repaired, products and components that could be repaired should not be reconditioning and products or components that could be reconditioned should not be recycled (Stahel 1982). Hence, there is a hierarchy between the different levels in accordance with the waste hierarchy (Stahel 1982).

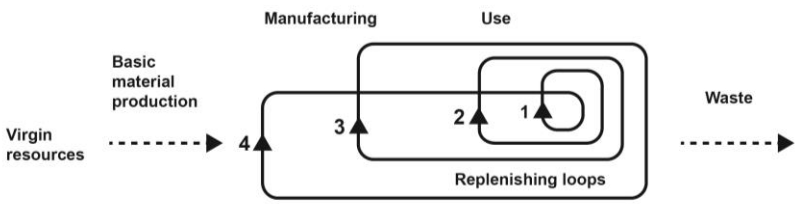

Figure 2-4 The self-replenishing system (product-life extension), based on Stahel (1982)

Cradle-to-Cradle

Another concept closely linked to industrial ecology and the ideas of Stahel is the cradle-to-cradle concept. Michael Braungart and William McDonough have been key figures in developing this concept (McDonough, Braungart 2010). It builds on the same idea that production systems or industrial systems should mimic natural ecosystems (McDonough, Braungart 2010). A key concept in cradle-to-cradle is that waste equals food, as it does in the natural ecosystems (McDonough, Braungart 2010). In the natural ecosystem, there is no waste as waste from one biological process is food for another biological process (McDonough, Braungart 2010). The idea is that the industrial processes should imitate these biological processes by designing out waste (McDonough, Braungart 2010). The cradle-to-cradle concept divides all materials into two categories: technical or biological nutrients (McDonough, Braungart 2010). Technical nutrients are inorganic or synthetic materials which can be used repeatedly while maintaining the same level of quality (McDonough, Braungart 2010). Biological nutrients are organic materials which can decompose into the natural environment (McDonough, Braungart 2010). The cradle-to-cradle concept does not believe that eco-efficiency is needed to reach a closed loop system, as they argue that doing less bad is simply not good enough (McDonough, Braungart 2010). Instead, we need to do the right thing by designing products or services in the right way (McDonough, Braungart 2010) so that the materials at the end of their life can go into either the biological or the technical system (McDonough, Braungart 2010). If the energy system is based on renewables, then the materials can continue to circulate endlessly in either the technical or biological system (McDonough, Braungart 2010). Hence, if the system is designed correctly then there are no limits to growth and it is not necessary to reduce the environmental impact or resource consumption.

The Ellen MacArthur Foundation

The Ellen MacArthur Foundation represents one of the most recent developments within the circular economy field. The Ellen MacArthur Foundation defines the circular economy as *"an industrial economy that is restorative by intention"* (Ellen MacArthur Foundation 2012, 22).The Ellen MacArthur Foundation is strongly influenced by the cradle-to-cradle concept (Ellen MacArthur Foundation 2012). They apply the same division between biological and technical nutrients in their model of the circular economy (figure 2-5), and do not focus on eco-efficiency, similar to the cradle-to-cradle concept. Furthermore, their five principles are in line with the cradle-to-cradle concept and comprise designing out waste, building resilience through diversity, renewable energy, thinking in systems and considering waste as food (Ellen MacArthur Foundation 2012). However, according to the foundation, they also draw on concepts such as regenerative design, performance economy, industrial ecology and biomimicry (Ellen MacArthur Foundation 2012).

Stahel's replenishing loops are also evident in the loops included in the technical system (see figure 2-4).

According to the Ellen MacArthur Foundation (2012), a circular economy makes not only environmental sense but also economic sense. Based on the statistics of sharp price increases in commodities, they argue that the resource prices have increased rapidly over last 10 years, cancelling out the reduction in resource prices obtained during the last 100 years as a result of improvements in technology and efficiency (Ellen MacArthur Foundation 2012). Hence, due to the increases in resource prices and the higher end-of-life treatment costs, a circular economy makes economic sense (Ellen MacArthur Foundation 2012). They introduced four simple circular principles that can create value (Ellen MacArthur Foundation 2012).

- The first is called the power of the inner circles and implies that the savings in terms of materials, labour, energy, capital and environmental savings are largest within the inner circles in the circular economy model (Ellen MacArthur Foundation 2012). Hence, the greatest savings can be found by maintaining the product, followed by reusing the product, and so on (Ellen MacArthur Foundation 2012).
- The second principle is called the power of circling longer and covers keeping products, components and materials in use for longer periods of time (Ellen MacArthur Foundation 2012).
- The third principle is called the power of cascaded use and inbound material/product substitution. This principle covers the possibility cascading products, components and materials across different product categories, thereby substituting virgin material inflows (Ellen MacArthur Foundation 2012).
- The final principle is called the power of pure, non-toxic or at least easier-to-separate input and design. It is a precondition to creating the circular flows that the materials have a certain purity and the products and components have a certain quality. It requires changes to the design of products and materials in order to achieve the necessary quality of the products and purity of the materials (Ellen MacArthur Foundation 2012).

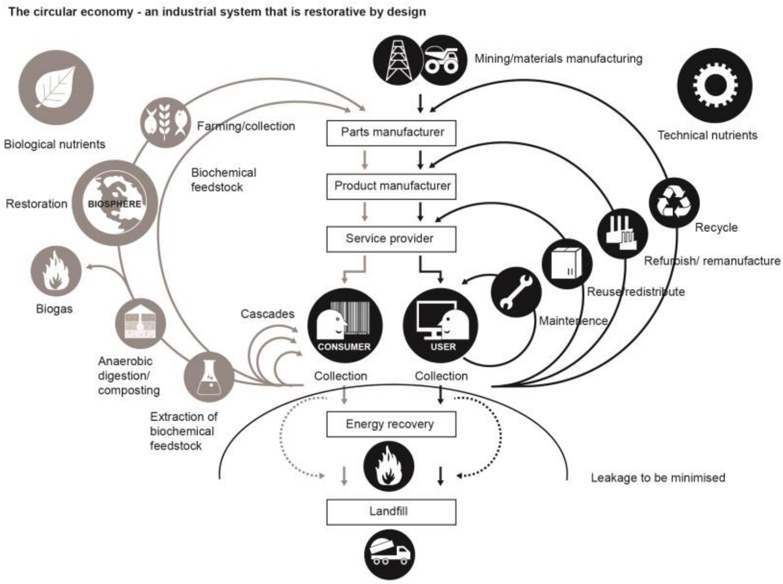

Figure 2-5 Overview of the circular economy model applied by the Ellen MacArthur Foundation, differentiating between the biological nutrients and the technical nutrients, based on the Ellen MacArthur Foundation (2012)

Sub-conclusion

The historical roots of the circular economy reveal that the idea of a closed loop economy dates back to at least the 1960s when Georgescu-Roegen linked the second law of thermodynamics to economy. His ideas inspired several other thinkers such as Boulding, Daly and Pearce and Turner. Daly put forward the idea of a steady state economy and the degrowth movement, whereas Pearce and Turner believed in market forces and in the concept that part of the solution is to include the externalities in the price. In industrial ecology the industrial system should strive to mimic natural ecosystems. Natural ecosystems work as a closed system whereby waste is not waste but rather an input into new processes. Hence, in industrial ecology the idea of a closed system is also prevalent. This is also evident in the model of the three types of ecosystems. Industrial ecology has a more explicit focus on material streams, in contrast to ecological economics and environmental economics. In industrial ecology eco-efficiency, the reduction of environmental impacts and resource consumption are also key elements in creating a closed loop system. However, more recent concepts, such as cradle-to-to-cradle and the Ellen MacArthur Foundation, have not included eco-efficiency and the reduction of resource consumption in their models.

2.1.2 THE CIRCULAR ECONOMY AND RESOURCE EFFICIENCY AT EU LEVEL

More recently, resource efficiency and the circular economy have entered the European political agenda. The European Commission published two communications on resource efficiency in 2011, namely the flagship initiative on resource efficiency in Europe (European Commission 2011a) and the roadmap to resource efficiency (European Commission 2011c). The flagship initiative on resource efficiency is one of seven flagship projects developed as part of the Europe 2020 Strategy (European Commission 2011b). The objective of the flagship is to create a policy framework which can support the transition towards a resource efficient and low carbon economy (European Commission 2011b). It emphasises the importance of resource efficiency for the European and global economies and for securing jobs and growth in Europe (European Commission 2011b).

The roadmap sets a number of specific targets and objectives on how to reach a more resource-efficient and low carbon economy (European Commission 2011c). It puts down a vision, milestones and actions to be carried out by the Commission and the Member States on how to reach a more resource-efficient Europe (European Commission 2011c). Four focus areas are identified, namely sustainable consumption and production, turning waste into a resource, supporting research and innovation and removing environmentally harmful subsidies (European Commission 2011c). The Commission also launched a EU Resource Efficiency Platform in 2012 and set up a Resource Efficiency Finance Round Table (European Commission 2014b). The EU Resource Efficiency Platform is placed within DG Environment with the purpose of providing guidance to the European Commission, Member States and private actors on resource efficiency (European Commission 2014b). In 2008, the European Commission also adopted the raw material initiative, setting out a strategy to ensure access to raw materials (European Commission 2008d). It also includes a list of critical raw materials in the European Union, which is published regularly.

The first circular economy package should have been published in 2014, but it was withdrawn in connection with the change of the Commission in 2014. In 2015, the European Commission adopted a revised circular economy package (European Commission 2015c). This package included a communication on the EU Action Plan for the Circular Economy, a list of follow-up initiatives and four revised legislative proposals on waste (European Commission 2015c). The circular economy action plans specifies actions which should help close the loop of product life cycles through greater recycling and reuse (European Commission 2015c). The action plan also specifies actions for production, consumption, waste management and the market for secondary raw materials (European Commission 2015c). Furthermore, it emphasises the role of the Ecodesign Directive and states that circular economy aspects should be included in the Ecodesign Directive, such as the proposal that energy labelling could include durability information, and that circular economy aspects could be considered in connection with the GGP (European Commission 2015c). The circular economy action plan emphasises four key areas: production, consumption, waste management and from waste to resources (European Commission 2015c).

2.1.3 DEFINITION OF CIRCULAR ECONOMY AND RESOURCE EFFICIENCY

The understanding of the circular economy has developed during this PhD. I began this PhD project at around the same time that the Ellen MacArthur Foundation launched their first report on the circular economy, thus their model influenced my understanding and definition of the circular economy. However, as I started to examine the different schools of thought that were also engaged in creating a circular economy or closed loop system, I soon realised that the idea of creating a circular economy is not new but rather dates back to at least the 1960s.

My Definition of Circular Economy

My starting point at the beginning of the PhD was the Ellen MacArthur Foundation. Therefore, I looked into their definition of the circular economy as *"an industrial economy that is restorative by intention"* (Ellen MacArthur Foundation 2012, 22). However, I struggled with this definition. When is a system restorative by intention and how would I assess it? I found that their definition of a circular economy was not sharply defined and difficult to apply in a real life situation. Furthermore, the circular economy should not only close material loops, it should also have a reduced environmental impact compared to a linear economy. It is not enough for the materials to circulate in closed loops if this still results in environmental degradation. These aspects were not included in the definition by the Ellen MacArthur Foundation. However, they were embedded within Stahel's definition of the self-replenishing system as "*an economy based on a spiral-loop system that minimizes matter, energy-flow and environmental deterioration without restricting economic growth or social and technical progress"* (Stahel 1982, 74). In line with ecological economics and the idea of a steady state economy, I found myself critical of the idea of continuous economic growth. Therefore, growth is not included in my definition. Stahel also uses the word "economy" when defining his self-replenishing system. In my search for a definition of circular economy, one of the things that puzzled me was the use of the word *"*economy*"*. In English, it can be translated as the state of a country or region in terms of its production, the consumption of goods and services, the supply of money, and the careful management of an available resource. In the Danish expression, "cirkulær økonomi", the word "økonomi" is often used more narrowly to define financial or monetary aspects. This presented some challenges at the beginning of my PhD because I have primarily focused on the physical flows within the consumption and production system. The definition of circular economy is therefore:

> A consumption and production system based on closed loops that minimises resources, energy-flows and environmental degradation without restricting economic, social or technical progress.

Strategies for Closing the Loops

The next step in defining a circular economy is to provide a more specific definition of closed circular loops. Both the Ellen MacArthur Foundation and Stahel's replenishing system provided inputs for my understanding of the closed circular loops. The model, presented in figure 2-6, categorises five different strategies for creating a circular economy, namely (1) reduce, (2) maintenance and repair, (3) reuse, (4) reconditioning and remanufacturing, and finally (5) recycling. A product or component can go through several of these strategies, and the same strategy more than once, before finally being recycled. In line with the waste hierarchy, there is also a hierarchy between the circles. Maintenance and repair should be prioritised before reuse. Reuse should be prioritised before reconditioning and remanufacturing. Finally, reconditioning and remanufacturing should be prioritised before recycling. This is what is denoted by the power of the inner circles in the value principles of the Ellen MacArthur Foundation.

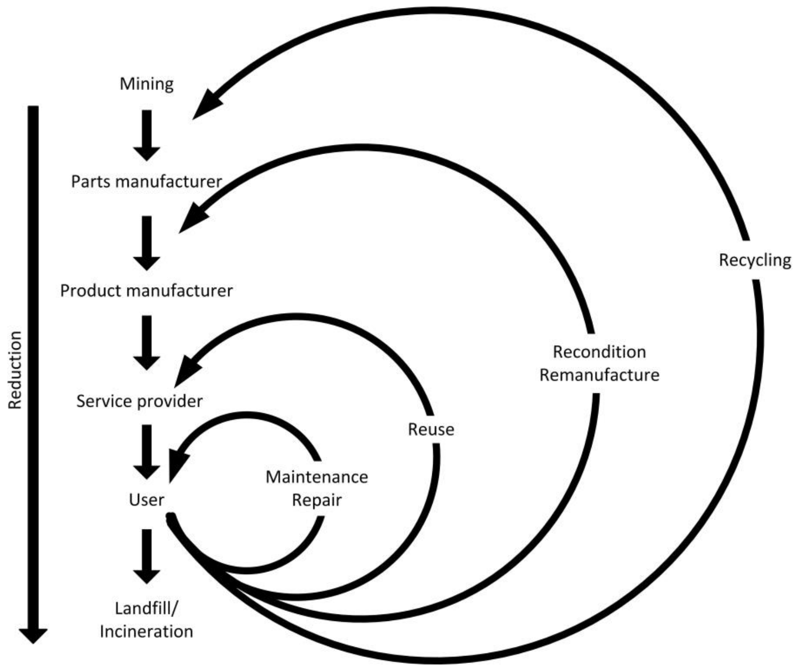

Figure 2-6: The model of the circular economy applied in the study, based on Ellen MacArthur Foundation (2012) and Stahel (1982)

I have introduced reduce to the model to represent eco-efficiency as a strategy for creating a circular economy. The purpose of this strategy is to reduce the environmental impact from the product while taking its entire life cycle into consideration. After working with the circular economy model presented by the Ellen MacArthur Foundation in real life, I realised that it had some shortcomings. At the beginning of my PhD I used the model to map those of my case companies' existing activities which could be considered to be circular or contributing to a circular economy. I found that many of their existing activities related to optimising production by reducing material and energy input and optimising energy consumption during the use phase were not adequately covered by the model. This can be explained by the fact that model is rooted in the cradle-to-cradle concept, which states from the outset that eco-efficiency is not part of the toolbox, because if the production system works as a biological system and the energy is based on renewable energy, then efficiency is not needed. However, in my understanding we are far from having reached a circular economy and our energy production remains highly dependent on fossil fuels. Therefore, in my opinion eco-efficiency is still highly relevant and has also been incorporated into my definition of circular economy. Georgescu-Roegen's coupling of the second law of thermodynamics and the economy also implies that entropy in a closed system will continue to increase. Therefore, materials and energy become increasingly dissipated in a system and are thus more and more difficult to recycle. Based on this fact, I became increasingly critical towards the idea that eco-efficiency is not an important component in circular economy. In industrial ecology, on the other hand, eco-efficiency and dematerialisation are important aspects for reaching type II and III ecosystems.

Maintenance and repair are further strategies in creating closed loops in the circular economy. Repair covers the correction of a specific fault in a product or component (Stahel 1982, King et al. 2006) and maintenance covers aspects such as servicing and updating the product. The purpose of this strategy is to increase the lifespan of the product. When the lifespan of a product is increased, then the environmental impact will decrease relatively because fewer products need to be produced to provide the same service. The next strategy is the reuse of the product. Reuse is understood as direct reuse and thus there is no upgrading or repair prior to reuse. Again, the purpose of this strategy is to avoid or postpone the production of new products by extending the lifetime of the product. The next circle covers reconditioning and remanufacturing. For simplification, the two strategies reconditioning and remanufacturing are grouped together because it is assumed that the processes the products typically undergo during reconditioning or remanufacturing are similar, although they vary in degree and extent. When a product is remanufactured or reconditioned, it typically undergoes sorting, inspection, disassembly, cleaning, reprocessing and reassembly, the replacement of components, and final testing (Hatcher et al. 2011). Refurbishment was used in the model developed by the Ellen MacArthur Foundation and reconditioning was used in Stahel's model. The two terms are often used interchangeably, and either reconditioning (Parkinson, Thompson 2003) or refurbishment (Shu, Flowers 1993) is considered to be part of the remanufacturing process. For simplification I have only included reconditioning in the model and I consider the two concepts to be synonymous. Usually, a third party or the original manufacturer performs the reconditioning or remanufacturing and subsequent reselling of the product. Typical processes are upgrading of the product and the repair or replacement of modules or components. For a detailed definition of the various strategies, see table 2-1.

	Definitions
Reduce and Maintenance	Reduce is related to the concept of eco-efficiency and is defined as the reduction of resources, energy or environmental impacts throughout the life cycle of the product (Lifset, Graedel 2002). Maintenance covers repairing or restoring a component or product to a specified condition in accordance with prescribed procedures (Ebeling 2004).
Repair	The correction of specific faults in a product or component. The quality of a repaired product will typically be lower than a remanufactured or reconditioned product. Furthermore, the warranty of a repaired product is less than that of a new product and may not cover the entire product but only the repair. (King et al. 2006, Thierry et al. 1995, Ijomah, Childe 2004).
Reuse	Is interpreted as direct reuse. Direct reuse is the reuse of the whole product as it is for its original task. (Ilgin, Gupta 2010, 571)
Recondition and remanufacturing	Reconditioning is the process of returning a used product to a satisfactory working condition that may be inferior to its original specifications. Generally, the resulting product has a warranty that is less than that of a newly manufactured equivalent. The warranty applies to all major wearing parts. Less work content than remanufacturing, but more than repairing. All major failed components, or those that are on the point of failure, are rebuilt or replaced, even when the customer has not reported or noticed faults in those components. (Ijomah, Childe 2004, 8, King et al. 2006) Remanufacturing is the process of returning a used product to at least original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent. Greatest degree of work content due to the total dismantling of the product and the restoration and replacement of its components.(King et al. 2006, 8)
Recycling	Is defined in line with the European Waste Framework Directive as, "*any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes*" (European Commission 2008f, 10).

Table 2-1: Definition of the different strategies to reach a circular economy.

Defining Resource Efficiency and the Link to Circular Economy

In this PhD, I also worked with the term resource efficiency and I have to some extent used the terms resource efficiency and circular economy interchangeably. In this section, I will define resource efficiency and elaborate on the difference between the two concepts.

The reason why I focused on resource efficiency, especially in the beginning of my PhD, is because I began my work by looking into the European policy framework regulating resource efficiency. At the time the European Union had not yet published their Action Plan on Circular Economy. Instead, the European Flagship (European Commission 2011a) and the Roadmap on Resource Efficiency (European Commission 2011c) had just recently been published. Therefore, I started by focusing on resource efficiency. For the same reason, my definition of resource efficiency is also based on the definition applied by the European Commission, where resource efficiency is defined as "*using the Earth's limited resources in a sustainable manner while minimising impacts on the environment. It allows us to create more with less and to deliver greater value with less input."* (European Commission 2015e), whereby resource is defined as "*objects of nature which are extracted by man from nature and taken as useful input to man-controlled processes*" (Udo Haes et al. 2002) and can be considered as natural resources, industrial resources or waste-as-resources (Huysman et al. 2015). This understanding of resource efficiency includes a decoupling of economic growth from resource consumption and environmental impacts. It is the same definition of resource efficiency as applied in section 5.2.1..

Linking this definition to my definition of circular economy, there are some similarities. Both resource efficiency and circular economy in the applied definitions strive to minimise resource consumption and environmental impact. The circular economy also provides the solution, namely that consumption and production system should be circular, whereas within the definition of resource efficiency the means are more open to interpretation. However, the strategies or means to improve resource efficiency that I have applied in my understanding of resource efficiency are very similar to the strategies used to create the closed loops in the circular economy. These include reducing resource and energy consumption, durability, reparability, refurbishment/reconditioning, remanufacturing and recycling. Therefore, I also apply a very broad understanding of resource efficiency, as resource efficiency can also be seen more narrowly in line with the concept of eco-efficiency or simply optimising resource consumption. As I have this broad understanding of resource efficiency and consider that resource efficiency should be improved using many of the same strategies applied in circular economy, the differences in the actual application of these two understandings are not that great. One of the more significant differences between the two concepts, however, is that the circular economy is the end-goal and the ideal that we strive to create, whereas resource efficiency is rather a means to achieve this. Hence, resource efficiency is in my understanding a central component in the circular economy and can help create a circular economy.

2.2 ECODESIGN

The review of the different schools of thought, which have provided insight into the concept of circular economy, showed that design was often assigned an important role. In industrial ecology, the incorporation of environmental considerations into product and process design (ecodesign) is considered an important means to avoid environmental impact. Ecodesign is an important element in creating the technological changes necessary to reduce the environmental impact cf. the IPAT equation described earlier. Cradle-to-cradle and the circular economy concept developed by the Ellen MacArthur Foundation also emphasise designing out waste as an important goal to reach. Thus, changing the design of products and services is an important element in creating a circular economy and is the subject of this study. My starting point was ecodesign and how ecodesign could close the loops in the circular economy. The following section will introduce ecodesign and how this concept can be used to design with the intention of closing the loops in the circular economy by improving maintenance and repair, reuse, reconditioning and refurbishment and recycling.

2.2.1 INTRODUCTION AND DEFINITIONS

Papanek was one of the first to introduce sustainable or environmental factors in the design process in the 1970s (Papanek 1971). This first concept was characterised by a critical view of the existing society, scepticism towards technology and a romanticism of nature. The designers were assigned a central position as "*a bridge between human needs, culture and ecology"* (Keitsch 2012p. 183). Since then, the concept has developed further and additional concepts have emerged with the aim of implementing environmental factors into design. This section will provide an introduction to the main concepts and definitions (see table 2-2). These concepts include, but are not limited to, green design, ecodesign, design for the environment and design for sustainability.

In the 1980s, green design (Mackenzie 1997, Burall 1991) was introduced concurrently with the emergence of the green consumer movement (Madge 1997, Sherwin 2000). Green design can be seen as the introduction of environmental factors into everyday design practices, thereby demonstrating that green design was not against the industry (Sherwin 2000). The concept, furthermore, focused on the redesign of products and, to a lesser extent, represented a complete change of the product system.

In the 1990s, ecodesign emerged as a new design concept integrating environmental considerations into product development (Brezet, van Hemel 1997, Tischner et al. 2000, Karlsson, Luttropp 2006). Moreover, ecodesign considers environmental impacts from the product or the service's entire lifecycle. Other definitions of ecodesign emphasise the combination of business-oriented design goals and environmental considerations, drawing on the fact that *eco* can stand for both eco(nomics) and eco(logy) (Karlsson, Luttropp 2006). The development of ecodesign is also linked to design for the environment (Keitsch 2012). Design for Environment can be defined as a “process by which a full spectrum of environmental considerations is taken into account as a routine step in the product or process design sequence” (Allenby, Graedel 2003: 230). Both design for the environment and the ecodesign concepts widely comprise quantitative and empirical methods and are linked to the development of lifecycle assessment methodologies. Lifecycle assessments assess the environmental impact of a product or a service over its entire lifecycle (Sherwin 2000). The final concept to be introduced here is sustainable design or design for sustainability. This concept applies a more holistic approach and includes environmental, social and economic issues (Spangenberg et al. 2010). Furthermore, there is a tendency for design for sustainability to move from the product approach towards a system approach (Dewberry 1996, Spangenberg et al. 2010).

Green design	Ecodesign	Sustainable design
The introduction of environmental factors into everyday design practice. Tends to focus on the redesign of products. (Dewberry 1996)	Ecodesign strives to balance and reduce the environmental impacts at each stage in a product's lifecycle (Dewberry 1996). Ecodesign includes human sustainability priorities together with business interrelations (Karlsson, Luttropp 2006). “Integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product’s life cycle” (European Standard 2011, 2)	Includes a more holistic approach, including environmental, social and economic issues moving from a product to a system approach (Spangenberg et al. 2010). ()

Table 2-2: Definitions of the existing concepts working with the implementation of environmental factors into product design.

Ecodesign is defined in the present study as the implementation of environmental issues in the design process taking the entire life cycle of the product into consideration. However, ecodesign is more than the redesign of products. It includes different levels of change. Two models can be highlighted to explain these different levels of change: Brezet’s different stages of ecodesign innovation (Brezet 1997) and Charter’s four-step model of ecodesign innovation (Charter, Chich 1997). Charter and Chich's (1997) four-step model includes re-pair, re-fine, re-design and re-think. Brezet's (1997) model, which can be seen in figure 2-7, includes the four levels of eco-efficiency improvement (1) product improvement, (2) redesign product, (3) function innovation and (4) system innovation. Hence, both models suggest that ecodesign can imply different levels of change. This can be changing the product to improve its environmental performance, a redesign of the product, or a more radical change such as function or system innovation. This understanding of ecodesign as more than product improvement and the redesign of products will be applied in the study. Hence, when striving to improve the overall resource efficiency, the performance of both function and system innovations will also be possible new solutions.

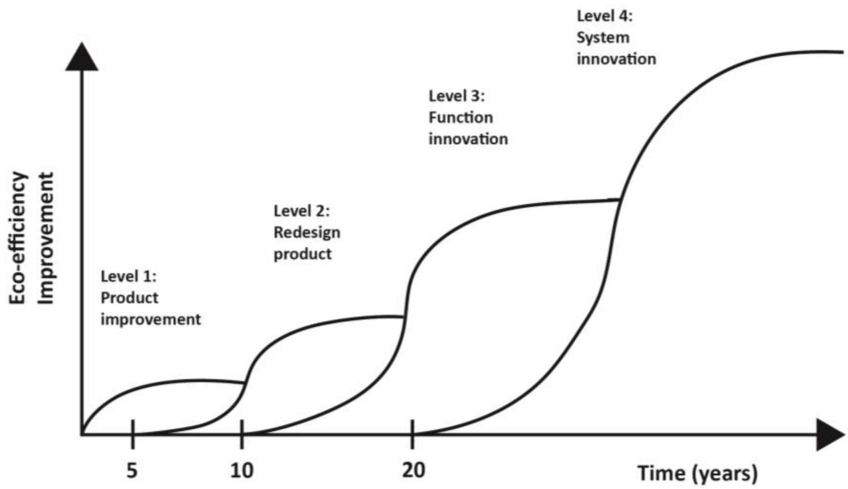

Figure 2-7: Different levels of eco-efficiency improvement, based on (Brezet 1997).

2.2.2 INTEGRATION OF ECODESIGN INTO COMPANIES

Even though ecodesign or similar concepts have been around for more 30 years, their implementation in companies remains a challenge (Pigosso et al. 2013, Bovea, Pérez-Belis 2012). As expressed by Bovea and Pérez-Belis, ecodesign's "*implementation is scarce and the case studies are, in many cases theoretical examples, without the backing of a product company*" (Bovea and Pérez-Belis, 2010, p.70). Existing literature has also identified some of the core gaps in terms of implementing and managing ecodesign in companies (Pigosso et al. 2013). Firstly, existing ecodesign practices are not sufficiently systematised and new tools for technical product design are detrimental to managerial models. Secondly, ecodesign is often not integrated into the broader context of the company, such as in corporate strategy, product development and management. Thirdly, companies lack a roadmap to support them in continuously improving the implementation in their company and thereby implementing ecodesign on higher levels. Finally, companies have difficulties in prioritising and defining which ecodesign practices to use and in proceeding from pilot projects towards implementing ecodesign in the core business. Thus, the movement from the development of the different ecodesign tools and strategies towards actual implementation in companies remains a challenge.

Casper Boks' review in 2006 identified several studies and literature reviews which identified barriers and success factors for integrating ecodesign into product development or companies. Johansson (2002) conducted a comprehensive literature review of success factors when integrating ecodesign into product development. Tukker at al. (2001)identified the state-of-the-art implementation of ecodesign practices in companies. Cramer and Stevels (2001) discussed conditions for the successful implementation of ecodesign. Lindalh (2003) examined how designers use design for environmental methods (DfE) and identified some barriers to the integration of ecodesign, such as a missing life cycle perspective, missing information and limited commitment from the designer. Mathieux et al. (2002) identified obstacles from integrating ecodesign based on case studies of European electronics companies. Handfield et al. (2001) also identified obstacles in connection with the integration of environmental aspects during product development. Pujari et al. (2003) discussed strategic considerations in relation to the integration of environmental factors during new product development. This included aspects such as environmental policy, top management support, the role of environmental coordinators, the involvement of the suppliers and the coordination between different functions. Finally, Boks himself has made a number of suggestions on how to better integrate ecodesign in companies.

In his review, Boks (2006) gathered all these success factors and obstacles and divided them according to their relevance for dissemination within the organisation or to their relevance for ecodesign principles (see table 2-3). Based on the review, Boks tested the relevance of the identified success factors through semi-structured interviews with major electronics multinationals in Japan and a questionnaire survey (Boks 2006). The main success factors for the dissemination of ecodesign within an organisation were (1) customised ecodesign tools tailored to the company's needs, and (2) good management commitment and support (Boks 2006, 1352). The main success factors for the application of ecodesign principles were (1) environmental issues playing a role in all business activities, environmental design guidelines, (2) rules and standards very specific to the company and (3) the inclusion of environmental issues in a company's technology strategy (Boks 2006, 1353). The main obstacles for disseminating ecodesign knowledge in an organisation were (1) too great a gap between ecodesign proponents and those who should apply it, (2) organisational complexities and a lack of appropriate infrastructure and (3) a lack of cooperation between departments (Boks 2006, 1353). The main obstacles for applying the ecodesign principles in the final product were (1) no demand from the market and a lack of environmental goals and visions for individual development projects (Boks 2006, 1354). In chapter 12 these success factors and obstacles are discussed in relation to the case company.

	Success factors	**Obstacles**
Relevance for the dissemination of ecodesign within the organisation	Customised ecodesign tools tailored to the company's needs. Generally good contact between departments about environmental issues Good international network Good management commitment and support Clear environmental goals and vision Alignment of operational and strategic dimensions. Use of environmental checkpoints, reviews, milestones and roadmaps Presence of a so-called "environmental champion" Cross-functional teamwork Environmental design guidelines, rules and standards that are very specific to a company	Available tools too complex Organisational complexities, lack of appropriate infrastructure Lack of cooperation between departments Too great a "gap" between ecodesign proponents and those that have to execute it Lack of management commitment and support Lack of environmental goals and vision for the development organisation as a whole Lack of industrial context in general or not connecting environmental with business considerations.

	Success factors	**Obstacles**
Relevance for ecodesign principles	Market research Ecodesign considerations early in the product development process Inclusion of environmental issues in company's technology strategy Adopting a strong consumer focus, good market research Goals and targets at managerial level Training consumers and customers in environmental issues Good involvement of suppliers expertise in product development processes Environmental issues play a role in all business activities Good environmental education and training programmes for all product development personnel Make good use of examples of good design solutions, also from other companies Use of environmental checkpoints, reviews, milestones and roadmaps Presence of a so-called environmental champion Cross-functional teamwork Environmental design guidelines, rules and standards that are very specific to the company Follow up studies learn from previous experience in a systematic way	A lack of lifecycle thinking Organisational complexities Lack of innovative thinking Lack of testing Lack of experiences Lack of appropriate marketing studies Issues too material-related Issues addressed in terms of end-of-life or recyclability Too little involvement of sales and marketing departments Supply chain problems No demand for the market Lack of follow-up projects Lack of time/too time-consuming Lack of (quality of) data Not enough legislative incentives Lack of environmental goals and vision for individual development projects

Table 2-3: Success factors and obstacles for the integration of ecodesign into companies from Boks (2006, 1351).

2.2.3 ECODESIGN TOOLS

During the past 30 years, several review articles and books have been published on the ecodesign tools developed to design more environmentally conscious products (Byggeth, Hochschorner 2006, Bovea, Pérez-Belis 2012, Tischner et al. 2000). These reviews strive to provide an overview and classification of the different tools and approaches. A simple way to divide the tools is to distinguish between assessment tools and improvement tools (Vallet et al. 2013). Assessment tools can be used to evaluate the environmental impact of an existing product and service or to compare different tools (Vallet et al. 2013). Improvement tools, on the other hand, are used to develop a more environmentally friendly product (Vallet et al. 2013). Tischner et al. (2000) further divided the tools into four categories. The first category comprises tools that can be used to analyse environmental strengths and weaknesses. These tools can also be used to compare products in terms of their environmental impact. An example of such a tools is lifecycle assessments. The second category is tools which can be used for setting priorities and selecting those areas with the most important improvement potential. The third category is a tool to implement ecodesign into the design and development process by providing assistance in designing, brainstorming and specifying ideas. These tools help the designer or product developer to find the right ecodesign strategy or idea. It covers tools such as spider diagrams, rules of thumb, expert rules and ecodesign checklists. The fourth category covers tools which can be used to coordinate with other important criteria such as cost-benefit analyses and economic feasibility studies. It includes tools such as environmental cost accountings, house of environmental quality, evaluation matrices and benefit analysis.

As the purpose of this PhD has been to implement ecodesign in companies, the focus was on tools which support the designers or product developers in integrating environmental concerns into product development, i.e. tools belonging to category three. Based on the reviews of the ecodesign tools by Tischner et al. (2000), Bovea and Pérez-Belis (2012) and Byggeth and Hochschorner (2006), a selection was made of the tools which could be used to implement ecodesign in the product development and design process. These tools are presented in table 2-4.

Tool	**Purpose**	**Sources**
AT&T Checklist	Questions developed to help the designer address environmental aspects during the design process	(Keoleian et al. 1995)
Kodak Checklist		(Betz, Vogl 1996)
Fast five Philips Checklist		(Meinders 1997)
Ten Golden Rules	The ten golden rules are ten rules that can be used to integrate environmental demands in product development. The rules are generic and need to be customised to be directly useful in product development. The tool can be used to improve the environmental performance of products or compare different products or concepts.	(Luttropp, Lagerstedt 2006b)
Eco-Design Checklist Method	The tool combines checklists with semi-qualitative information. It can be used to identify weak points based on semi-qualitative	(Wimmer 1999)

Tool	Purpose	Sources
	assessment on parts, product and function level and redesigns are suggested to increase the environmental performance of the product.	
Product Investigation Leaning and Optimization Tool (Pilot)	An improved version of the Ecodesign Checklist Method. It includes additional guidelines on how to improve the environmental performance of products and detailed explanations and examples on each guideline.	(Wimmer, Züst 2003)
EcoDesign Checklist	The tool consists of a set of questions that makes it possible to make a qualitative assessment of the product in a lifecycle perspective and provides suggestion improvement strategies.	(Tischner et al. 2000)
LiDS-Wheel	Provides the designer with an overview of the environmental improvement potential through eight environmental improvement strategies.	(Brezet, van Hemel 1997)
Strategy List	The list provides ecodesign criteria and strategies which can be used as a basis for developing company-specific criteria and strategies	(Tischner et al. 2000)

Table 2-4: Overview of tools focusing on the integration of environmental aspects into product development to improve the environmental performance based on (Bovea, Pérez-Belis 2012, Byggeth, Hochschorner 2006).

Based on the tools given in table 2-4, one tool was selected based on the following criteria: the tool should be freely available, it should be in English or Danish and should provide specific design recommendations on how to improve the environmental performance of the product. Based on these criteria, the Ecodesign Pilot was selected. Many of the tools provide quite general design recommendations which then need to be transformed into specific recommendations by the user. This applies especially to the ten golden rules, the LiDS Wheel and the fast five Philips checklists. Furthermore, a product category specific ecodesign was selected to provide more product specific design recommendations. The selection was made based on a guide for ecodesign tools from 2005 developed in connection with the Ecodesign Awareness Raising Campaign for electrical and electronic SMEs (Fraunhofer IZM 2005). The European association for standardizing information and communication systems (ECMA) 341 standard for environmental design consideration for information and communication technology (ICT) and consumer electronic (E) products was selected as the product specific guideline (ECMA 2004). It was selected because it again encompassed some of the more comprehensive lists of design recommendations and because it was a standard developed by the industry representatives and therefore considered applicable by the industry.

Design for Remanufacturing

None of the selected tools or guidelines specifically targeted design for reconditioning or design for remanufacturing. Therefore, specific design recommendations targeting design for remanufacturing were examined. When a product is remanufactured, the products typically undergo sorting, inspection, disassembly, cleaning, reprocessing and reassembly, the replacement of components and final testing (Hatcher et al. 2011). Therefore, design for remanufacturing covers design recommendations which can improve these processes. Amezquita et al (1995) identified relevant design for remanufacturing guidelines such as easy disassembly, easy cleaning of parts, easy inspection, easy replacement of parts, easy reassembly, reusable components, modular components and the standardisation of fasteners and interfaces (Amezquita et al. 1995). Chater and Gray (2008) identified design for X strategies relevant for design for remanufacturing. They included design for core collection, ecodesign, design for disassembly, design for multiple life cycles, design for upgrade and design for evaluation. The RemPro matrix also provides product properties which the designer should prioritise if the remanufacturing potential of the product is to be improved (Sundin, Lindahl 2008). It includes aspects such as easy identification, easy verification, easy access, easy handling, easy separation, easy securing, easy alignment, easy stacking and wear resistance (Sundin, Lindahl 2008). Ijomah et al. (2007b) developed specific design for remanufacturing recommendations. These recommendations are presented in appendix A. They focused on the mechanical and electromechanical sector and included design recommendations covering the disassembly of the product, cleaning, remanufacturing and test of the components and assembly of the final product.

Design Recommendation for Closing the Loops

A review was made of the Ecodesign Pilot and the ECMA 341 standard identifying ecodesign recommendations which could help close the loops in the circular economy. The design recommendations were grouped into the following categories: material efficiency, energy efficiency, maintenance, repair, reuse of product parts, durability, recyclability and disassembly. Remanufacturing was also included. Table 2-5 shows which categories of design recommendations are relevant in relation to the different strategies for closing the loops defined in section 2.1.3. The different groups of recommendations were selected based on the definitions of the strategies provided in table 2.1 section 2.1.3. The actual design recommendations can be found in appendix A. The design recommendations are applied in part two for the purpose of examining how to design electrical and electronic equipment for closed material loops in the circular economy.

Strategies	**Recommendations**
Reduce	Recommendations for material efficiency Recommendations for energy efficiency
Maintenance and repair	Recommendations for repair Recommendations for disassembly Recommendations for durability Recommendations for maintenance Recommendations for manufacturing
Reuse	Recommendations for durability Recommendations for maintenance Recommendations for reuse of product parts
Recondition and Remanufacturing	Recommendations for disassembly Recommendations for durability Recommendations for maintenance Recommendations for repair Recommendations for remanufacturing Recommendations for reuse of product parts
Recycling	Recommendations for recycling Recommendations for disassembly

Table 2-5: Overview of the categories of design recommendation relevant for closing the loops

CHAPTER 3 RESEARCH DESIGN AND METHODS

The research design and the methods applied in this PhD thesis are explained in this section. The chapter will open with a description of the process of developing this PhD project and how my role as a researcher developed during the PhD as this has had implications for the research questions, research design and selected methods. Methodology sections are included in separate chapters describing the more detailed methodological aspects of the specific case study. This chapter, therefore, introduces the process of developing this PhD thesis along with general descriptions and reflections on research design, research strategy, the methods applied and the validity of the study.

3.1 THE PROCESS OF DEVELOPING THIS PHD THESIS

My PhD project began in early 2013 and ran until the end of 2016 and was interrupted by a period of maternity leave from March 2015 to December 2015. During the first two years of the PhD, I worked on two externally funded research projects, namely Ecodesign Directive 2.0: From Energy Efficiency towards Resource Efficiency and Designing out Waste. Both projects were funded by the Danish Environmental Protection Agency (Danish EPA), but on different terms. The Ecodesign Directive 2.0 was conducted as a consultancy project for the Danish EPA and was a knowledge-building project aimed at providing inputs to the ecodesign process and the implementation of resource efficiency requirements.

Ecodesign Directive 2.0 From Energy Efficiency towards Resource Efficiency

The purpose was to examine how resource efficiency requirements can be further implemented into the implementing measures and the voluntary agreements under the Ecodesign Directive.

The Danish EPA's Development and Demonstration Program for environmental technologies (MUDP funds) funded the Designing out Waste project. Therefore, the Designing out Waste projects also had an explicit focus on creating actual changes within companies. I worked on the two projects synchronously, and therefore there was an interplay between the regulatory aspects and the activities in the case companies. The fact that I had to deliver on these two projects also had implications for how my PhD project was able to develop. In both projects, the research objectives were given in overall terms. Therefore, I also had some limitations regarding how the scope of my PhD thesis could develop. Furthermore, the case companies in the Designing out Waste projects were also predefined to some extent.

Designing out Waste

The purpose of the project was to improve resource efficiency and convert waste to resources by, (1) testing ecodesign processes on selected product groups, (2) gaining practical experience with improving resource efficiency and closing the material loops and (3) developing further communication and collaboration between the producers and the waste handlers.

3.1.1 PART ONE: REGULATING RESOURCE EFFICIENCY

Part one is partly based on the results from the Ecodesign Directive 2.0 project. The purpose of the Ecodesign Directive 2.0 project was to provide specific and possible solutions to how requirements could be set for resource efficiency. The project was primarily aimed at building knowledge which could then be used by the Danish EPA in the ecodesign process. To gain an insight into the political processes of the Ecodesign Directive, I participated in the following workshops, seminars and conferences in Brussels during 2013 and 2014:

- eceee seminar on ecodesign and innovation, January 22nd 2013
- Conference on Product Policy - International Trends in Ecodesign & Energy Labelling, February 20th-21st 2014
- Conference organised by the Nordic Council of Ministers Working Group for Sustainable Consumption and Production on Resource Efficiency on Ecodesign as a Tool for Resource Efficiency and Circular Economy, June 3rd 2014
- Green Week Brussels 2014: Circular economy saving resources, creating jobs, June 3rd-5th 2014

During these workshops, seminars and conferences I was able to observe the discussions between industries, NGOs, consumer organisations, trade associations, officials and politicians on, amongst other things, the Ecodesign Directive and its role. This gave an insight into how the political debate was developing and what the hot topics were at the time. During this period, I experienced that the focus of the Ecodesign Directive began to change. In the first eceee seminar I participated in, a policy officer from DG Energy referred to the Ecodesign Directive as an energy directive (eceee 2013). A year later, at the conference on Product Policy – International Trends in Ecodesign & Energy Labelling, there was an entire workshop dedicated to resource efficiency and product policies (European Commission 2014d). Hence, during my PhD project the political discussion began to focus more attention on resource efficiency aspects.

During my PhD project, the focus of the political process has also moved from resource efficiency towards the circular economy. In September 2014, the first

Communication on Circular Economy (European Commission 2014a) was published, however it was withdrawn again in December 2014. Then in December 2015, the Action Plan on Circular economy was published (European Commission 2015c). Participating in the political processes made it possible to understand how the resource efficiency and circular economy agenda was developing within the EU. This understanding was applied later when conducting the analyses and when making conclusions and recommendations. During the workshops, seminars and conferences I was also able to identify the relevant stakeholders for interviews concerning the Ecodesign Directive and the integration of resource efficiency requirements. An overview of the interviews conducted is provided in tables 3-3 to 3-6 .

3.1.2 PART TWO: DESIGNING FOR A CIRCULAR ECONOMY IN COMPANIES

Part two was partly funded by the project Designing out Waste, but only two of the three case companies were included in the PhD thesis, namely B&O and Tier1Asset.

The process at B&O began in March 2013 with a meeting with the environmental consultant (1999-2013) and the environmental manager at B&O. During the meeting, the scope of the project was discussed. A round of interviews followed the meeting in May 2013. The purpose of the interviews was to map B&O's circular activities and help define the scope of the project. The interviewees were selected in collaboration with the environmental consultant (1999-2013), who was our contact person and the one responsible for the project at B&O. After the interviews, the scope of the workshop was specified in collaboration with the environmental consultant (1999-2013). Based on the meeting and the interviews, a workshop design was developed and approved by the environmental consultant (1999-2013). A date for the workshop was set in November 2013.

All was set, however shortly afterwards the environmental consultant (1999-2013) found a new job and the workshop was postponed until a new environmental consultant had been found. This change of contact person had implications for the further course of action at B&O. Firstly, the employee at B&O who had participated in developing the workshop and setting out the purpose was no longer present. Thus, the employee with an ownership of the project at B&O was no longer part of the organisation. Secondly, the new environmental consultant (2013-2016) had just begun at B&O and was therefore new to the job and the organisation when the workshop took place. Thus, she did not have the same network in the organisation to draw upon when finding participants for the workshop and when integrating the findings of the workshop into the company. As a result, the workshop was downscaled and had fewer participants. Another aspect which had implications for the process at B&O was their financial situation. Since the global financial crisis in 2007-2009, B&O has faced financial difficulties with reduced turnover and has posted an annual loss for a number of years (Berlingske Business 2015). This affected the process because it had implications for the resources B&O was able to allocate to the project.

The process at Tier1Asset began with a meeting and a tour of their facilities in October 2014. It was followed by an interview round in November 2014, mapping both non-technical and design barriers for reconditioning. Tier1Asset was not included in the original project description for Designing out Waste. They differ from the other case companies in that they are not an original equipment manufacturer (OEM) but rather a reconditioner of equipment from former users of IT equipment. For this reason, they are not directly able to affect the design of the products in order to improve the reconditioning process. The purpose was therefore to map Tier1Asset's experiences with reconditioning computers and to use this to develop guidelines for the OEMs on how they could design products with improved reconditioning potential.

3.1.3 THE INDUSTRY AND WASTE TREATMENT SECTOR

The object of study of this PhD thesis was electrical and electronic equipment and in order to gain an understanding of this sector and the waste treatment of EEE, I participated in an industry conference, a workshop on the greening of electronics and visited pre-treatments facilities for WEEE in Denmark. A list is provided below:

- Electronics Goes Green Conference in Berlin September 2012
- Green Electronics 2013 workshop on resource efficiency in the Electric and Electronics Industry November 4th to 6th 2012
- Visit to Averhoff, a Danish waste treatment facility conducting pre-treatment of WEEE
- Visit to DCR Miljø A/S, a Danish waste treatment facility conducting pre-treatment at WEEE

The industry conference provided an insight into what the industry was doing to reduce the environmental impacts as well as on-going research projects on the topic. The workshop Green Electronics had an explicit focus on resource efficiency and was very relevant to understanding some of the challenges faced by the industry in relation to resource efficiency. The visits and guided tour at the pre-treatment facilities provided an understanding of the pre-treatment of WEEE and some of the challenges the waste treatment sector is facing. It was helpful when going through the scientific literature on waste treatment of WEEE and gave a better understanding of the waste treatment technologies. Interviews were performed as part of the visit (for details see table 3-6). Interviews were also performed with the executive secretary of the European Electronic Recycler Association (EERA) and with the manager of Danish Producer Responsibility (for details see table 3-6). The interviews also helped form a clear picture of the waste treatment sector.

3.1.4 MY ROLE AS A RESEARCHER

My role as a researcher, or my idea of my role, developed during the course of the PhD. It was also formed by the two projects which funded my PhD project. The Ecodesign 2.0 project should provide inputs to the Danish EPA. The purpose was to provide possible solutions for how requirements could be set for resource efficiency. My role was to collect information on the subject, analyse it and communicate the results. It was then up to the Danish EPA to use the knowledge in the political process.

Part two of the PhD was funded by the Danish Environmental Protection Agency's Development and Demonstration Program for environmental technologies (MUDP funds) through the project Designing out Waste, and therefore the project focused on performing actual changes in companies. At the beginning of the PhD project, I had the idea to do action research, understood as *"an approach in which the action researcher and members of a social setting collaborate in the diagnosis of a problem and in the development of a solution based on the diagnosis"* (Bryman 2012: 397). I intended to go into these companies to test ecodesign approaches and tools to improve the resource efficiency aspects of their products. I saw my role as a facilitator of change.

This proved a difficult task for several reasons. Firstly, even though ecodesign and similar concepts have existed since the 1970s (Papanek 1971), the integration of ecodesign into companies is still limited (Pigosso et al. 2013, Bovea, Pérez-Belis 2012). The integration of ecodesign is a task that has previously proven to be difficult. This was also the case with B&O, where it was difficult to gain sufficient support for the project and to get the actual changes implemented into their standard procedures. Furthermore, my affiliation with the companies (mainly B&O) was not close enough to make it possible to do action research. We had several meetings at B&O, conducted interviews and ran the workshop. However, in order to have done actual action research a much closer affiliation to and collaboration with the company would have been necessary. For instance, I should have been located at the company for a period and should have participated in the design process. However, this was not possible due to the set-up of the projects, whereby several companies were involved. Therefore, my understanding of my role as a researcher changed during the PhD from facilitating changes in an organisation towards a more traditional role collecting data, analysing and communicating the results.

3.2 RESEARCH DESIGN

A qualitative research strategy was chosen for the PhD thesis. The PhD thesis is divided into two parts. Part one focuses on regulation and how regulation can help improve resource efficiency and comprises two separate studies. The research was designed as a selection of case studies examining different research objectives. The main method applied for examining the case studies comprised qualitative research interviews, document reviews and a workshop conducted at B&O. The conceptual framework examining circular economy and ecodesign was used to analyse the findings in the case studies and then additional theories and literature reviews were used in the analysis in part two to examine the two case companies. An overview of the research design is provided in figure 3-1.

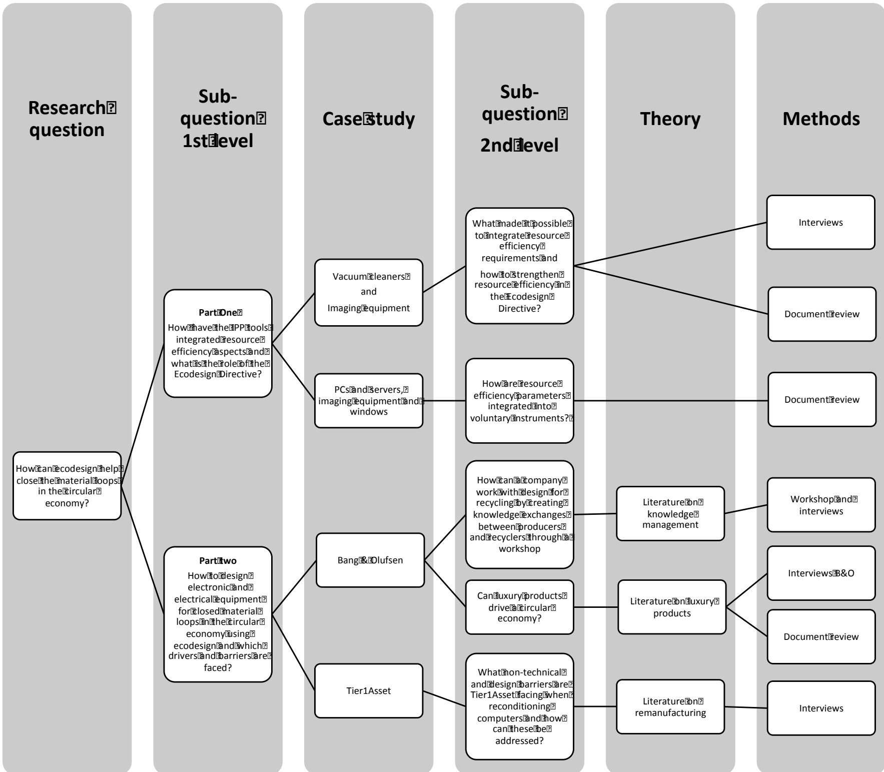

Figure 3-1: Overview of the research design. The research questions have been simplified to fit the framework.

3.2.1 QUALITATIVE RESEARCH STRATEGY

Qualitative research can be connected with certain features (Bryman 2012). Qualitative research often has an inductive relationship between theory and research, implying that theory is generated from the empirical research (Bryman 2012). Some researchers have also suggested that qualitative research can be used to test theories and thereby represents a more deductive relationship between theory and research (Bryman 2012). Epistemologically, qualitative research is often connected to an interpretivist position (Bryman 2012). Thus, the social world can be understood by studying the participants' interpretation of that world (Bryman 2012). Ontologically, qualitative research tends to be linked to constructivism (Bryman 2012). Therefore, social properties are a result of interaction between individuals and not something that can be studied separate from the individuals who take part in the construction of the social properties (Bryman 2012).

A qualitative research strategy is often understood by comparing it to a quantitative research strategy (Bryman 2012). Table 3-1 provides an overview of the differences between qualitative and quantitative research. Typically, qualitative research is concerned with words rather than numbers (Bryman 2012). In qualitative research, it is those being studied who provide the point of orientation of the research (Bryman 2012). What they consider important and significant is what should be studied (Bryman 2012). In quantitative research, on the other hand, it is the researcher who sets out what is important and significant and should be studied (Bryman 2012). In qualitative research, the researcher seeks a close relationship with those being studied as this makes the researcher able to understand the world as they see it (Bryman 2012). In qualitative research, the researcher has a more distant relationship to those being studied, and this can in fact be considered desirable to ensure the objectivity of the researcher (Bryman 2012).

In qualitative research, theory and concepts often emerge from the data, whereas in quantitative research, theory and concepts are often tested (Bryman 2012). Qualitative research is also often more focused on the process, examining events as they develop over time as a result of the interaction between the participants in the social setting (Bryman 2012). Quantitative research often has a more static approach (Bryman 2012). Qualitative research is typically unstructured whereas quantitative research is more structured (Bryman 2012). Qualitative research also typically focuses on contextual understanding instead of generalisation (Bryman 2012). There is a focus on understanding the behaviour, values and beliefs of those being studied in that specific context (Bryman 2012). Qualitative studies also tend to focus on rich deep data instead of hard, reliable data (Bryman 2012). In a qualitative research strategy, the researchers are typically looking for meaning rather than behaviour (Bryman 2012). They want to understand why people are acting and not only how they are acting (Bryman 2012). Qualitative research also studies people in their natural environment.

Quantitative	**Qualitative**
Numbers	Words
Point of view of researcher	Points of view of participants
Researcher distant	Researcher close
Theory testing	Theory emergent
Static	Process
Structured	Unstructured
Generalization	Contextual understanding
Hard, reliable data	Rich, deep data
Macro	Micro
Behaviour	Meaning
Artificial settings	Natural settings

Table 3-1: Some common contrasts between quantitative and qualitative research (Bryman 2012: 408).

A qualitative research strategy was selected based on the research question proposed, which was how ecodesign can close the material loops in the circular economy for electrical and electronic equipment through regulation and in companies. In the research question, I want to understand how to change these aspects. I am asking questions like "how" instead of "to what extent" and am therefore looking for meaning rather than behaviour. The integration of ecodesign into companies is not only about specific design criteria or design changes; it is also about the integration of these design criteria into the design process and the organisation of the company. Therefore, the individuals taking part in the organisations are essential to the understanding of how to close the material loops. Regulation is constructed based on a political process involving a number of stakeholders. Therefore, in both part one and part two of the PhD thesis, the points of view of the participants are important and are forming the research. The research questions also have to be studied in their natural setting and for that reason it is not possible to separate the subject under study from its context. This also implies that I am looking for a contextual understanding of the problems. Summing up, a qualitative research strategy was selected because it is the points of view of the participants which are important for this research, whereby I am looking for meaning rather than behaviour, I am examining aspects in their natural setting, looking for a contextual understanding and for rich deep data.

3.2.2 CASE STUDIES AS RESEARCH DESIGN

Case studies were used as research design. A case study can be defined as "*an empirical inquiry that investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident*" (Yin 2014: 16). According to Yin (2014), a case study is relevant when you want to understand a real world case and when contextual conditions are of importance for the case. The case study enables the researcher to conduct an in-depth study of the research object and to gain a thorough understanding of it (Flyvbjerg 2006). The case study makes it possible to study a phenomenon in society on its own terms (Flyvbjerg 2006). I wanted to examine and understand aspects in the real world and develop an in-depth understanding of how the materials loops could be closed. Therefore, case studies were a relevant research approach. I wanted to examine how to improve resource efficiency and how to close the materials loops in companies and what role regulation through the Ecodesign Directive could play in this regard. How to close the material loops in a company or whether to achieve this through regulation is also context dependent. I also wanted an in-depth understanding of how to close the material loops. For these three reasons, a case study research design was selected.

An aspect often discussed in relation to case study research is whether or not you can generalise based on a case study (Bryman 2012). According to Flyvbjerg(2006), it can be possible to generalize from a single case study, but generalization in scientific research is overrated and the use of "good examples" is underrated. The case selection is, according to Flyvbjerg (2006), decisive for the generalizability of the case. Table 3-2 provides different types of case selection along with the purpose of the case. Flyvbjerg (2006) argues that particularly the choice of an extreme case or a critical case can increase the generalizability of the case.

Types of selection	**Purpose**
A. Random selection	To avoid systematic bias in the sample. The sample's size is decisive for generalizability.
1. Random sample	To achieve a representative sample that allows for generalization for the entire population.
2. Stratified sample	To generalise for specially selected subgroups within the population.
B. Information-oriented sample	To maximize the utility of information from small samples and single cases. Cases are selected on the basis of expectations about their information content.
1. Extreme/ deviant cases	To obtain information on unusual cases, which can be especially problematic or especially good in a more closely defined sense.
2. Maximum variation cases	To obtain information about the significance of various circumstances for case process and outcomes (e.g. three to four cases that are very different on one dimension: size, form of organization, location, budget).
3. Critical cases	To achieve information that permits logical deduction of the type, "If this is (not) valid for this case, then it applies to all (no) cases"
4. Paradigmatic cases	To develop a metaphor or establish a school for the domain that the case concerns.

Table 3-2: Strategies for the selection of samples and cases from Flyvbjerg (2006: 230).

In the PhD study I have conducted a number of case studies with different research objectives. All cases were information-oriented with the purpose of obtaining rich information.

The cases conducted in part one can all be considered extreme or deviant cases. The voluntary agreement for imaging equipment and the implementing measure for vacuum cleaners were selected based on a review of all adopted implementing measures and acknowledged voluntary agreements in 2013. The two cases were selected because they included some of the most elaborated resource efficiency requirements. Thus they could be considered extreme or deviant cases and can provide information on those cases where resource efficiency requirements were successfully implemented. The three product groups, PCs and servers, imaging equipment and windows, were also selected because they contained the more elaborate resource efficiency criteria and can therefore also be considered extreme or deviant cases.

The two company cases B&O and Tier1Asset were predefined in the projects and therefore there was no typical case selection process. However, the two cases still had certain characteristics corresponding to the research strategies described in table 3-2. In the article examining whether luxury products can support a circular economy, B&O could be considered a critical case because they produce consumer electronics, a product category characterised by fast technological development. Therefore, if B&O is able to produce durable products then producers of luxury products with slower technological development are able to do the same. Tier1Asset reconditions consumer electronics such as computers, which is a product group characterised by a high turnover of devices due to the short innovation cycles of the hardware (Robinson 2009). It is therefore a product group difficult to recondition and resell and the case can be considered extreme or deviant according to the definitions in table 3-2.

3.2.3 THE RELATIONSHIP BETWEEN THEORY AND RESEARCH

The conceptual framework described in chapter 2 has been the starting point of this PhD thesis. Additionally, I have applied different theories or literature to a certain topic to explain some of the findings observed in the case studies.

As previously mentioned, a qualitative research strategy is often associated with an inductive relationship between theory and observation, but some researchers have also argued that qualitative studies can be applied to testing theories (Bryman 2012). In the PhD thesis, I have applied both a deductive and an inductive approach. In the deductive approach, the researcher develops a hypothesis based on theoretical considerations and tests the hypothesis in the observations (Bryman 2012). The researcher moves from theory to observation (Bryman 2012). Here, theory can also be literature on a certain topic and often is (Bryman 2012). The researcher might then revise the theory based on the findings from the observations (Bryman 2012). Thus the deductive approach also contains an element of induction (Bryman 2012). In the inductive approach, the researcher draws generalizable conclusions from observations (Bryman 2012). Hence, the researcher moves from observation to theory (Bryman 2012). However, often the end result will not be theory but rather in the form of empirical generalisations (Bryman 2012).

In the PhD I have not solely applied either a deductive or inductive approach, but I have been inspired by either a deductive or an inductive approach. In part one concerning the regulatory framework, I was inspired by an inductive approach. I examined the integration of resource efficiency requirements into the Ecodesign Directive through two case studies. I made observations by participating in seminars, workshops and conferences on the Ecodesign Directive and through interviews with selected stakeholders. Based on these observations and interviews, I made generalisations and developed recommendations on how to further strengthen the focus on resource efficiency requirements in the Ecodesign Directive.

In part two, which examines the case companies, I was more inspired by a deductive approach. I did also take a point of departure in the observations, but I then applied theory or literature on a certain topic to understand the findings. In the study examining whether luxury products could help drive a circular economy in chapter 10, a mapping of B&O's circular activities and circular product attributes was made. Then, we examined the literature on luxury products and their characteristics and used it to understand and explain what we had found in the case study. Finally, we proposed that a link between luxury products exists, providing suggestions for expanding the literature on the subject.

In the study examining how a company can work with design for recycling by creating a knowledge exchange between producer and recycler through a workshop, the theory on the management of knowledge was applied to analyse the workshop and explain some of the difficulties experienced following the workshop in integrating the "new knowledge" into company procedures. In the workshop at B&O, I also used literature on ecodesign regarding how to improve the recyclability of their products. After the workshop, the learning from the workshop was compared to the literature on ecodesign and an evaluation was made of the ecodesign literature.

In the Tier1Asset case, the literature on ecodesign and design for remanufacturing was used to discuss and understand the findings from the interviews and the learning from the case study could add to the existing literature.

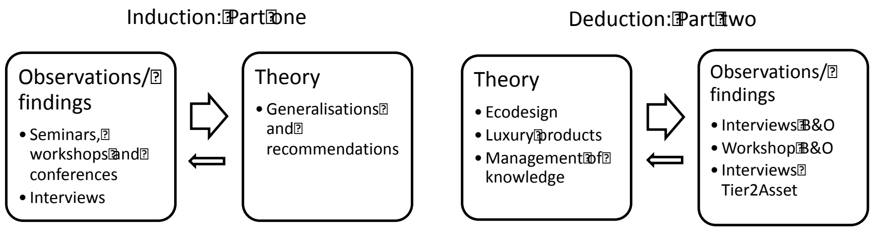

Figure 3-2: Induction and the deductive approach. The process was not solely either inductive or deducting but more iterative, as illustrated by the smaller arrows.

3.2.4 METHODS

The main methods applied for examining the two case studies were qualitative research interviews, document reviews and then a workshop conducted at B&O. Document reviews were used in all case studies and more detailed descriptions can be found in the individual methodology sections in the chapters. The workshop is described in detail in section 11-3.

Qualitative Research Interviews

One of the main methods applied for data collection was qualitative research interviews. The qualitative research interview tries to understand the world from the perspective of the interviewees and uncover their lifeworld (Brinkmann 2009). It is an attempt to try and grasp the world as it looks from the point of view of the interviewee. However, the qualitative research interview is also a site of knowledge creation through the interaction between the interviewer and the interviewee (Brinkmann 2009). The knowledge created from interviews will have certain characteristics and will be constructed, relational, based on conversation, contextual, linguistic, narrative and pragmatic (Brinkmann 2009). Typically, qualitative research interviews can be either unstructured or semi-structured (Bryman 2012). In an unstructured interview, the interviewer typically has predefined issues or topics which should be covered during the interview (Bryman 2012). In a semi-structured interview, the interviewer typically has a list of questions but can vary the sequence of the questions (Bryman 2012). The interviewer can also ask supplementary questions (Bryman 2012). I used semi-structured interviews because they have an open and flexible structure, while at the same time enabling us to structure the interview and make sure that the interviewer keeps their focus.

Overview of the interviews conducted

During the PhD, 19 interviews were made with employees at Tier1Asset and B&O, representatives from the waste treatment sectors, and stakeholders involved in the Ecodesign Directive. An overview of these interviews is presented in table 3-3 to 3-6. Furthermore, four meetings were held at B&O. During these meetings, the workshop concept was developed, however the meetings also provided insights into the company and its circular activities.

Interviews conducted at Tier1Asset

Company	**Interviewee**	**Format & documentation**	**Purpose**	**Date**
Tier1Asset	Two employees from the production working with cleaning and changing components	Interview Recorded and transcribed	To map their experience with reconditioning and possible design improvements.	November 17th 2014
	Employee responsible for grading of the products	Interview Recorded and transcribed	To map their experience with reconditioning and possible design improvements.	November 17th 2014
	Employee from service working with repair of sold products	Interview Recorded and transcribed	To map their experience with reconditioning and possible design improvements.	November 17th 2014
	Employee responsible for software	Interview Recorded and transcribed	To map their experience with reconditioning and possible design improvements.	November 17th 2014
	The head of operations	Meeting and guided tour Recorded and transcribed	To gain a detailed understanding of the business model and to identify success factors and barriers	October 22nd 2014

Table 3-3: Overview of the interview conducted during at Tier1Asset.

Interviews conducted at Bang & Olufsen

Company	Interviewee	Format & documentation	Purpose	Date
B&O	Environmental consultant (1999-2013) Environmental manger	Meeting Minutes	To introduce and discuss the Designing out Waste project and get an introduction to B&O	March 5th 2013
	Environmental consultant (2013-2016) Senior manager product quality centre	Meeting Minutes	Discussion of a strategy in relation to the circular economy.	March 26th 2014
	Environmental consultant (2013-2016)	Telephone meeting Minutes	Discuss the workshop at B&O	April 14th 2014
	Environmental consultant (1999-2013)	Interview Recorded and transcribed	Map B&O's circular activities and develop the workshop concept	May 30th 2013
	Service and production waste	Interview Recorded and transcribed	Map B&O circular activities and examine possibilities for new activities	May 30th 2013
	Director of research	Interview Recorded and transcribed	Map B&O circular activities and examine possibilities for new activities	March 20th 2014
	Technology specialist	Interview Recorded	Map circular activities in relation to their use of plastics and possible actions	May 30th 2013
	Environmental consultant (2013-2016)	Telephone interview Recorded and transcribed	Circular economy activities, luxury products and reorganization of the company	2016

Table 3-4 Interviews conducted at B&O during the PhD.

Interviews conducted to examine the Ecodesign Directive

Company	Interviewee	Format & documentation	Purpose	Date
Electrolux	Karl Edsjö - industry representative	Interview Recorded and transcribed	The resource efficiency agenda in the EU and in the Ecodesign Directive and the opinion of an industry representative. Information on the two case studies.	February 28th 2014
European Environmental Bureau (EEB)	Stephane Arditi - NGO	Telephone interview Recorded and transcribed	The resource efficiency agenda in the EU and in the Ecodesign Directive and the opinion of an environmental NGO. Information on the two case studies.	February 24th 2014
DG Energy	Ewout Deurwaarder - policy officer, Energy Efficiency and Ecodesign and Energy Labelling	Telephone interview Recorded and transcribed	The resource efficiency agenda in the EU and in the Ecodesign Directive. Information on the process of developing the implementing measure on vacuum cleaners.	March 4th 2014
DG Energy	Robert Nuij - head of sector, energy efficiency of products	Telephone interview Recorded and transcribed	The resource efficiency agenda in the EU and in the Ecodesign Directive. The role of DG Energy and their view on the role of the Ecodesign Directive. Information on the two case studies.	March 31st 2014
DG Environment	Ferenc Pekar - policy officer, Ecodesign and Energy Labelling Interview	Telephone interview Recorded and transcribed	The resource efficiency agenda in the EU and in the Ecodesign Directive. The role of DG Environment. Information on the two case studies.	March 28th 2014
EuroVApr	Interviewee	Telephone	The resource efficiency	March 6th

int	1 - president of EuroVAprint	interview Recorded and transcribed	agenda in the EU and in the Ecodesign Directive and the process of developing the voluntary agreement covering Imaging Equipment.	2014
EuroVAprint	Interviewee 2 -president of EuroVAprint (former)			
BIO Intelligence Service	Adrian Tan - project manager	Interview Recorded and transcribed	The resource efficiency agenda in the EU and in connection with the Ecodesign Directive with a specific focus on MEErP.	August 12th 2014

Table 3-5: Overview of the interviews conducted to examine the Ecodesign Directive.

Interviews with the waste treatment sector

Company	Interviewee	Format	Purpose	Date
Averhoff	Tom Ellegaard - works manager	Interview Recorded and transcribed	Discussion of Averhoff's role in the project Designing out Waste and to gain insights into the waste treatment of WEEE and the design challenges they face.	April 16th 2013
DCR Environment A/S	Simon Zittlau Halvarsson - sales manager	Interview Recorded and transcribed	Discussion of DCR Environment's role in the project Designing out Waste and to gain insights into the waste treatment of WEEE and the design challenges they face	November 20th 2013
European Electronic Recyclers Association (EERA)	Norbert Zonneveld - executive secretary	Telephone Interview Recorded and transcribed	To gain an understanding of the European Recyclers and their character and diversity. To examine how the future of recycling might look like. Map general challenges and design challenges faced by the recyclers.	July 3rd 2014
Danish Producer Responsibility	Johnny Bøwig manager DPA	Interview Recorded	To gain an understanding of the collection and recycling of WEEE in Denmark and the challenges faced.	October 22nd 2014

Table 3-6: Interviews conducted to examine the waste treatment of electrical and electronic equipment.

Steiner Kvale's Seven stages of an interview

When designing, conducting and analysing the interviews for this PhD thesis, I used the seven steps defined by Kvale and Brinkmann (2009). Applying the seven steps can help ensure that the objectives and theses of the interviews are clear from the beginning of the process and that the right questions are asked at the right time (Brinkmann 2009). Kvale and Brinkmann's (2009) seven stages include thematizing, design, interviewing, transcribing, analysing, verifying and reporting (Brinkmann 2009).

In the first stage, thematizing includes clarifying the purpose of the study and describing the topics that are examined (Brinkmann 2009). Before I conducted the interviews, a research question for that specific study was formulated, which the interview should help elucidate and answer. The research question might develop as the study progressed, but there was an initial starting point. A specific purpose was also written down for all interviews before they were conducted.

The second step is to plan the research design. When the specific research question was determined, the research design was developed and interviewees were selected. In the case companies, the interviewees were selected in collaboration with our contact person in the company. The identification of relevant interviewees in connection with the Ecodesign Directive was made based on the conferences, seminars and workshop on the Ecodesign Directive I participated in. Furthermore, the snowball method was used to identify additional interviewees (Biernacki, Waldorf 1981). Hence, at the end of each interview the interviewees were asked whom else to interview in relating to the integration of resource efficiency aspects into the Ecodesign Directive.

The third stage is to conduct the interview based on the interview guide (Brinkmann 2009). For all interviews, an interview guide was made and included the purpose of the interview, the themes and the specific interview question. However, due to the semi-structured interview format, it was possible to deviate from the themes and questions. All interviews were conducted either by me alone or together with a colleague and all were recorded. Due to resource constraints and geographic location it was not possible to do all interviews face-to-face. Therefore, particularly those interviews conducted in connection with the Ecodesign Directive were made via telephone. Interviews conducted by telephone have limitations and weaknesses, as it is not possible to observe body language and facial expressions, which can be important features in an interview (Bryman 2012). However, the fact that the interviews were conducted by telephone was not assessed as significantly affecting the output of the interviews. The conversations during the interviews were fluid and the interviewees provided detailed answers to the questions. Furthermore, the subjects and questions were not of a nature where body language and facial expressions were important for the interpretation of the statements.

The fourth stage is transcription (Brinkmann 2009). The main part of the interviews was transcribed for details (see table 3-3 to 3-6). I transcribed part of the interviews myself, but due to time constraints an assistant helped transcribe the rest of the interviews. By transcribing the interview, I gained a more profound understanding of the materials from the interview (Bryman 2012). I achieved an understanding of the nuances in the way things were said and not only in what was said. By listening and transforming the recordings into text, the first part of the analysis had already begun (Brinkmann 2009). Therefore, transcribing the interviews oneself can also be an advantage.

Analysing is the next and fifth stage of conducting interviews (Brinkmann 2009). The interviews were all analysed and coded. The last stage is verification

(Brinkmann 2009). The information from the interviews, which was used directly in the PhD thesis, was verified. For the interviews conducted in connection with the Ecodesign Directive, the interviewees verified the information used from the interviews. For the interviews conducted at the companies, the contact person in the company verified the information used from the interviews.

Document reviews

Document reviews were also used to gain insight into and analyse the case studies. An overview of the documents used in the different studies is provided in table 3-7. Document reviews were used in the study *from energy efficiency to resource efficiency within the Ecodesign Directive*, whereby various documents developed during the ecodesign process were reviewed and analysed. Document reviews were also the main method of data collection in the study of resource efficiency and ecolabels, whereby resource efficiency criteria were identified in the Nordic Ecolabelling, EU Ecolabelling and the EU guidelines for GPP and EPEAT. Finally, in the study examining whether luxury products can help support a circular economy, a review was made of B&O's corporate social responsibility reports and previous studies of B&O.

Study	Documents
From Energy Efficiency to Resource Efficiency within the Ecodesign Directive	Preparatory studies, minutes from stakeholder meetings, minutes and presentations from consultations forums, working documents, stakeholder comments, proposal notifications to the WTO and final regulation.
Resource Efficiency and Ecolabels	Nordic Ecolabelling criteria documents for computers, imaging equipment and windows and exterior doors. EU Ecolabelling criteria documents for personal computers and imaging equipment. EU GPP Guidelines for office IT equipment, imaging equipment and windows, glazed doors and skylights. EPEAT criteria for PCs and displays and imaging equipment.
Can Luxury Support a Circular Economy?	B&O's corporate social responsibility rapports 2011-2012, 2012-2013, 2013-2014, 2014-2015 and 2015-2016 Previous studies of B&O and their company strategies, culture, value and their work with environment and sustainability.

Table 3-7: Document reviews to analyse the cases in the PhD thesis.

3.3 VALIDITY OF THE STUDY

Generally validity can be referred to as whether you are identifying, measuring and observing what you say you are (Bryman 2012: 390). In qualitative research, validity can be divided into internal validity and external validity (Bryman 2012). Internal validity is if there is a good agreement between the researchers' observations and the ideas that develop based on these observations (Bryman 2012). External validity refers to what extent it is possible to generalise the findings of the study to another social context (Bryman 2012).

3.3.1 INTERNAL VALIDITY

Respondent validation was used in the PhD thesis to ensure the internal validity of the study. Respondent validation is when the researchers provide the individuals involved in the study with an account of the findings (Bryman 2012). I mainly conducted interviews and therefore the individuals involved in the study are mainly interviewees with the exception of the workshop held at B&O. In the study examining the Ecodesign Directive in chapter 5, the interviewees had the possibility of commenting on quotations and statements from the interviews used in the case study. The comments and more elaborated explanations of some of the statements by the interviewees were included in the article. This validated the statements based on the interviewees and the way they were interpreted. The environmental consultant (2013-2016) at B&O commented on the design recommendations from the workshop. Furthermore, the results were discussed amongst the researchers from Aalborg University involved in the workshop. This validated the results of the workshop and ensured that the main body of the participants had a similar understanding of the design recommendations resulting from the discussions during the workshop. The environmental consultant (2013-2016) and the senior director global quality validated the study examining whether luxury products can drive the circular economy. The environmental consultant (2013-2016) and the senior director global quality commented on the final draft of the article and, based on a discussion of these comments, some of the statements were altered to ensure a mutual understanding.

Triangulation was also used in the study of the Ecodesign Directive chapter 5. Here, triangulation is defined as the use of more than one source of data or method when studying social aspects (Bryman 2012). In the study of the ecodesign directive, interviews were made with actors involved in the process of developing the implementing measure for vacuum cleaners and the voluntary agreements to examine the process. Furthermore, minutes, presentations, stakeholder comments and other written material from the process of developing the implementing measure and the voluntary agreement were used to analyse the process. Thus two different data sources were used in the analysis.

3.3.2 EXTERNAL VALIDITY - GENERALIZABILITY

Generalizability can, as mentioned in qualitative research, also be referred to as external validity (Bryman 2012). In qualitative research, generalizability is considered difficult due to the tendency to use case studies and small samples (Bryman 2012). However, as mentioned earlier, Flyvbjerg (2006) argues that it is possible to generalise based on a case study depending on how the case study was selected. He emphasises that critical cases are especially good in terms of generalizability because they allow the researchers to obtain information that permits logical deductions, such as if this is (not) valid for this case, then it applies to all (no) cases (Flyvbjerg 2006: 230).

Part one: Regulating Resource Efficiency

The case studies in part one were all extreme or deviant cases. This case selection is used when the researcher wants information on an unusual case that can be especially good or problematic in a more closely defined sense(Flyvbjerg 2006: 230).

The study of the Ecodesign Directive in chapters 5 examined the voluntary agreement for imaging equipment and the implementing measure for vacuum cleaners. Both product groups were selected because they represented best practice when it comes to the integration of wider resource efficiency requirements into the Ecodesign Directive. The cases could therefore provide detailed knowledge on the integration of resource efficiency requirements into the Ecodesign Directive. The idea was to cover the ecodesign process as widely as possible by selecting an implementing measure and a voluntary agreement, representing the two different approaches possible within the Ecodesign Directive. Still, the analysis of the two case studies showed that many of the same aspects were important in spite of the different contextual setting. Therefore, it is concluded that the case findings may also be applicable for the integration of resource efficiency requirements in other implementing measures and voluntary agreements. The findings of the two studies are generalizable, unless the contextual setting changes significantly.

The study examining the integration of resource efficiency criteria in selected voluntary instruments studied the three product categories of computers, imaging equipment and windows. The three product categories were selected as they also represented best practice cases of a wider integration of resource efficiency criteria into the examined voluntary instruments and therefore can also be considered extreme or deviant cases. The three case studies were selected to provide the widest possible range of resource efficiency criteria. The intention was also to examine whether the learning from the voluntary instruments could be used in the integration of resource efficiency requirements into the Ecodesign Directive. Here, it was emphasised that the Ecodesign Directive and the voluntary instruments have different contextual settings. The Ecodesign Directive sets mandatory minimum requirements and the voluntary instruments represent the best performing products on the market. These different contextual settings of the instruments need to be considered before transferring the requirements from the voluntary instruments to the Ecodesign Directive.

Part two: Designing for a Circular Economy in Companies

The case studies for part two were predefined, therefore an actual case selection did not take place. However, the case studies still had certain characteristics similar to the selection strategies from Bent Flyvbjerg (2006).

In the study of B&O, examining whether luxury products can support a circular economy, B&O can be considered a critical case compared to other producers of luxury products because they produce consumer electronics, a product category characterised by fast technological development and which therefore suffers from technological obsolescence. Thus, if it is possible to establish links between luxury products and the circular product attributes such as durability, long lifespan, timeless design, availability of spare parts for consumer electronics, then it is also likely that other luxury product groups which are not characterised by a fast technological development, such as bags, will have the same links to circular economy. However, this does not imply that all luxury products are circular; this still requires an individual evaluation. The design recommendations form the workshop at B&O provided some company specific design recommendations and therefore these recommendations cannot be directly used in other companies. Some of the design recommendations were product specific and these could be used for similar product groups. Finally, some of the design recommendations were more generic and could be used for many types of electrical and electronic equipment.

The case study of Tier1Asset can be considered an extreme or deviant case because they recondition complex products with a fast technological development such as computers, smartphones, and tablets. Therefore, the case study might also provide a more comprehensive account of non-technical barriers and design barriers. However, there are some limitations. Tier1Asset conducts limited repairs, therefore the case study does not provide a full account of design barriers and non-technical barriers in relation to repair. The non-technical barriers and design barriers identified in the Tier1Asset case both had a company specific character and a more generic character. Therefore, some of the more generic barriers in the case studies can be generalised more widely to the reconditioning of other products groups with another set-up, whereas the more company specific barriers identified can only be generalised to companies reconditioning the same product groups and with a similar set-up at their facility

3.4 METHODOLOGICAL DEMILITATIONS

I have only used qualitative methods. These methods are appropriate for providing an in-depth understanding of a problem field. However, they are less apt at providing a picture of how prevalent these issues are. My definition of a circular economy states that the a circular economy is a system of consumption and production based on closed loops that minimises resources, energy flows and environmental degradation without restricting economic, social and technical process. However, in my PhD I have not assessed whether the provided recommendations will in fact minimise resources, energy flows and environmental degradation. Examining these aspects could be conducted through ecodesign assessments tools such as LCA. It could therefore be interesting to examine whether closed loop business models, such as the one applied by Tier1Asset, do in fact minimise resources, energy and environmental degradations.

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PART ONE

REGULATING RESOURCE EFFICIENCY

PART ONE: REGULATING RESOURCE EFFICIENCY

Resource efficiency is an important component in reaching a more circular economy and has been a focus point of the European Commission since 2011. As explained in chapter 1, in order to close the material loops in the circular economy, a regulatory push is important because some aspects might not always be in the direct interest of the producers. The European Integrated Product Policy (IPP) and the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan (SCP/SIP action plan) set overall strategies and goals for the European Environmental Product Policies. The main environmental product policies covering electrical and electronic equipment are the Ecodesign Directive, the WEEE Directive, the RoHS Directive, the EU Energy Label, the EU Energy Star Regulation, the Ecolabels and the EU guidelines for Green Public Procurement (GPP). The Ecodesign Directive is especially interesting in relation to design because it focuses explicitly on the design phase, applies a lifecycle perspective and sets minimum performance requirements. Many of the listed product policies have been assigned a role in reaching a more resource efficient and circular Europe. The question is therefore:

> How have the EU product policies covering electrical and electronic equipment integrated resource efficiency aspects and what is the role of the Ecodesign Directive?

In order to answer these two research questions, the following sub-questions are raised:

- *How have the environmental product policy evolved in the European Union?* To answer this question, the Integrated Product Policy and the Sustainable Consumption and Product Action Plan are reviewed. The purpose is to understand the background of the European product policies and how they developed historically.
- *Which environmental policy instruments regulate the resource efficiency of electrical and electronic equipment?* The European environmental product policies covering electrical and electronic equipment are reviewed. The review focuses on the scope of the different instruments and which types of resource efficiency aspects they cover, if any.
- *What made it possible to integrate resource efficiency requirements into the implementing measure for vacuum cleaners and the voluntary agreement for imaging equipment? Based on this experience, how could the focus on resource efficiency be further strengthened in the Ecodesign Directive?* This question is answered in the article *From Energy Efficiency towards Resource Efficiency within the Ecodesign Directive*. The article examines

the processes and stakeholder interactions behind the development of the implementing measure covering vacuum cleaners and the voluntary agreement covering imaging equipment. Based on the two case studies, recommendations are made on how to further strengthen the uptake of resource efficiency requirements into the Ecodesign Directive.

- *How are resource efficiency parameters integrated into the Nordic Ecolabel, the EU Ecolabel, the EU guidelines for Green Public Procurement (EU GPP) and the American Electronic Product Environmental Assessment Tool (EPEAT)? And how can these experiences be applied when integrating resource efficiency requirements into the Ecodesign Directive?* This is answered in a chapter from the report *The Ecodesign Directive 2.0: From Energy Efficiency towards Resource Efficiency* (Bundgaard et al. 2015). The chapter includes a review of the resource efficiency criteria in the four voluntary product policy instruments and a discussion on how these requirements could be transferred to the Ecodesign Directive.

Part one ends with discussions and conclusions and how the European environmental product polices regulate resource efficiency and what the role of the Ecodesign Directive is.

Delimitation

Part one includes a general review and an analysis of all policy instruments covering electrical and electronic equipment and a more detailed review and analysis of the implementation of resource efficiency requirements into the Ecodesign Directive and the EU Ecolabels. It has not been possible within the framework of this PhD thesis to make a detailed review and analysis of all the product instruments. Another delimitation is product compliance. Product compliance is essential if the policy instruments are to have an actual effect on improving resource efficiency. However, studies have shown that the non-compliance rate is high for both the products covered by the Ecodesign Directive and the EU Energy Labelling Directive (Molenbroek et al. 2013). Even though there are significant problems with non-compliance within the Ecodesign Directive, it is not further dealt with in this PhD thesis. Another delimitation is looking into the potential of the Ecodesign Directive to change consumption patterns

CHAPTER 4 REGULATION OF RESOURCE EFFICIENCY IN THE EU

This chapter provides an introduction to the strategies, action plans, initiatives and product policies at the EU level that are relevant for regulating the resource efficiency of electrical and electronic equipment. The chapter is descriptive and includes an introduction to the relevant European environmental product policies strategies and an introduction to the policy instruments relevant for the resource efficiency of electrical and electronic equipment. This chapter also provides the background knowledge to the discussion in the two following chapters as well as in chapter 7 and 8, which provides the discussion and conclusions for the research question for part one.

4.1 THE EUROPEAN ENVIRONMENTAL PRODUCT POLICIES

Environmental Product Policy (EPP) received scientific attention during the early 1990s (Rubik, Scholl 2002). This period was marked by a general shift from the traditional focus on environmental aspects in the production phase towards a more comprehensive focus on the environmental impacts of products during their lifecycle from cradle to grave. The European Union has developed its interpretation of the EPP, called the Integrated Product Policy (IPP), with the purpose of formulating a common product-oriented environmental policy (Charter 2001).

4.1.1 INTEGRATED PRODUCT POLICY

IPP emerged in 1996 when the Commission assigned Ernst&Young and the University of Sussex to make a review of the national and international developments of the IPP (Tanasescu 2009). It was followed by a one-day workshop in 1998 where discussions on the definition, objectives and priorities for an EU-level IPP were initiated (Tanasescu 2009). Then, in 1999, the EU environmental ministers agreed on the need for a policy that focuses on developing and implementing an integrated approach, taking into account the entire lifecycle of products. The purpose of the IPP was to work with the market and engage all stakeholders in continually improving the environmental performance of products and services from a life cycle perspective (Charter 2001). With the reliance on market forces, the IPP also reflects a transition from government to governance in environmental policy (Scheer, Rubik 2006). While governance represents a more horizontal steering of the political process with networks, non-state actors participate in the governing process (Jordan et al. 2005). Governance can reflect different degrees of self-organizing networks where governments play a varying role (Jordan et al. 2005). Governance is more to be seen as a spectrum of different degrees of self-organizing networks with more or less government involvement and steering rather than a completely new type of governing style that replaces the old.

In February 2001, a green paper on the IPP (European Commission 2001) was published. The purpose of the green paper was to initiate a public debate on the IPP. In the green paper, the IPP was defined as "*an approach which seeks to reduce the life cycle environmental impact of products from the mining of raw materials to production, distribution, use, and waste management*" (European Commission 2001: 5). With this, the IPP introduced the concept of lifecycle thinking to European environmental policies. The green paper also underlined the importance of the strong involvement of stakeholders, including consumers, non-governmental organisations, industry and retailers. The green paper also defined the role of the public authorities as facilitators rather than as direct interventionists, following the governance approach in the IPP concept. Thus, legislation was not the primary focus of the IPP. However, the IPP should use a mix of policy instruments where appropriate.

The green paper presented four strategies on how to implement the IPP approach. These strategies included (1) using market forces to the greatest extent possible. Due to the reliance on market forces, it was important to (2) get the price right, which was the next strategy proposed. Taxes and subsidies were identified as those means most effective for internalising external costs, but supplementary actions were also identified, such as better information to the consumers on the environmental aspects of the products. The leads us to the next strategy, namely (3) green demand. The consumers should demand more environmentally friendly products, as this gives the producers an economic incentive to improve the environmental performance of their products. The final strategy (4) is supply side measures and covers instruments to encourage companies to apply a life cycle approach. Furthermore, Annex III in the green paper lists instruments and proposed actions for the implementation of the IPP in the European Union. It includes economic instruments taking action to identify price elements which prevent the take-up of greener products on the market and an investigation into differentiated taxation. Additional instruments were producer responsibility, ecolabels, environmental declarations, public procurements, product information, ecodesign guidelines, standards for environmental design, a review of the potential of new approaches in legislation to encourage green design, product panels and supportive instruments such as EMAS, the research and development programs, LIFE programs and environmental reporting.

The green paper was followed by a communication on the IPP from the European Commission in 2003 (European Commission 2003a). The communication suggested five IPP approaches, namely lifecycle thinking, working with the market, stakeholder involvement, continuous improvement and a mixture of policy instruments. The communication identified policy tools suitable for supporting the implementation of the IPP, including taxes and subsidies, voluntary agreements and standardisation, public procurement legislation and other legislation (RoHS, the Ecodesign Directive and Waste Directive). However, taxes and subsidies were merely considered a long-term target. More specific tasks and instruments which could support the implementation of the IPP were also identified, such as making life cycle information and life cycle assessment tools available, the existing Environmental Management System (EMAS), the coming Ecodesign Directive, green public procurement, EU Ecolabels, the EU energy labelling scheme and the European car-labelling scheme.

The actual implementation of IPP had two trails (Tanasescu 2009). The first was a process of revision and adaptation of already existing tools to make them more focused on products (Tanasescu 2009). This included a revision of EMAS and the EU Ecolabels, creating guidelines for the LCAs, and the greening of public procurements (Tanasescu 2009). Furthermore, it was also during this period that the Ecodesign Directive was developed. Secondly, studies were conducted identifying products with the greatest potential for environmental improvements and possible ways to reduce the environmental impact of some of the products (Tanasescu 2009).

4.1.2 SUSTAINABLE CONSUMPTION AND PRODUCTION POLICIES

The next development within European environmental product policies was the publication of the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan (SCP/SIP action plan) in 2008 (European Commission 2008e). The action plan was a result of the European Development Strategy from 2006. The action plan had a broader scope than the IPP as it also included the social and economic dimensions. Furthermore, the action plan applied the idea of green growth, whereby the companies can transform environmental considerations into business opportunities.

The purpose of the action plan was to help improve "*the overall environmental performance of products through their lifecycle, promoting and stimulating the demand of better products and production technologies and helping consumers to make better choices through a more coherent and simplified labelling* (European Commission 2008e, 3). Three main issues were identified, namely smarter consumption, leaner production and global action. Smarter consumption covered actions which could help change the behaviour of producers and consumers by raising awareness of sustainable consumption. Leaner production covered actions aimed at reducing the environmental impact from production processes. Finally, sustainable consumption and production should be promoted on a global scale. The plan addressed many of the same policy instruments as the IPP, such as the Ecodesign Directive, the EU Energy Labelling Directive, the Energy Star regulation, the Ecolabel regulation, the EU guidelines for Green Public Procurement (GPP), EMAS and an Environmental Technical Verification scheme. The action plan indicated a number of weaknesses in the existing policy framework, mainly that the regulatory instruments were not sufficiently connected and the synergies between the instruments were not utilised. The implementation should have been more dynamic and forward looking to ensure that product performance continued to improve. Furthermore, the national and regional approaches were not sufficiently harmonised. Therefore, the intention of the action plan was to integrate the potential of the policy instruments taking a dynamic approach. The following actions were proposed: an extension of the Ecodesign Directive, a revision of the Ecolabel regulation, a revision of the EMAS regulation, a communication on Green Public Procurement, a revision of the EU Energy Labelling Directive and a regulation for an Environmental Technology Verification scheme.

Even though the IPP and SCP concern separate policy areas within the European Union, they are very related and there is a large degree of overlap. Their purposes are similar and they apply many of the same policy tools to achieve their goals, such as the ecolabels, GPP, EU Energy Label, Ecodesign Directive and EMAS. The two concepts IPP and SCP also represent the development over time within the environmental field in general from the product focus to a focus on sustainability in broader terms.

4.2 EUROPEAN ENVIRONMENT POLICIES COVERING ELECTRICAL AND ELECTRONIC EQUIPMENT

The purpose of part one has been to examine how resource efficiency aspects of electrical and electronic equipment are regulated in Europe and to analyse the role of the European Ecodesign Directive. Therefore, only European product policies are included in the introduction. Furthermore, the REACH regulation was excluded because it has a much broader scope and does not focus specifically on products but rather on chemical substances. This section provides an introduction to the European environmental product policies covering electrical and electronic equipment. It includes the mandatory product policies such as the Waste Electrical and Electronic Equipment (WEEE) Directive, the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive, the Ecodesign Directive and the EU Energy labelling Directive. Furthermore, it includes the voluntary policy instruments such as the EU Ecolabel Regulation, the EU Energy Star Regulation and the EU guidelines for GPP.

4.2.1 THE MANDATORY ENVIRONMENTAL POLICY INSTRUMENTS

The WEEE Directive

The first WEEE Directive entered into force in February 2003 (European Union 2002). In August 2012, a revised WEEE Directive entered into force and was effective from February 2014 (European Commission 2012a). The purpose of the WEEE Directive is to contribute to the prevention, reuse, recycling and recovery of electrical and electronic waste (European Commission 2012a). This should reduce the disposal of waste and contribute to a more efficient use of resources and the recovery of valuable secondary raw materials (European Commission 2012a). The WEEE Directive covers electrical and electronic equipment and, in Annex I, provides a list of the product categories covered (European Commission 2012a). The WEEE Directive obliges Member States to ensure that a free-of-charge collection system is set up for consumers and retailers (European Commission 2012a). It also sets a minimum rate for collection and recovery, recycling and prepare for reuse targets which the Member States should comply with. In the revised WEEE Directive, the product categories are regrouped from 2018 and the recycling targets also include prepare for reuse. However, specific targets are not included for prepare for reuse. The various categories, along with recovery, recycling and prepare for reuse and recycling targets, are presented in table 4-1. The minimum collection rate should be 45% of the average weight of electrical and electronic equipment placed on the market during the last three years (European Commission 2012a, Article 7). Annex VII in the WEEE Directive also specifies substances, mixtures and components which need to be removed for selective treatment (European Commission 2012a).

The WEEE Directive introduces the producer responsibility principle into European product regulation. This principle, in the context of the WEEE Directive, makes the producer financially responsible for the collection, treatment, recovery and disposal of WEEE in an environmentally sound way. The idea behind introducing the principle was to establish a financial feedback mechanism. The mechanism would encourage the producers to design products which would be easier to prepare for reuse or recycle. The Member States have implemented the WEEE Directive differently (van Rossem et al. 2009). In particular, the introduction of producer responsibility has varied across Member States. Many Member States have set up collective financial responsibility systems which do not provide the producers with the same incentives to change the design of their products as individual producer responsibility does (Sander et al. 2007, van Rossem et al. 2009). Therefore, the WEEE Directive has not resulted in design changes of the products which could improve the reuse, recycling or recovery of electrical and electronic equipment.

	August 2012-August 2015		August 2015 - August 2018			From 15. August 2018	
Categories	**Recovery**	**Recycling**	**Recovery**	**Prepare for reuse Recycling**	**Categories**	**Recovery**	**Prepare for reuse Recycling**
Larger household appliances	80 %	75 %	85 %	80 %	1. Temperature exchange equipment	85 %	80 %
2. Smaller household appliances	70 %	50 %	75 %	55 %	2. Screens and monitors	80 %	70 %
3. IT and telecommunications equipment	75 %	65 %	80 %	70 %	3. Lamps		80 %
4. Consumer equipment and photovoltaic panels	75 %	65 %	80 %	70 %	4. Large equipment	85 %	80 %
5. Lighting equipment	70 %	50 %	75 %	55 %	5. Small equipment	75 %	55 %
6. Electrical and electronic tools	70 %	50 %	75 %	55 %	6. Small IT and telecommunications equipment	75 %	55 %
7. Toys, leisure and sports equipment	70 %	50 %	75 %	55 %			
8. Medical devices	70 %	50 %	75 %	55 %			
9. Monitoring and Control Instruments	70 %	50 %	75 %	55 %			
10. Automatic dispensers	80 %	75 %	85 %	80 %			

Table 4-1: Product categories and recover, recycling and prepare for reuse and recycling targets in the revised WEEE Directive (European Commission 2012a).

The RoHS Directive

The Restriction of Hazardous Substances (RoHS) Directive entered into force in February 2003 (European Commission 2003b). In January 2013, a recast of the RoHS Directive from 2011 came into effect (European Commission 2011e). The objective of the RoHS Directive is to restrict the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment (European Commission 2003b, article 1). The RoHS recast Directive restricts the same substances as the first directive from 2003. Article 4 specifies that Member States should ensure that new electrical and electronic equipment put on the European market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) (European Commission 2003b). However, a list of exemptions is provided in Annex III and Annex IV in the recast of the RoHS Directive (European Commission 2011e). The recast makes it easier for the European Commission to include additional restrictions on substances through delegated acts. The first delegated act was adopted in 2015 and restricts the use of four additional substances: Bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP) (European Commission 2015d). The recast RoHS Directive covers the same categories as the WEEE Directive prior to 2018 (table 4-1), but also includes a category eleven covering other electrical and electronic equipment not covered by any of the categories listed in categories one to ten (European Commission 2011e). Hence, in the recast all electrical and electronic equipment is in principle included unless otherwise specified. In addition to the expansion of the product scope and the ease of including new substances, the recast also includes the RoHS Directive in the CE marking scheme, sets clearer requirements for manufactures, importers and distributors, formalizes the process for requesting exemptions and sets requirements for a conformity assessment.

The Ecodesign Directive

The Ecodesign Directive was adopted in July 2005 (European Commission 2005). In March 2008, a revised Ecodesign Directive was adopted, stepping into force in October 2009 (European Commission 2009a). The most important change to the revised Ecodesign Directive was the expansion of the scope from energy–using products to energy-related products. The directive establishes a framework for setting ecodesign requirements to ensure the free movement of these products within the European market (European Commission 2009a). Ecodesign is here defined as *"the integration of environmental aspect into product design with the aim of improving the environmental performance of the product throughout its whole life cycle"* (European Commission 2009a, article 2 (23)). The Ecodesign Directive provides the setting for adopting implementing measures or self-regulation such as voluntary agreements. The implementing measures and voluntary agreements set minimum performance requirements which the products need to comply with in order to obtain a CE marking. Working plans are developed specifying which product groups should be covered by implementing measures or voluntary agreements during the next three years. At present (August 2016), 24 implementing measures and 3 voluntary agreements have been adopted. A more detailed description of the Ecodesign Directive and the ecodesign policy process is presented in chapter 5.

EU Energy Labelling Directive

The EU Energy Labelling Directive was adopted in 1992 (European Commission 1992a) and in 2010 a recast of the EU Energy Labelling Directive was adopted (European Commission 2010b). The purpose of the directive is to establish a harmonised framework for end-user information through labelling and standard product information (European Commission 2010b). The label provides information on energy consumption during use as well as other essential resources during use where relevant and additional information allowing the end-users to choose more efficient products (European Commission 2010b, article 1). The first directive targeted household appliances, but in the recast the scope was extended to energy-related products with a significant direct or indirect impact on energy consumption during use. The extension of the scope aligns the EU Energy Labelling with the Ecodesign Directive, thereby making it possible to better utilise the synergies between the two instruments. The specific information requirements for the product groups are set in delegated regulations and are thereby legally binding when adopted by the Commission.

4.2.2 THE VOLUNTARY ENVIRONMENTAL POLICY INSTRUMENTS

European Energy Star Regulation

The Energy Star program was initiated by the US Environmental Protection Agency in 1992 to promote energy efficient products. It provides information making it possible for the consumer to select the most energy-efficient product. The Energy Star program covers a wide list of products such as appliances, building products, commercial food service equipment, electronics, heating and cooling, lighting, office equipment and water heaters.

In 2001, the European Union and the government of the USA made an agreement on the coordination of an energy efficiency labelling program for office equipment not covered by EU Energy Labelling. In December 2006, the agreement was formalised through a council decision (European Commission 2006). The European Energy Star programme is voluntary and establishes rules for energy efficiency labelling programs, making it possible for consumers to select the most energy efficient product. Furthermore, for imaging equipment it sets requirements for the efficient use of consumables. It covers computers, servers, displays, imaging equipment and UPSs.

The EU Ecolabel Regulation

Ecolabels are voluntary instruments which provide the consumer with reliable information on the environmental performance of products or services. Based on this information, the consumer can make an informed choice whether to buy a product with a higher environmental performance. The ecolabelled products should represent the environmentally best performing products on the market. If the demand for products with a higher environmental performance increases, it can encourage the producers to develop products with a better environmental performance.

The European Commission launched the regulation on the EU Ecolabel in 1992 (European Commission 1992b), which was revised in 2000 (European Commission 2000) and again in 2009 (European Commission 2009b). The purpose of the EU Ecolabel is to establish a voluntary ecolabel award scheme to promote products with a reduced environmental impact during their entire lifecycle and to provide consumers with information on the environmental impact of the product (European Commission 2009b). The ecolabelled products should represent those products on the market with the best environmental performance. The EU Ecolabelling criteria should consider the whole lifecycle of the product and should focus on the most significant environmental impact (European Commission 2009b). The EU Ecolabel should especially focus on: climate change, impacts on nature and biodiversity, energy and resource consumption, the generation of waste, the release of hazardous substances into the environment, pollution, the substitution of hazardous substances, durability and reusability, impact on the environment and health and safety, ethical aspects and the reduction of animal testing. The European Union Ecolabelling Board (EUEB) manages the EU Ecolabelling. The ecolabelling criteria for the individual product groups are adopted through a Commission decision. In 2016, criteria were developed for the following electrical and electronic equipment: imaging equipment, personal computers, notebook computers, televisions, heat pumps and water-based heaters.

The EU Green Public Procurement Guidelines

The public authorities are major consumers and can therefore use their purchasing power to move the market by choosing environmentally friendly goods (European Commission 2008c). The European Commission defines GPP as *"a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle*" (European Commission 2008c, 4). Since 2008, the European Commission has developed guidelines for Green Public Procurements (GPP) (European Commission 2008c). These guidelines include verifiable environmental criteria for products and services which Europe's public authorities can use in the public procurements process. The criteria are based on a lifecycle approach. The criteria are divided into two groups, namely core criteria and comprehensive criteria. The core criteria are easy to apply and target key areas of environmental performance. The comprehensive criteria include more environmental aspects or a higher level of environmental performance. The EU guidelines for GPP builds on existing criteria such as the EU Ecolabel, the EU Energy Star Regulation and national environmental criteria. The following electrical and electronic products are covered: electrical and electronic equipment used in the health care sector, imaging equipment, indoor lighting, office IT equipment, street lighting and traffic signals, indoor lighting and water-based heaters.

4.3 INTENDED SYNERGIES IN THE POLICY MIX

Since the introduction of the IPP into European environmental product policies in 2001, the concept has developed. In 2008, the sustainable consumption and production action plan added new dimensions to the existing framework. During this period, the mix of policy instruments has also changed. New instruments were included and the existing instruments were revised in an effort to achieve the objectives set out in the different strategies. The instruments in the current policy mix applied different means to improve the environmental performance of electrical and electronic equipment. The voluntary instruments should create a market for the environmentally best performing products, and the mandatory policy instruments should remove the worst performing products from the market. The proposed synergies are illustrated in figure 4-1.

The EU Ecolabel provides consumers with the necessary information to select the environmentally best performing products on the market and thereby help pull the market towards more environmentally friendly products. The EU guidelines for GPP should help public authorities purchase more environmentally friendly products and, in a similar fashion, help pull the market towards greener products. The EU Energy Labelling and the EU Energy Star regulation provide the consumers with information about the efficiency of the product during its use, regarding mainly energy but also other essential resources. This information enables the consumer to select the most efficient product. The EU Energy Labelling has been effective in transforming the market towards more energy efficiency products (Bundgaard et al. 2013, Molenbroek et al. 2013). These instruments follow the principle in the IPP through their reliance on market forces.

Even though the communication on the IPP emphasises the importance of working with the market, mandatory instruments setting requirements for the minimum environmental performance of electrical and electronic equipment were also adopted. The Ecodesign Directive and the RoHS Directive remove the worst performing products from the market, thereby they push the bottom of the market towards improved environmental performance. The WEEE Directive makes the producer financially responsible for the collection, treatment, recovery and disposal of WEEE, thereby internalising the environmental costs of the end-of-life treatment of WEEE. It does not directly set minimum requirements for product design and therefore it is not included in figure 4-1. The life cycle perspective was included in the Ecodesign Directive, the EU Ecolabels and the EU guidelines for GPP.

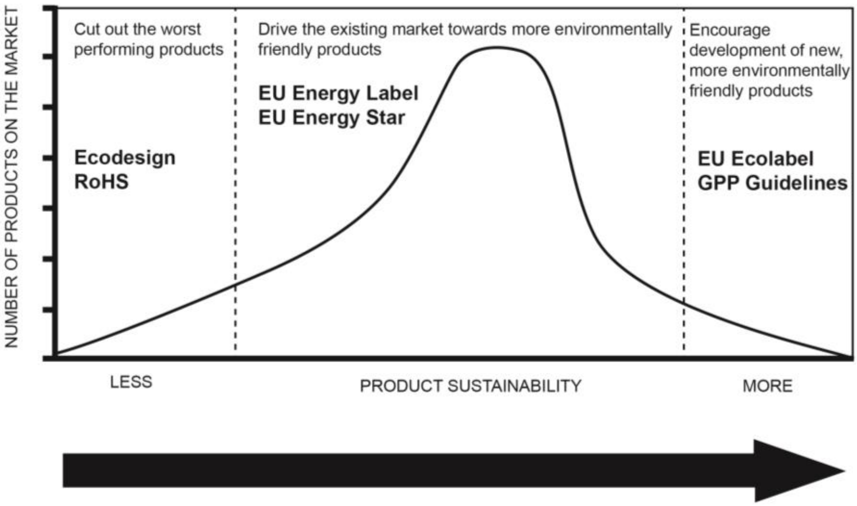


Figure 4-1: Intended synergies between the product policy instruments based on (Huulgaard 2015, Dalhammar 2007).

Resource efficiency and the circular economy have become new focus points for the European Commission and several of the policy instruments from the IPP and SCP have been identified as important instruments in achieving the targets set down in these strategy documents. However, how do the policy instruments target resource efficiency aspects and how can they help support a circular economy? These questions are examined in the following chapters.

CHAPTER 5 FROM ENERGY EFFICIENCY TOWARDS RESOURCE EFFICIENCY WITHIN THE ECODESIGN DIRECTIVE

The Ecodesign Directive is an instrument in the IPP policy mix which targets the design phase, applies a life cycle perspective and can set mandatory minimum requirements for energy-related products. Therefore, the Ecodesign Directive is in a strong position to improve the resource efficiency of electrical and electronic equipment. Nevertheless, the integration of resource efficiency requirements into the adopted implementing measures and voluntary agreements are limited (Bundgaard et al. 2015). A few product groups have succeeded in integrating resource efficiency aspects. The present chapter examines two of the product categories which have succeeded in integrating resource efficiency requirements, namely the implementing measure covering vacuum cleaners and the voluntary agreement covering imaging equipment. The processes and stakeholder interactions are examined to reveal what made it possible to integrate the resource efficiency requirements into the regulation. Based on the analysis, recommendations are made on how to further strengthen the focus on more diverse resource efficiency requirements in the Ecodesign Directive.

Chapter 5 includes a scientific article that was accepted with minor revisions by the Journal of Cleaner Products. The enclosed article is the resubmitted version. The article is a further development and update of a chapter from the report *The Ecodesign Directive 2.0: From Energy Efficiency towards Resource Efficiency* (Bundgaard et al. 2015). The Authors are Anja Marie Bundgaard, Arne Remmen and Kristina Overgaard Zacho. The report was published by the Danish Environmental Protection Agency in 2015. The Danish Environmental Protection Agency also provided financial support for the development of the report

Not included for online publication

CHAPTER 6 RESOURCE EFFICIENCY AND ECOLABELLING

Ecolabelled products represent the environmentally best performing products on the market and could thus potentially be based on the most comprehensive resource efficiency criteria of the instruments in the policy mix. Therefore, this chapter examines the integration of resource efficiency requirements into four voluntary instruments: the EU Ecolabel, the Nordic Swan, EU green public procurement and the EPEAT, covering three energy-related products, namely PCs and servers, imaging equipment and windows, and determines whether these requirements can be transferred to the Ecodesign Directive.

This chapter contains a revised chapter from the report *The Ecodesign Directive 2.0: From Energy Efficiency towards Resource Efficiency* authored by Anja Marie Bundgaard, Arne Remmen and Kristina Overgaard Zacho (Bundgaard et al. 2015). Only minor corrections have been made in this version of the already published chapter. The introduction to the chapter has been revised to fit into the new context and language corrections were made. The report was published by the Danish Environmental Protection Agency in 2015, which financially supported the study. The chapter is a further development of chapter five, called *Resource Efficiency and Ecolabelling,* in the report *Addressing Resource Efficiency through the Ecodesign Directive: A Review of Opportunities and Barriers* (Dalhammar et al. 2014) published by the Nordic Council of Ministers.

RESOURCE EFFICIENCY AND ECOLABELLING

Green demand and better information for consumers were part of the strategies included in the green paper and communication on IPP as strategies to improve the environmental performance of products (European Commission 2001, European Commission 2003a). Consumer demands have also been identified as an important driver of ecodesign (Houe, Grabot 2009). Ecolabels are instruments which can guide the consumer in purchasing the environmentally best performing products. Ecolabelled products should represent the environmentally best performing products on the market, and they apply a lifecycle perspective. Therefore, they can set criteria for resource efficiency aspects. The proposition was therefore that ecolabelling could include comprehensive and ambitious resource efficiency criteria and that the experiences from the ecolabels could be used to set mandatory resource efficiency requirements in the Ecodesign Directive. To examine this, a review was made of the criteria targeting resource efficiency in four voluntary product policies, namely the Nordic Ecolabel, the EU Ecolabel, the EU Guidelines for GPP and the American Electronic Product Environmental Assessment Tool (EPEAT). Three energy-related product groups were selected, namely PCs and servers, imaging equipment and windows. An overview of the criteria documents reviewed in this chapter can be found in table 6-1. The purpose is to examine which types of resource efficiency requirements are already integrated into voluntary policy instruments and whether these requirements could be transferred to the Ecodesign Directive.

	PCs and servers	**Imaging equipment**	**Windows**
Nordic Ecolabel	(Nordic Ecolabelling 2009)	(Nordic Ecolabelling 2007)	(Nordic Ecolabelling 2008))
EU Ecolabel	(European Commission 2011d)	(European Commission 2012f)	✗
EU Guidelines for GPP	(European Commission 2012d)	(European Commission 2014b)	Old version used; new version under development

Table 6-1: Overview of the voluntary instruments and product groups included in the review.

The voluntary criteria for these three products were analysed with the aim of finding resource efficiency criteria. Table 6-2 presents the resource efficiency parameters covered in the voluntary instruments for these three products. The review merely focuses on resource efficiency requirements other than energy and therefore this review is not a full account of the criteria in the four instruments.

Resource efficiency parameter	**PCs and servers**	**Imaging equipment**	**Windows**
Declaration of reusability, recyclability and recoverability (RRR) ratio			
Threshold of reusability, recyclability and recoverability (RRR) ratio	NE, EPEAT	EPEAT	
Easy disassembly (improved options for recycling and repair)	NE, EU E, EPEAT, GPP	NE, EU E, GPP, EPEAT	NE
Declaration of recycled content	EPEAT	EU E	
Threshold of recycled content	EU U, GPP, EPEAT	EU E, NE, GPP, EPEAT	NE, GPP
Hazardous substances (in lights, plastic parts and coatings, surface treatment, batteries)	NE, EU E, GPP, EPEAT	NE, EU E, GPP, EPEAT	NE, GPP
Bill of Materials (BOM)		NE, EPEAT	NE
Identification of plastic components	NE, EPEAT, GPP	NE	NE, GPP
Contamination of plastics	NE, EU E, EPEAT		
Mono-material	NE, EPEAT, GPP	NE	
Sustainable wood			NE, GPP
Efficient use of materials during use phase (paper and ink)		NE, EU E, GPP	
Durability (extended warranty, upgradability and repair, spare parts, modularity)	NE, EU E, GPP, EPEAT	NE, EU E, GPP, EPEAT	NE, GPP
Waste from manufacturing			NE
Take-back Reuse, recycling and recovery systems	NE, EPEAT	NE, EU E	NE, GPP
Packaging	EU E, GPP	EU E, NE	NE
Information requirements related to resource efficiency	NE, EU E	EU E, NE, GPP	NE

Table 6-2: An overview of the resource efficiency criteria found in the four schemes Nordic Ecolabelling (NE), European Ecolabel (EU E), EU guidelines for Green Public Procurement (GPP) and EPEAT for the three product groups PCs and servers, imaging equipment and windows

6.1 RESOURCE EFFICIENCY CRITERIA AND THE TRANSFERABILITY TO THE ECODESIGN DIRECTIVE

The following section includes a description and discussion of the existing resource efficiency criteria in the four voluntary instruments for the three product categories. Furthermore, the section includes a discussion on whether or not these criteria can be transferred to the Ecodesign Directive. Energy requirements are excluded from the review as the focus is on resource efficiency requirements other than energy.

When discussing transferability to the Ecodesign Directive, the ecolabels and the Ecodesign Directive are two distinct instruments with different purposes. The Ecodesign Directive is a mandatory instrument setting minimum requirements for energy-related products entering the European market, whereas the ecolabels are voluntary instruments targeting the environmentally best performing products on the market. Therefore, the level of ambition in the two instruments is not the same. However, bearing this in mind, it is possible to use the experience from the ecolabels in future resource efficiency requirements in the Ecodesign Directive.

When considering the inclusion of resource efficiency requirements in an implementing measure, article 15 in the framework directive for setting ecodesign requirements (European Commission 2009a) is important. Article 15 specifies which criteria the requirements in the implementing measures should meet in order to be considered as ecodesign requirements (see figure 6-1). Furthermore, article 15 specifies that *"specific ecodesign requirements shall be introduced for selected environmental aspects, which have a significant environmental impact"* (European Commission 2009a, p. 21). This was also evident in the two case studies of vacuum cleaners and imaging equipment, where resource efficiency requirements were found significant in the preparatory study. Finally, it should be possible for market

Article 15, paragraph 5

Implementing measures shall meet all the following criteria:

(a) there shall be no significant negative impact on the functionality of the product, from the perspective of the user;

(b) health, safety and the environmental shall not be adversely affected;

(c) there shall be no significant negative impact on consumers in particular as regards the affordability and the life cycle cost of the product;

(d) there shall be no significant negative impact on industry's competitiveness;

(e) in principle, the setting of an ecodesign requirement shall not have the consequences of imposing proprietary technology on manufactures; and

(f) no excessive administrative burden shall be imposed on manufactures.

(European Commission 2009a, article 15)

Figure 6-1: Criteria the requirements (implementing measures) should comply with to be considered.

surveillance authorities to verify whether the products comply with the requirements in the implementing measures. If these criteria are fulfilled, it should be possible to set resource efficiency requirements in the implementing measures or voluntary agreements. However, these need to be evaluated for each product group, as these criteria will be highly dependent on the product group in question. This review will focus on whether the requirements can be verified and whether the environmental aspect selected for a requirement has a significant impact.

6.1.1 THRESHOLD OF REUSABILITY, RECYCLABILITY AND RECOVERABILITY RATIO

Neither of the ecolabels included requirements for the declaration of reusability, recyclability and recoverability (RRR) ratios. The Nordic Ecolabel and the EPEAT set criteria for the threshold of material recovery for computers. They require that 90% of the weight of plastics and metals in the enclosure of the computer can be recovered. Energy recovery is excluded from these ecolabel criteria as it is considered the least resource efficient option. It is worth noting that the criteria are set for the recyclability of the materials in the enclosure and not the recyclability of the entire product. The recyclability of the product is more complex than the recyclability of the materials. The recyclability of the product also depends on how the different components and materials are assembled, whereas the recyclability of the materials only depends on the inherent properties of the materials. EPEAT gold also sets a requirement threshold of 90% reusability and/or recyclability for imaging equipment. Here, reusability and recyclability are combined.

Both declaration and threshold requirements for the RRR ratio could be transferred to the implementing measures and voluntary agreements of the Ecodesign Directive if a common methodology could be developed on how to calculate the RRR ratio for products and materials. Thus, it would also be possible to verify these requirements based on the technical information provided by the producers. Declaration requirements to the RRR could be implemented by first providing knowledge on the issue, which could then later be used to set meaningful threshold requirements. Furthermore, future requirements to the RRR ratio should be made according to the waste hierarchy, hence prioritising reuse before recycling and recycling before recovery. However, setting requirements for the RRR ratio of the material or the product will not ensure that the materials or products are in fact reused, recycled or recovered. It merely says something about the potential for the materials or products to be reused, recycled or recovered. The actual reuse, recycling or recovering will depend on the infrastructure for collection and treatment and the technologies available. Therefore, it might be difficult to assess the actual improvement potential.

6.1.2 DISASSEMBLY

The Nordic Ecolabel, EU Ecolabel and EPEAT set criteria for design for easy disassembly for both computers and imaging equipment, whereas the EU guidelines for GPP only set criteria for design for easy disassembly for imaging equipment. The EPEAT criteria are very generic whereas the Nordic Ecolabel, EU Ecolabel and EU guidelines for GPP set more detailed criteria emphasising that it should be easy for qualified or professionally trained personnel to dismantle the products with generally available tools. The criteria regarding disassembly target increasing the recyclability of the materials, but also improving options for reuse and the prolonged durability of the products. The EU Ecolabel encourages the use of screws and snap-fixes, especially for parts containing hazardous substances. The EU Ecolabel also emphasizes that valuable components, like circuit boards and other components containing precious metals in computers, should be easy to remove manually. Furthermore, the EPEAT restricts the use of glued and moulded metals. These are examples of requirements aimed at improving the recyclability of the products by both enabling easy disassembly and reducing the contamination of the materials in the product. Disassembly is not really addressed for windows. The Nordic Ecolabel criteria for windows and exterior doors set one criterion targeting disassembly, namely that it must be possible to separate glazing from metals and plastics for recycling.

Requirements targeting easy or manual disassembly could be possible categories to transfer to the Ecodesign Directive. The requirements for easy or manual disassembly could be verified by performing disassembly tests, or the producers could provide a video showing the dismantling of the product, which is how the requirements are verified in some of the ecolabels. Easy or manual disassembly can help improve the reparability and upgradability of the product, thus improving its durability. According to Masanet et al. (2002), manual disassembly in the waste treatment process of electrical and electronic equipment is increasingly being replaced by automatic or destructive disassembly in many developed countries. Therefore, it is questionable whether requirements for easy or manual disassembly will improve the recyclability and recoverability of electrical and electronic equipment if they are fed into an automatic or destructive disassembly system. However, manual disassembly is still performed when economically feasible or when regulation requires it, e.g. in the WEEE Directive. Therefore, it might still be a relevant category, especially in relation to valuable components or components that contain hazardous substances. Furthermore, requirements targeting easy or manual disassembly might also improve automatic or destructive disassembly. However, this is an aspect that should be further examined. The waste treatment industry is also continuously developing new technologies. Therefore, it is not possible, based on the findings of this study, to assess whether or not requirements for manual disassembly will improve the recyclability and recoverability of electrical and electronic equipment in the future. However, requirements targeting automatic or destructive disassembly could be considered in addition to the requirements targeting manual disassembly.

6.1.3 DECLARATION AND THRESHOLD OF RECYCLED CONTENT

The EU Ecolabel and the EPEAT set criteria for the use of recycled plastics for both computers and imaging equipment. The EU Ecolabel and EU guidelines for GPP set a threshold requirement of not less than 10% recycled plastics for both product categories. The most ambitious example of requirements regarding recycled content is found in the EPEAT for imaging equipment, where a minimum of 25% post-consumer recycled plastics is required. The Nordic Ecolabel sets a cautious criterion for imaging equipment, where one component with a weight above 25 g must contain reused or recycled plastic. However, there is no minimum threshold for the content. In the next revision of the Nordic Ecolabel for computers, a requirement has been suggested that computers should be made of recycled plastics. In addition to requirements for the content of recycled plastics, the EPEAT also requires *a minimum content of bio-based plastics* in imaging equipment. The Nordic Ecolabel for windows sets threshold criteria for the content of recycled material. It requires that 30% of non-renewable materials should be recycled materials for windows. Furthermore, the EU guidelines for GPP for windows states that extra points can be awarded to products in proportion with their recycled content.

Criteria for the declaration and thresholds of recycled plastics, recycled materials and bio-based plastics were found in the voluntary instruments. Setting criteria for the threshold of recycled materials can help create a market for these materials. However, before transferring these requirements to the Ecodesign Directive, it is important to assess whether the manufacturers of recycled materials can handle the increase in demand that such requirements would create. Again, a possibility could be to begin by setting declaration requirements and then tightening them continuously by setting threshold requirements. A challenge when setting criteria for recycled materials is that there are currently no reliable technologies for an analytical assessment of the recycled content in the products (Ardente et al. 2011a). It implies that verification can be challenging and dependent on supplier declarations. The environmental benefits of using recycled materials will depend on the type of material.

6.1.4 HAZARDOUS SUBSTANCES

The EU guidelines for GPP, the Ecolabels and the EPEAT for computers and imaging equipment include an elaborated list of criteria for hazardous substances. The instruments mix information requirements, threshold requirements and the exclusion of certain substances. The requirements are both general requirements for the entire product and requirements for specific materials and components such as plastic, batteries and backlighting. Many of the criteria in the Nordic Ecolabel, the

EU Ecolabel, and GGP guidelines are listed according to the REACH regulation's risk phrases, but for most criteria a list of exemptions exists. In the EU Ecolabel criteria for imaging equipment, one of these exemptions takes into consideration the use of recycled materials by setting less strict requirements for the content of hazardous substances in recycled materials. Thus, the stricter requirements for hazardous substances do not eliminate the possibility of including recycled materials in the product, which is important to help develop a market for recycled materials. Requirements for the content of mercury or the exclusion of intentionally added mercury in backlights and displays are included in the EPEAT, the Nordic Ecolabel and the EU Ecolabel for computers and the EU guidelines for GPP for imaging equipment. The RoHS Directive already restricts mercury to a maximum value of 0.1%; however, exemptions are made concerning various types of lamps. The voluntary instruments remove the exemptions and thus strengthen the requirements in the RoHS Directive.

Criteria for hazardous substances are also included in the Nordic Ecolabelling and the EU guidelines for GPP for windows. A list of general criteria on hazardous substances is included that prohibits the use of certain chemicals in windows, the release or leaching of certain chemicals from the product under normal use conditions, and the use of certain chemicals in packaging. Further, chemical products (paint, adhesive, sealants, putty, etc.) in the finished windows must satisfy certain requirements. The Nordic Ecolabel sets criteria for chemical substances in plastics. However, the Nordic Ecolabel differentiates between virgin and recycled plastics and thus again does not hinder the use of recycled plastics in labelled products. Furthermore, the use of mercury asbestos is restricted in plastics by the Nordic Ecolabel, and lead is restricted in plastics by the EU guidelines for GPP. The EU guidelines for GPP also set restrictions on the use of chemicals in, for example, paint, adhesive, sealants, and putty. Furthermore, pressure impregnation is not permitted and the use of nano-materials should be documented.

The criteria for hazardous substances in the Nordic Ecolabel, the EU Ecolabel, and the EU GGP guidelines are first and foremost in place to avoid the exposure of humans and the environment to hazardous substances. However, there is also a trade-off at the end-of-life phase and could theoretically provide better opportunities to recycle the materials by setting stricter requirements on hazardous substances.

An important issue to consider before including requirements for hazardous substances is whether chemical requirements should be included in the Ecodesign Directive, or whether chemicals should solely be regulated through the RoHS Directive and the REACH regulation. Hence, instead of including requirements for chemicals in the Ecodesign Directive, an expansion of the RoHS Directive could be proposed. A study has already been conducted on the subject matter (Gross et al. 2008), and inspiration for a future expansion of the RoHS Directive can be found therein. The environmental improvement potential and the ability to verify the requirement will depend on the specific substance.

6.1.5 BILL OF MATERIALS

Bill of Materials (BOM) is defined in Ardente et al. (2011c) as a "*document that synthesizes a detail of the product's composition*" (Ardente et al. 2011c, p. 13). In the voluntary instruments, no full BOM requirements exist for computers, imaging equipment or windows. However, an interesting criterion in the Nordic Ecolabel for windows is the product description criterion stating that the materials and chemical products which comprise the window should be specified, including a percentage weight. There are no BOM requirements in the EPEAT, but there is the requirement for an inventory of intentionally added chemicals related to the category hazardous substances.

The BOM is identified in scientific literature (Ardente et al. 2011c) as an important source of information: to conduct lifecycle assessments, to measure the product's recyclability, recoverability and the recycled content and to identify priority resources and hazardous substances in the product which should be taken into consideration during the end-of-life phase. Hence, BOM can be seen as a premise for many other requirements to improve a product's resource efficiency. Ardente et al. (2011c) make a more detailed identification of elements considered critical and important to include in a BOM, and include material typology, employed masses, connections among different materials and the placement of the components in the assembly/disassembly process, and the content of hazardous or other substances that negatively affect the RRR (Ardente et al. 2011c, p. 22). Furthermore, it is proposed that BOM include a disassembly scheme and a disassembly report. Ardente et al. (2011c) also suggest that priority resources should be identified and listed in the BOM to ensure their reuse or recycling.

The information proposed by Ardente et al. (2011c) to be included in a BOM is much broader than the information requirement currently found in the Nordic Ecolabel for windows. However, it is a first step to setting criteria for BOM for products, and it could interesting to further examine how these criteria have been implemented and verified for ecolabelled windows. Within the Nordic Ecolabel of computers, it has been suggested that requirements for the use of rare metals should be included (Nordic Ecolabelling 2009). However, due to the complexity of the supply chain of electrical and electronic equipment, this is an issue that is complex to approach (epeat 2013) especially for small producers, as they might not have the ability to force these requirements onto their larger suppliers. An issue that might prove difficult in relation to BOM is the protection of intellectual property rights, whereby the industry might oppose such requirements. Hence, it would require the setup of a system that could ensure companies' intellectual property rights.

6.1.6 IDENTIFICATION OF PLASTIC COMPONENTS

The Nordic Ecolabel includes criteria for the identification of plastic components for all three product groups. For windows, computers and imaging equipment, the Nordic Ecolabel (and the EU guidelines for GPP for windows and computers) requires that plastic parts above 50 g / 25 g must be visibly labelled for recycling according to ISO 11469 (generic identification and marking of plastics products). This standard provides a system for the uniform marking of products and parts of plastic and is intended to help identify different plastic types and parts to ensure correct handling during waste recovery or disposal. It implies that plastic parts are labelled with an identification marking which allows the visual identification of polymer types, implying that the making can only be read manually. Visual marking of plastic parts according to certain ISO standards might be quite easy to visually verify by market surveillance authorities when dismantling the product. However, the environmental improvement potential is questionable. The study by Masanet et al. (2002) assessed how the ISO 11469 is actually applied during waste handling and treatment. The study showed that when plastic parts were manually sorted, the use of ISO labels was in fact an effective strategy for improving the recyclability of plastic parts, but the study also indicated that up to 20% of the ISO labels were incorrect. For automatic sorting systems, the ISO labels had no effect as these systems sort according to the plastics' mechanical, optical and electrostatic properties. Hence, the effectiveness and thereby the environmental improvement potential of visual marking of plastic according to ISO 11469 depends on the sorting systems. Therefore, before setting criteria for the visual marking of plastics in the Ecodesign Directive or prolonging the criteria for the marking of plastics in the voluntary instruments, it is recommended that it be investigated to what extent the waste is manually sorted for the product group in question, and how the future waste treatment of the product might look like. Furthermore, alternative marking methods should be examined for application automatic sorting systems, for example.

6.1.7 CONTAMINATION OF MATERIALS

The Nordic Ecolabel, EU Ecolabel and EPEAT set requirements for computers regarding the contamination of materials. The Nordic Ecolabel requires that large plastic parts (above 25 g) must not be painted or metallized and that chlorine based plastics must not be contained in the enclosure and chassis. The EU Ecolabel requires that plastic parts shall not have a chlorine content greater than 50% by weight. EPEAT requires that larger plastic parts should be free from PVC and that paints or coatings not compatible with recycling should be eliminated. It might be possible to transfer the requirements regarding the contamination of materials to the implementing measures and the voluntary agreements under the Ecodesign Directive. Requirements regarding the contamination of materials are relevant for the recyclability, as the potential for recycling is reduced if incompatible materials are combined after disassembly. The limiting of paints in particular was documented in the study by Masanet et al. (2002) to be an effective strategy to improve the recyclability of plastic. Hence, there seems to be an environmental improvement potential. Furthermore, depending on the specific requirement, it might in many cases also be something that could be verified visually. However, some of the requirements also target hazardous substances, such as PVC, and again it is questionable whether chemicals should merely be regulated in the RoHS Directive and the REACH regulation or whether they should also be included in the implementing measures and voluntary agreements under the Ecodesign Directive.

6.1.8 MONO-MATERIALS

In terms of mono-materials, the Nordic Ecolabel for both computers and imaging equipment sets requirements for the use of compatible plastic types and states that the enclosure should use a maximum of two types of polymers that are separable (also a EU guidelines for GPP award criterion for computers). The EPEAT for computers similarly requires a reduced number of plastics (epeat 2014). Using compatible or a reduced number of plastics can improve the recyclability of, for example, thermoplastics, as a mixture of different polymers or a contamination of the plastic fractions can significantly decrease the plastics' properties and thereby the use of the recycled materials (Beigbeder et al. 2013). Hence, including requirements in the Ecodesign Directive regarding compatibility or a reduced numbers of polymers or plastics could potentially improve the recycling of plastics. However, whether this potential will be utilized strongly depends on the recycling system that the products enter. Therefore, setting these types of requirements should be supplemented with a dialogue with the stakeholders from the recycling industry to ensure the effectiveness of these types of requirements.

6.1.9 SUSTAINABLE SOURCING OF WOOD

As the name indicates, the sustainable sourcing of wood covers more than resource efficiency. However, there is an interface between sustainable sourcing of wood and resource efficiency. An example is where the extended use of reused wood would contribute to reduced deforestation. Criteria for the sustainable sourcing of wood only apply to windows. The main focus of the criteria is targeting sustainable wood and wood coming from legal sources. The Nordic Ecolabel for windows sets threshold requirements for the amount of wood deriving from certified forests. The EU guidelines for GPP for windows sets a threshold requirement of 70% for the use of wood from certified forests, which ensures that the wood derives from forests managed in a sustainable way. This criterion targeting sustainable materials, and more specifically sustainable wood, is quite product specific and linked to the fact that windows can consist partly of wood.

Setting requirements for sustainable sources of wood in the Ecodesign Directive will only be relevant for a small number of energy-related product categories. However, windows, for which a preparatory study is currently being made, could be a relevant product category. A risk of setting this type of mandatory requirement for the sustainable sourcing of wood could be that the supply cannot follow the demand and that the producers might be dependent on a small number of suppliers. This should be examined before setting the requirements. More generally, the sustainable sourcing of materials could be relevant for other product groups, such as in setting requirements regarding conflict minerals in the Ecodesign Directive.

6.1.10 EFFICIENT USE OF MATERIALS DURING THE USE PHASE

The efficient use of resources other than energy during the use phase is included for imaging equipment and targets the consumables: paper and ink. The Ecolabels and the EU guidelines for GPP address this differently, but all schemes set requirements for the capability of duplex printing and the printing of two or more sides on one sheet of paper. Furthermore, the EPEAT, EU Ecolabel and the EU guidelines for GPP set requirements for duplex printing as default.

Energy consumption in the use phase is an aspect which has been widely covered by existing implementing measures and voluntary agreements under the Ecodesign Directive, but it is also relevant when targeting other resources. As mentioned, an example is the Nordic and EU Ecolabel criteria for imaging equipment, where a more efficient use of paper and ink cartridges is promoted. These types of requirements are already included in the voluntary agreement for imaging equipment under the Ecodesign Directive (duplex availability, default duplex setting, and information requirements targeting resource efficiency of e.g. paper) (EuroVAprint 2012). However, the category is also highly relevant for other product groups. An example of requirements within this category could be to set a requirement for an automatic detergent dosing system for washing machines to avoid the over-dosage and overconsumption of detergents.

6.1.11 DURABILITY

Various criteria were found in the voluntary instruments targeting durability. The criteria can be divided into the following categories: direct criteria for the durability of the product, extended warranty, upgradability and repair, spare parts and modularity. The categories are closely interlinked and therefore are all dealt with within the overall category of durability. All criteria strive to extend the lifetime of the product, thereby preventing electronic waste. Durability is also related to the previous category of disassembly, where criteria targeting the easy disassembly for repair and upgradability were included.

Criteria for durability are set for imaging equipment in both the Nordic Ecolabel and the EU Ecolabel, albeit differently. The durability requirements in the EU Ecolabel are aimed at the cartridge and its reusability, whereas the Nordic Ecolabel requirements are aimed at quality assurance and the maintenance of the entire product. The durability criteria for windows strive to hinder early wear of the products.

An extended warranty was included in the EPEAT criteria for computers for three years or as a service arrangement. The EU Ecolabel for imaging equipment included an extended warranty for five years and finally the Nordic Ecolabel for windows included a 10-year warranty for parts of the windows (thermo panels and wood rot). The length of the warranty is, of course, product specific, as evident in the criteria examined. Further, it is also related to the availability of spare parts.

Criteria for upgradability and repair were only found for computers and imaging equipment. However, this type of criteria could also be relevant for windows, such as upgradability to a higher energy class. Upgradability as a means to increase durability was found in the Nordic Ecolabel, EPEAT and the EU guidelines for GPP and covers general criteria on upgradability with common tools and, more specifically, criteria such as the easy expansion of the computer's memory and replacement of computer batteries.

Both the EU Ecolabel, the Nordic Ecolabel and the EPEAT require that spare parts and components for repair are available for 5, 5 and 3 years, respectively. Determining how long spare parts should be available can be a challenge. On one hand, components should be available to enable repair, but on the other hand the risk is that a too large inventory of components will be out-dated and never utilized. This is counterproductive from both an economic and a resource efficiency point of view and needs to be considered when setting future requirements for spare part availability.

Modular design and easy disassembly enable upgrading and repair and are thus prerequisites for lifetime extension. Modular design is only required in the ecolabels (EU Ecolabel, Nordic Ecolabel and EPEAT) for computers and is linked to upgradability and repair requirements. For computers, there are specific requirements for upgradability with common tools and/or consumer instructions in all ecolabels and this may reflect the rapid technological development of computers, which spurs high replacement rates. Upgradability can potentially reduce the frequency of replacement. In addition, the EU Ecolabel and EPEAT set requirements for imaging equipment regarding reparability and upgradability.

The voluntary instruments include general criteria on durability, warranty, upgradability and repair, spare parts and modularity to ensure upgradability and repair. All these requirements could possibility be verified by market surveillance authorities. Improved durability is part of waste prevention and thereby the improvement of resource efficiency and should be included as possible resource efficiency requirements in the Ecodesign Directive. Durability is also included as a topic in the work carried out by Joint Research Centre (Ardente et al. 2012).

Furthermore, an interesting study was conducted by RREUSE (RREUSE unknown), where they looked into the reparability of domestic washing machines, dishwashers and fridges. The study identifies the main obstacles to the repair of these product categories and there is an overlap with the criteria found in the ecolabels. The study identifies the main obstacles as: (1) rapid changes of product design, (2) difficulties accessing spare parts, (3) increasing lack of access to repair and service manuals, software and hardware for reuse and repair centres and (4) increasing difficulty in disassembling products for repair (RREUSE unknown, p. 3-4). Hence, there seems to be an improvement potential for at least these product categories. However, it is important to ensure that prolonging the lifetime of the product is the environmentally best solution from a lifecycle perspective, e.g. that possible environmental benefits are not evened out by increased energy consumption of the older product compared to a new, more energy efficient product. Additionally, increasing the durability of products might decrease sales of new products in a saturated market. Hence, including these types of requirements in the Ecodesign Directive may face some unwillingness from the side of some manufacturers in the industry, while producers with high quality products could have a competitive advantage due to such requirements.

6.1.12 WASTE FROM MANUFACTURING

The Nordic Ecolabel for windows and exterior doors sets criteria for improving resource efficiency during manufacturing. The Nordic Ecolabel for windows and exterior doors sets some overall criteria for the separability of the waste fractions from the production and the handling of hazardous waste. Furthermore, it sets criteria for the handling of the individual materials at end-of-life. The individual criteria apply to the entire production process in the factory where the ecolabelled products are manufactured and they also apply to subcontractors' production of insulation units, casements and frames (Nordic Ecolabelling 2008). By including requirements for manufacturing, the labels expand the scope from a product focus towards a production focus. The Ecodesign Directive, as the name states, mainly sets requirements for the design of the product, however targets the environmental performance of the entire product lifecycle. Therefore, design requirements for the product that might improve the manufacturing process would be relevant. However, as many electronic products are produced outside Europe, it might be difficult to enforce these criteria.

6.1.13 TAKE-BACK SCHEMES

The Nordic Ecolabel for computers and windows includes a criterion that national legislation, regulation or agreements within the sector regarding recycling systems should be followed. The Nordic Ecolabel for windows further sets a criterion of having a system in place that ensures the collection for recycling of plastic windows. It is not known why only plastic windows are targeted in this criterion. The Nordic and EU Ecolabels for imaging equipment set criteria for a take-back system or return system for toner, ink modules and containers. Furthermore, the Nordic Ecolabel for imaging equipment requires that a system is set up for consumables to ensure their reuse or recovery. The EPEAT requires the provision of a product take-back service for computers. Getting the used products into the reuse or recycling system is key to the reuse, recycling and recovery of the products, components and materials. Therefore, take-back schemes are important means of reducing the environmental impacts from electrical and electronic equipment. However, take-back systems and reuse, recycling and recovering are covered by the WEEE Directive, and setting criteria in the Ecodesign Directive for take-back systems and reuse, recycle and recovery systems could create an overlap with the WEEE Directive. Hence, it should be discussed whether such an overlap is advisable. However, for consumables or products that are not covered by the WEEE Directive or other legislation, it could be a good possibility.

6.1.14 PACKAGING

The EU Ecolabel sets the criteria that the packaging of computers and imaging equipment should be made of recycled or biodegradable material. More specifically, cardboard boxes must consist of 80% recycled material, and 75% of the materials in plastic bags must be recycled, biodegradable or compostable.

Transferring these types of requirements to the Ecodesign Directive might again create an overlap with the European Directive on packaging and packaging waste (European Commission 2011g). Hence it can be questioned whether the Ecodesign Directive is the right place to incorporate requirements for packaging as the directive on packaging and packaging waste already aims to limit the production of packaging waste by promoting recycling, reuse and recovery (European Commission 2011g).

6.1.15 INFORMATION REQUIREMENTS RELATED TO RESOURCE EFFICIENCY

The Nordic Ecolabel includes criteria for all three product groups regarding consumer information that is intended to help improve resource efficiency. The EU Ecolabel has this type of criteria for both imaging equipment and computers. Criteria regarding consumer information include recommended maintenance, cleaning and refurbishment that could help prolong the lifetime of the product. Furthermore, the Nordic Ecolabel and the EU Ecolabel include criteria on what should be done with the product at its end-of-life, and the EU Ecolabels also include an indication of the expected life time of the product.

In the effort to improve resource efficiency, the consumers are important actors. The consumer is crucial in improving resource efficiency during the use phase, such as printing double-sided, maintaining the windows to extend their life span, and upgrading their existing products instead of buying new ones. They are also important actors in a product's end-of-life as they ensure the correct disposal of the products, which is a precondition for proper waste collection, reuse and recycling. Therefore, requirements for consumer information on resource efficiency are important requirements to include in the Ecodesign Directive. Furthermore, consumer information is also an issue emphasised in the framework Ecodesign Directive. Information requirements are easy for market surveillance authorizes to verify as they can be verified by looking through the documentation provided by the producers. Information requirements targeting resource efficiency are already widely applied in the currently adopted implementing measures and voluntary agreements, as documented in section 5.4.2.

6.2 SUB CONCLUSION

When setting requirements in the Ecodesign Directive, many aspects need to be considered and the requirements vary depending on the product group. The possible requirements found in the ecolabelling schemes could work as an inspiration for future requirements in the implementing measures and voluntary agreements. However, this needs to be assessed for each product category and backed up with further studies. Table 6-3 provides an overview of the requirements proposed and inputs from the discussions in this chapter. Additional and relevant resource efficiency requirements most likely exist. These are merely the requirements identified based on a review of the Ecolabels, EPEAT and the EU guidelines for GPP for the selected product categories.

Possible requirements	**Environmental improvement potential**	**Verifiable**	**Additional Comment**
Declaration and threshold of reusability, recyclability and recoverability ratio	Difficult to document as it will only indicate the potential and not the actual RRR ratio	If a common methodology is developed to calculate RRR ratio	First declaration requirements could set followed later by threshold requirements
Disassembly • Easy disassembly for a qualified professional with tools usually available. • Screws and snap-fixes • Restricts the use of glued and moulded parts • Easy to remove valuable components, e.g. circuit boards	Improve the reparability and upgradability of the product. Might improve recycling and recovery of the materials, however it will depend on the waste treatment system	Could be verified by disassembly test or a video of the dismantling of the product	Disassembly requirements targeting automatic or destructive treatment system could be examined Easy disassembly or removal of contaminated components could be considered
Declaration and threshold of recycled content	Depending on the material, the impact from reused or recycled materials can be significantly lower than virgin materials. Helps create a market for reuse or recycled materials	Not possible or very difficult to verify	
Hazardous substances	Will depend on the substance	Will depend on the substance	Overlap with the RoHS Directive and the REACH regulation
BOM • Full/ detailed • Priority metals / rare earth elements	Of importance for setting other resource efficiency requirements	Will depend on the requirements	The property rights of companies might provide a challenge
	Could potentially		

Possible requirements	**Environmental improvement potential**	**Verifiable**	**Additional Comment**
• Hazardous substances	increase the recyclability and recoverability of priority metals and rare earths		
	Could help the recyclers to remove components containing hazardous substances		Overlap with the RoHS Directive, REACH regulation but focus more on in formation
Identification of plastic components	Will depend on the waste treatment system (manual/ automatic)	Possible – visual verification	Examine alternative marking methods
Contamination of materials • Avoid painted, metalized and coating	Indications that it could have a positive effect on the recycling and recovering of materials	Depending on the requirement, it could be verified visually	Linked with the RoHS Directive and REACH regulation.
Mono-materials • Reduced number or compatible polymers/plastics	Could improve the recycled plastics properties and thereby reuse / recycling potential		The improvement potential will strongly depend on the waste treatment system.
Sustainable wood sourcing	Could potential reduce deforestation	Verified in the ecolabels through different certification schemes	Other materials could be considered such as conflict minerals. Need to ensure that supply can follow the demand
Efficient use of materials during the use phase	Verifiability will depend on the type of requirement proposed	Energy consumption in the use phase is already included in all existing implementing measures and voluntary	Efficient use of materials during the use phase

Possible requirements	**Environmental improvement potential**	**Verifiable**	**Additional Comment**
		agreements	
Durability requirements • Extended warranty • Upgradability • Repair • Spare parts • Modularity	Extending product lifetime and thereby waste prevention	Can be verified	Increased durability of the product might reduce sales of new products in a saturated market.
Waste from manufacturing	Potentially large environmental improvement potential depending on the product	Might be difficult to enforce if produced outside Europe	
Packaging • Recycled materials • Bio-materials • Bio-degradable materials	Could promote recycled materials, bio-materials and bio-degradable materials		Overlap with the EU Packaging Directive
Information requirements	The end-consumers are important actors to ensure the durability, reuse, recycling and recovery of the products, components and materials	Easy to verify by looking though the information materials provided by the manufacturer	Are already largely implemented in existing IM and VAs

Table 6-3: Overview of the resource efficiency criteria in the four policy instruments and main discussion points.

CHAPTER 7 DISCUSSION: REGULATING RESOURCE EFFICIENCY IN EUROPEAN PRODUCT POLICIES

The previous two chapters have focused on the integration of resource efficiency requirements into the Ecodesign Directive and four voluntary instruments. The following section looks more broadly at the European environmental product policy instruments and how they target resource efficiency aspects. The purpose is to understand which role the Ecodesign Directive should play in improving the resource efficiency of electrical and electronic equipment.

7.1 RESOURCE EFFICIENCY ASPECTS IN THE POLICY INSTRUMENTS

The different policy instruments target different aspects of resource efficiency in their scope and the actual implementation and uptake of the instruments have had implications for how effective the instruments have been in targeting resource efficiency aspects. The following section will provide an overview of how the instruments target resource efficiency in their scope and in their actual implementation (table 7-1). Resource efficiency has been divided according to the five strategies to close the material loops described in section 2.1.3, namely (1) reduce, (2) maintenance and repair, (3) reuse, (4) reconditioning and remanufacturing and (5) recycling. Some resource efficiency requirements or criteria in the instruments might improve more than one of the five resource efficiency aspects. A green colour indicates that the instruments target resource efficiency in their scope and that specific requirements or criteria are set. The yellow colour indicates that resource efficiency aspects are included in the scope of the instruments but that no actual requirements, criteria or targets are set. The red colour indicates that neither are the specific resource efficiency aspects included in the scope of the instruments nor are actual requirements, criteria or targets set. The review of the criteria covering EU Ecolabels and the EU guidelines on GPP is based on the three product groups, namely imaging equipment, PCs and servers, and windows and therefore does not cover all criteria sets adopted. The review of the requirements in the implementing measures and voluntary agreements is based on a review in chapter 5 and on Bundgaard et al. (2015) and is from 2013.

	Ecodesign	EU Energy Star	EU Energy Label	RoHS	WEEE
Reduce	Included in the scope and specific requirements targeting resource efficiency.	Included in the scope and specific requirements for efficiency during use.	Included in the scope and specific requirements for efficiency during use.		Prevention included in the scope but no specific requirements.
Maintenance and repair	Included in scope and sets durability requirements.				
Reuse	Included in the scope and requirements targeting reuse.				Should contribute to reuse of WEEE, but no separate targets for reuse.
Reconditioning and remanufacturing	Included in the scope and requirements improving reconditioning and remanufacturing.				
Recyclability and recovery	Included in the scope and sets specific requirements to improve recyclability.			Included in scope and restricts the use of certain hazardous substances.	Included in the scope and sets specific targets for recycling and recovery of WEEE.

	GPP	EU Ecolabel
Reduce	Included in the scope and specific requirements targeting resource efficiency.	Included in the scope and specific requirements targeting resource efficiency.
Maintenance and repair	Included in scope and sets criteria targeting maintenance and repair.	Included in scope and sets criteria targeting maintenance and repair.
Reuse	Included in the scope and criteria targeting reuse.	Included in the scope and criteria targeting reuse.
Reconditioning and remanufacturing	Included in the scope and specific criteria improving reconditioning and remanufacturing.	Included in the scope and specific criteria improving reconditioning and remanufacturing.
Recyclability and recovery	Included in the scope and sets specific criteria to improve recyclability.	Included in the scope and sets specific criteria to improve recyclability.

Table 7-1: Resource efficiency aspects targeted by the product policy instruments. The green colour indicates that resource efficiency aspects are within the scope of the regulation and that specific requirements, criteria or targets are set. Specific requirements do not include information requirements. The yellow colour indicates that the resource efficiency aspects are within the scope of the directive or regulation but that the actual requirements, criteria or targets are not set. Red indicates that it is not within the scope of the directive and that requirements, criteria or targets are not set

In its scope, the WEEE Directive covers reduction through the prevention of waste, however actual targets have so far not been set for the reduction of WEEE . According to the scope of the WEEE Directive, it should also contribute to the reuse of WEEE, and in the latest revision of the directive prepare for reuse has been added to the recycling target. Now the targets can be reached through either recycling or preparing to reuse. However, the two categories are not separated and therefore no specific targets are set for reuse in the WEEE Directive. This makes it difficult to evaluate whether the directive will improve reuse. The WEEE Directive has succeeded in setting up a collection system and sets specific recycling and recovery targets. The WEEE Directive also introduced producer responsibility. The idea was that producer responsibility should create a financial incentive for the producers to design products which could contribute to the prevention, reuse, recycling or recovery of waste electrical and electronic equipment. In a number of Member States, a collective producer responsibility scheme has been implemented (van Rossem et al. 2009). Therefore, the incentives for the producers to design products which are easy to reuse, recycle and recover has not yet been created in many Member States (van Rossem et al. 2009).

The RoHS Directive addresses the recyclability of products by restricting the use of certain hazardous substances in electrical and electronic equipment. The use of hazardous substances can also influence reuse and repair if health issues are associated with these, but the main improvement is the recyclability of WEEE. The RoHS Directive has been able to change the design of electrical and electronic equipment because it specifically restricts the use of hazardous substance. The recast of the RoHS Directive has made it easier to include additional substances through delegated acts.

The EU Energy label focuses on the use phase and provides the consumers with information about the environmental characteristics of the products during the use phase. It mainly targets energy efficiency during use, but other essential resources during use are also within its scope. An example is the indication of water consumption for washing machines in the EU Energy Labelling. The EU Energy Labelling provides the consumer with information which makes it possible for the consumer to purchase the most efficient products. According to an evaluation of EU Energy Labelling and certain aspects of the Ecodesign Directive, the EU Energy Labelling has been an effective means of overcoming information barriers and influencing consumers and producers (Molenbroek et al. 2013). Thereby, the EU Energy Labelling has accelerated the market transformation towards more energy efficient products (Molenbroek et al. 2013, Bundgaard et al. 2013). Similarly, the EU Energy Star regulation focuses on the efficient use of resources, mainly energy, during the use phase. Therefore, it merely targets the reduction of energy, but it also concerns consumables.

The Ecodesign Directive is the sole mandatory policy instrument that applies a lifecycle perspective, and thus can set minimum requirements for a wide variety of resource efficiency aspects. Annex I in the Ecodesign Directive also specifics a wide variety of resource efficiency requirements which should be considered when developing the requirements. Hence, the Ecodesign Directive can target (1) reduce, (2) maintenance and repair, (3) reuse, (4) reconditioning and remanufacturing and (5) recycling. However, as documented in the article in chapter 5 and further in Bundgaard et al. (2015), the number of implementing measures and voluntary agreements setting specific requirements to resources other than energy are limited. Of the adopted implementing measures and acknowledged voluntary agreements in 2013, only five implementing measures and one voluntary agreement included specific requirements targeting resources other than energy. The specific requirements targeting resource efficiency aspects included the durability requirements for the hoses and motors of vacuum cleaners, the performance and durability requirements for lamps (fluorescent lamps, directional lamps and non-directional lamps) and water consumption in the use phase for household washing machines.

The voluntary agreement covering imaging equipment included the most elaborate resource efficiency requirements, including requirements for the efficient use of paper, that cartridges should not be designed in a way that prevents their reuse and recycling, the separability of plastic parts to improve recycling, easy disassembly, the marking of plastic, a restriction on the use of different types of plastic to improve recyclability, and the use of post-consumed plastic. As table 7-1 shows, the specific requirements integrated in the Ecodesign Directive covered all the resource efficiency aspects. However, only few product groups included specific resource efficiency requirements, and only the voluntary agreement covering imaging equipment included many diverse resource efficiency aspects. Information requirements targeting resource efficiency other than energy were more widely distributed in the adopted implementing measures and acknowledged voluntary agreements. In total, 16 of the 23 adopted implementing measures and voluntary agreements included information requirements targeting resource efficiency.

The EU Ecolabel applies a lifecycle perspective and should focus on the most significant environmental impact. Hence, from its outset the EU Ecolabels was able to target all resource efficiency aspects. The directive also specifies specific aspects which the criteria should focus on and includes criteria for issues such as energy and resource consumption, the generation of waste, the substitution of hazardous substances, durability and reusability. A full review of all criteria set in the EU Ecolabel were not performed, therefore the following evaluation is based on chapter 6, which examines three product groups, namely PCs and servers, imaging equipment and windows. The EU Ecolabel includes criteria covering easy disassembly, declaration and threshold of recycled content, hazardous substances, the contamination of plastics, the efficient use of materials during use (consumables such as paper and ink), durability, take-back systems for reuse, recycling and recovery, and packaging. Since the review was made in the beginning of 2013, several of the criteria have been revised. One of these is the EU Ecolabels covering computers. In the recent revision the criteria targeting resource efficiency has been further strengthened, including criteria such as lifetime extension, durability testing, rechargeable battery quality and lifetime, upgradability and reparability (European Commission 2016). In its scope, the EU Ecolabel covers all five resource efficiency strategies listed. Furthermore, specific criteria targeting the five resource efficiency strategies are identified in chapter 6. A challenge to the effectiveness of the EU Ecolabelling in improving the resource efficiency of electrical and electronic equipment is that is that the number of electrical and electronic product groups covered by the EU Ecolabelling is limited. Furthermore, the ecolabels for electrical and electronic equipment suffer from a low awareness and low uptake by producers (European Commission 2008a).

The EU guidelines for GPP also apply a lifecycle perspective in their scope and can thus target the resource efficiency strategies listed in table 7-1. The review in chapter 6 also revealed that the EU guidelines for GPP include a wide section on resource efficiency requirements targeting aspects such as easy disassembly, the threshold of recycled content, hazardous substances, the identification of plastic components, mono-materials, the efficient use of consumables, durability, take-back systems for reuse, recycling and recovering, and packaging. Hence the different resource efficiency aspects are also covered by specific criteria.

The Ecodesign Directive is the only mandatory instrument which can set requirements for a broad selection of resource efficiency aspects. The ecolabels and the EU guidelines for GPP also apply a life cycle perspective and include a wide selection of resource efficiency aspects, however they are voluntary instruments representing the best performing products on the market. Furthermore, the EU Ecolabel only covers a small selection of electrical and electronic products. The WEEE Directive and the RoHS Directive also set minimum performance requirements, but mainly target recyclability and reusability. Therefore, the Ecodesign Directive plays a key role in improving the resource efficiency of electrical and electronic equipment.

7.2 ACTUAL SYNERGIES BETWEEN THE ECODESIGN DIRECTIVE AND THE OTHER POLICY INSTRUMENTS

The product policies are intended to support each other in achieving the shared end goal of improving the environmental performance of products, as described in section 4.3. The following section will examine whether the intended synergies between the Ecodesign Directive and the other IPP instruments covering electrical and electronic equipment exist. The focus in on resource efficiency, however more general aspects with implications for the effectiveness of the instruments are also discussed.

7.2.1 THE ECOLABELS AND THE ECODESIGN DIRECTIVE

The EU Ecolabelled products should represent the environmentally best performing products on the market whereas the Ecodesign Directive should remove the worst performing products from the market. The ecolabels include many diverse criteria with the purpose of improving the resource efficiency of the products, while the specific resource efficiency requirements included in the Ecodesign Directive are still rather limited. Thus in terms of targeting resource efficiency requirements, the intended synergies between the EU Ecolabels and the Ecodesign Directive were found, whereby the ecolabels represent the top of the market and the Ecodesign Directive sets minimum performance requirements. As further documented in chapter 6, the experience from the ecolabels could be used when setting requirements in the Ecodesign Directive. This potential has already been utilised to some extent, as was documented in the case study of the voluntary agreement covering imaging equipment, where the ecolabels and the EU Energy Star Regulation were used to set the requirements. It eased the implementation process because the requirements and the standards from the ecolabels could be used. Furthermore, they knew that the requirements were workable for producers because they were already in use. Hence, in this case the intended synergies were both in place and effective.

Nevertheless, these synergies are not always in place. A report examining the product policies covering the environmental performance of household washing machines (Bundgaard et al. 2013) showed that at the time of the study (2012), the washing machines labelled with the Nordic Swan had some of the highest water and energy consumption of all products sold on the Danish market. The explanation was that the Nordic Eco labelling took health issues into consideration, but the other factor was that the criteria were out-dated (Bundgaard et al. 2013). Therefore, there is still improvement potential in utilising the synergies between the instruments. The review of the different instruments has shown that the definitions of the different products between the instruments are different, making a comparison difficult. One recommendation is therefore to further harmonise the product definitions and the calculation methods used to set the criteria with the Ecodesign Directive and the EU Energy Labelling. Another recommendation is to further synchronise the process of developing new or updating existing ecolabelling criteria with the corresponding product groups in the Ecodesign Directive and the EU Energy Labelling.

7.2.2 THE EU ENERGY LABELLING AND THE ECODESIGN DIRECTIVE

The EU Energy Labelling pulls the market towards more products with improved resource efficiency (mainly energy) during use by providing the consumer with the necessary information. The Ecodesign Directive pushes the market towards more environmentally friendly products by removing the worst performing products form the market. This synergy between the EU Energy Labelling and the Ecodesign Directive has been strengthened, as steps have been taken in the EU to synchronise the two instruments. The two instruments now both cover energy-related products and the process of developing the background studies, the implementing measures and the updates have been synchronised.

There remains, however, some potential for improvement. There are differences in the product groups covered by the Ecodesign Directive and the EU Energy Labelling. The EU Energy Labelling mainly targets energy in the use phase, whereas the Ecodesign Directive can target broader environmental requirements and other phases during the product lifecycle. Suggestions have been made to expand the scope of the EU Energy Labelling. In the Circular Economy Action Plan, it was proposed to include information on durability in the EU Energy Labelling. However, a concern regarding expanding the EU Energy Labelling is that it will make the EU Energy Labelling difficult to read and understand for the consumers (Molenbroek et al. 2013). The EU Energy Labelling has been effective in reducing the energy consumption of energy-related products because the consumers could use the labelling scheme to select the most energy efficient product, saving energy or water and thus also money. However, the question is whether the instruments will be as effective for the resource efficiency aspect, which does not provide a financial benefit to the consumer, such as the content of recycled materials or recyclability. Here, durability might be a good suggestion as this information is also highly relevant for the consumer from a financial point of view. A recommendation could therefore be to examine whether information on durability could be included in the EU Energy Labelling.

7.2.3 THE ROHS DIRECTIVE AND THE ECODESIGN DIRECTIVE

The Ecodesign Directive and the RoHS Directive both set minimum requirements and thereby use the same mechanism to transform the market towards greener products. However, the two directives have different product scopes. The RoHS directive has a broader product scope than the Ecodesign Directive, covering all electrical and electronic equipment, whereas the Ecodesign Directive covers selected energy-related product groups. This also implies that the RoHS Directive sets generic restrictions on hazardous substances, covering all electrical and electronic equipment, whereas the Ecodesign Directive can restrict the use of hazardous substances for specific product groups. This is, of course, a simplification, because the RoHS Directive can make exemptions and the Ecodesign Directive can make horizontal implementing measures covering more product groups, such as the implementing measure on standby time. However, due to the differences in product scopes, it might be easier to restrict the use of a certain substances in specific products through the Ecodesign Directive than it would be to make a generic restriction in the RoHS Directive, even though the latest revision of the RoHS Directive has made it easier to restrict additional substances through delegated acts. As mentioned in chapter 6, it is an on-going discussion whether the Ecodesign Directive should also include requirements for hazardous substances or whether these should be regulated in the RoHS Directive and the REACH regulation. However, there are already examples of requirements to hazardous substances in the Ecodesign Directive, such as information requirement for mercury content in the implementing measures covering lamps, PCs and servers, and televisions. Therefore, a recommendation could be to use the Ecodesign Directive to obtain information on hazardous substances in specific products and to use the Ecodesign Directive to restrict a hazardous substance for a specific product group where a general restriction of the hazardous substances through the RoHS Directive covering all electrical and electronic equipment is not needed.

7.2.4 THE WEEE DIRECTIVE AND THE ECODESIGN DIRECTIVE

The interaction between the Ecodesign Directive and the WEEE Directive is especially important when improving resource efficiency because the WEEE

Directive targets the prevention, reuse, recycling and recovery of WEEE. However, it is also important viewed in the light of the limited implementation of the individual producer responsibility in the EU. It was the intention that individual producer responsibility should encourage producers to change the design of their products to improve the prevention, reuse, recycling and recovery of WEEE. However, due to the implementation in many Member States of a collective producer responsibility scheme, this mechanism has had limited effects. The interaction with the Ecodesign Directive is even mentioned in the WEEE Directive (11), which states

> "Ecodesign requirements facilitating the re-use, dismantling and recovery of WEEE should be laid down in the framework of measures implementing Directive 2009/125/EC. In order to optimise re-use and recovery through product design, the whole life cycle of the product should be taken into account"

However, the review of the adopted implementing measures and voluntary agreements in Bundgaard et al. (2015) showed that the inclusion of specific requirements targeting reuse, dismantling and recovery is limited. Besides the voluntary agreement covering imaging equipment, none of the adopted measures or acknowledged voluntary agreements included specific requirements targeting reuse, dismantling or recovery. Quite a few, however, included information requirements targeting reuse, dismantling and recovery. An example of the missing utilisation of the synergies between the WEEE Directive and the Ecodesign Directive can be found when considering the list of substances, mixtures and components that have to be removed from any separately collected WEEE in the revised WEEE Directive Annex VII. Here, the Ecodesign Directive could play a larger role supporting the WEEE Directive by setting requirements for the easy dismantling of these substances, mixtures and components listed in Annex VIII in the WEEE Directive or other components which need to be removed to ensure an environmentally sound reuse, recycling, recovery or disposal of WEEE, thus compensating for the missing effect of the introduction of the individual producer responsibility.

CHAPTER 8 CONCLUSION PART ONE: REGULATING RESOURCE EFFICIENCY

This chapter will answer the two main research questions asked in part one, namely *how have the EU product policies covering electrical and electronic equipment integrated resource efficiency aspects and what is the role of the Ecodesign Directive*.

The IPP instruments cover different resource efficiency aspects and they have to some extent successfully improved resource efficiency. However, there is still considerable improvement potential. The RoHS Directive and the WEEE Directive have successfully improved the recyclability and recovery of electrical and electronic equipment by restricting hazardous substances and setting up take-back systems. It was initially the intention that the WEEE Directive should also stipulate that the producers design products for improved prevention, reuse and recycling by introducing producer responsibility. However, due to the prevalence of collective producer schemes, the WEEE Directive had not had the intended effect of stipulating design changes. The EU Ecolabels applies a lifecycle perspective and includes a board variety of resource efficiency criteria. However, few electrical and electronic product groups are covered by EU Ecolabelling criteria and the industry take-up of the criteria is low for electrical and electronic equipment. Therefore, the actual potential of the EU Ecolabel to improve the resource efficiency of electrical and electronic equipment is not fully utilised. The EU Energy Labelling has been successful in transforming the market towards more energy efficient products, however the EU Energy Labelling and the EU Energy Star regulation so far only target the use phase and have mainly included information requirements on energy efficiency.

The Ecodesign Directive is the sole mandatory product policy instruments which can set minimum requirements for the product design covering both the entire life cycle of the product and a broad variety of resource efficiency aspects. Therefore, the Ecodesign Directive has an important role to play in setting minimum requirements for resource efficiency aspects. As chapter 5 has shown, the actual integration of resource efficiency requirements besides energy remains limited. So far, five implementing measures and one voluntary agreement have included resource efficiency requirements other than energy and only the voluntary agreement for imagine equipment has included many diverse resource efficiency requirements. Therefore, further uptake of resource efficiency requirements in the

Ecodesign Directive is important to improve the resource efficiency of electrical and electronic equipment.

The two case studies of the voluntary agreement for imaging equipment and the implementing measure for vacuum cleaners provided recommendations for the further uptake of resource efficiency requirements in to the Ecodesign Directive. In the Ecodesign Directive, it is legally possible to set requirements for resource efficiency. However, the existing requirements have to a large extent focused on energy efficiency in the use phase. This can be explained by the focus of the Ecodesign Directive on the most significant environmental impact and is due to the fact that primarily energy-using products have been included in the scope. Thus, energy efficiency in the use phase has often had the largest environmental impact. Therefore, a recommendation is made to focus not just on the most significant environmental impact, but also on the largest improvement potential. It is also of interest regarding which types of requirements will be included when implementing measures for energy-related product groups, such as windows, are adopted.

The background studies (preparatory studies) made when developing implementing measures and voluntary agreements also play a key role in the uptake of resource efficiency requirements into the regulation. Therefore, a recommendation is to broaden the scope of the methodology for the ecodesign of energy-related products and the EcoReport tool and to develop the necessary resource efficiency indicators to ensure that resource efficiency aspects are sufficiently covered in the preparatory study. The stakeholders involved in the ecodesign process also play an important role in pressuring for the uptake of resource efficiency requirements. Therefore, a recommendation is to continue the open ecodesign process and strengthen stakeholder consultations during the preparatory study. The division of leadership of the product groups between the Directorate-General also had an impact on the uptake of resource efficiency requirements. Typically, the Directorate-General for Energy and the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs have the leadership of product groups. DG Environment is involved in the process but has not lead any of the implementing measures or voluntary agreements adopted or acknowledged in 2013. However, because DG Environment focuses on broader environmental aspects and drives the resource efficiency agenda, it is recommended that their role be strengthened. Finally, further work is needed on developing standards defining verification procedures and test methods for resource efficiency requirements.

The instruments in the policy mix apply different means to improve resource efficiency. The RoHS Directive and the Ecodesign Directive set minimum requirements to products and push the market towards increased resource efficiency. The WEEE Directive makes the producer financially responsible for waste treatment, sets requirements for take-back systems, and the recovery, recycling and prepare for reuse targets for electrical and electronic equipment. The EU Energy

Labelling and the EU Energy Star Regulation set requirements for consumer information and try to pull the market towards more resource efficient products by changing consumer behaviour. The EU Ecolabel represents the environmentally best performing products on the market and also tries to pull the market towards more environmentally friendly and resource efficient products by changing consumer behaviour. It is the intention that these synergies between the instruments should be utilised. Actions have been made at the EU level to improve the synergies between the different policy mixes. In particular, the synergies between the EU Energy Labelling and the Ecodesign Directive have been improved.

However, as chapter 6 has shown, the ecolabels already include a broad variety of resource efficiency requirements and many of the requirements can be integrated into the Ecodesign Directive if they can comply with the requirements specified in article 15 paragraph 5 of the Ecodesign Directive. The synergies between the Ecodesign Directive and the ecolabels can be, and to some extent already are, used as in the case of the voluntary agreement covering imaging equipment. However, there is a great potential for further utilising these synergies.

The synergies between the WEEE Directive and Ecodesign Directive could also be further utilised. The Ecodesign Directive could compensate for the limited effect the introduction of the producer responsibility has had on product design by setting requirements improving the prevention, reuse, recycling and recovery of WEEE. As a minimum, the Ecodesign Directive could ensure that substances, mixtures and components that have to be removed according to the WEEE Directive Annex VII can be removed easily (European Commission 2012a). Furthermore, the Ecodesign Directive could supplement the RoHS Directive by setting product specific restrictions to hazardous substances in addition to the more generic restrictions set out in the RoHS Directive.

Even though the policy instruments reviewed in this section are in place to improve the environmental performance of products, they are still part of the "better regulation" agenda. Hence, these policies must not hamper growth or the ability of companies and businesses to flourish (Malcolm 2011). As specified in article 15 in the Ecodesign Directive, *"there shall be no significant negative impact on industry's competitiveness….and no excessive administrative burden shall be imposed on manufactures"* (European Commission 2009a, article 15). Thus, the regulation will be assessed not only for its ability to improve resource efficiency or other environmental aspect, but also for its impact on business (Malcolm 2011). This will present a considerable challenge in reaching a circular economy, unless we believe in the models proposed by the Ellen MacArthur Foundations and Cradle-to-Cradle and in the fact that we can continue to have growth as an overarching strategy.

PART TWO

DESIGNING FOR A CIRCULAR ECONOMY IN COMPANIES

PART 2 DESIGNING FOR A CIRCULAR ECONOMY IN COMPANIES

Businesses are often regarded as the root of the problem when it comes to the prevailing take-make-and-dispose economy. However, as outlined by Rennings (2000), businesses can also help drive eco-innovation towards, for instance, a circular economy. Therefore, businesses can also be part of the solution in creating a circular economy. The main research question is:

> How to design electrical and electronic equipment for closed material loops in the circular economy using ecodesign and what are the drivers and barriers?

The research questions are answered through two case studies. The first case study is of Bang & Olufsen, a Danish producer of high-end audio and visual equipment. The case study examines what has been driving Bang & Olufsen's work of closing the loops in the circular economy and how Bang & Olufsen could improve the recyclability of their products by creating a knowledge transfer between producers and recyclers through a workshop. These research questions are answered in the following chapters:

1. Chapter 9 provides an introduction to B&O, including their history, current situation, organisational structure, product development and environmental aspects in product development.
2. Chapter 10 includes an article under review in the Journal of Cleaner Production. The title of the article is C*an Luxury Products Support a Circular Economy: A Case Study of Bang & Olufsen*, authored by Anja Marie Bundgaard and Rikke Dorothea Huulgaard. The article examines, as the title indicates, whether luxury products can support a circular economy. A literature review of luxury products and the values and drivers of luxury consumption is made and, based on the review, a conceptual model is developed linking luxury products and the circular economy. This model was then tested on a case study of Bang & Olufsen. The study only examines B&O's core products.
3. Chapter 11 answers the research question of *how a company can work with design for recycling by creating knowledge exchanges between producers and recyclers through a workshop*. B&O was part of the *Designing out Waste* project, and one of the outcomes of this project was a workshop focusing on developing company specific ecodesign guidelines targeting design for recycling. The chapter provides an account of how the workshop was designed and conducted as well as a specific design for recycling recommendations. The study focuses on both B&O's core products and their BeoPlay series.

4. Chapter 12 provides a discussion of the drivers and barriers identified in the B&O case study when closing the loops in the circular economy.

The second case study is of Tier1Asset, a reconditioner of computers, tablets and smartphones. This case study examines the non-technical and design barriers when reconditioning computers.

5. Chapter 13 answers the research question of *which non-technical and design barriers Tier1Asset experiences when reconditioning computers*. Based on these design barriers, recommendations are proposed to improve the reconditioning of computers.

Chapter 14 finishes part two with the final conclusions.

CHAPTER 9 INTRODUCTION TO BANG & OLUFSEN

This is an introduction to the case company Bang & Olufsen (B&O). The purpose of this introduction is to provide the reader with the relevant background knowledge to understand the case company. Over the course of my PhD B&O has faced many structural and organisational changes, many of which were a result of the challenging financial situation they were facing. The chapter therefore begins with a short introduction to the history of B&O and their current situation. Then a short introduction to their organisational and product development is provided. Finally, an introduction to B&O's work with environmental aspects and ecodesign is given.

9.1 HISTORY

Peter Bang & Svend Olufsen founded B&O in 1925. They were both engineers from the Electrotechnical School in Aarhus (Krause-Jensen 2013). Their first product was an eliminator (Krause-Jensen 2013). The eliminator was able to connect existing battery-driven radios to the main power supply, making the anode battery unnecessary (Krause-Jensen 2013). The success of the product made it possible for them to build their first factory in 1929 on the outskirts of Struer and to develop and mass-produce a radio which could be connected directly to the main power supply (Krause-Jensen 2013). Peter Bang was often described as a typical engineer who worked on new inventions, whereas Svend Olufsen took care of the commercial side of things (Krause-Jensen 2013). Svend Olufsen also invented their first marketing slogan "*Bang & Olufsen – the Danish Hallmark of Quality*" (Krause-Jensen 2013, 90). In 1952, B&O expanded their portfolio by launching their first television (Krause-Jensen 2013). At that time, B&O was at the cutting edge of technological development, launching amongst other things the world's first stereo pickup in 1957 (Krause-Jensen 2013). In the mid-1950s, B&O faced an economic setback due to increasing competition from other television and radio companies in Denmark (Krause-Jensen 2013).

Until the 1960s, B&O had primarily focused on the home market (Krause-Jensen 2013). However, after Denmark entered the European Free Trade Association in 1960, B&O embarked on a new business strategy to conquer a share of the European market (Krause-Jensen 2013). Their strategy was not to go for the mainstream market but to focus on industrial design and quality, which was also made evident by their slogan at the time: "*Bang & Olufsen. For those who discuss quality and taste before price*" (Krause-Jensen 2013, 91). Hence, from this point on design became, and still is, the primary selling point (Krause-Jensen 2013). The strategy was successful, and B&O developed from a local company into an international firm

(Krause-Jensen 2013). The design was inspired by Bauhaus and followed a Scandinavian functionalist modernism, while the goal was to strive for simplicity and avoid complicated user interfaces (Krause-Jensen 2013). This design strategy may also be seen as a response to Japanese products, which at that time had many complex technological features. Jacob Jensen was the chief external designer during this period (1960s and 1970s) and was introduced to the company by Jens Bang, the son of Peter Bang (Krause-Jensen 2013). Jacob Jensen had a large influence on the signature design and he was the head architect behind their signature "flat line" which characterised their audio-visual products (Krause-Jensen 2013).

At the end of the 1960s, B&O established partnerships with their retailers; the purpose was to ensure their loyalty (Krause-Jensen 2013). The seven Corporate Identity Components (7 CIC) were also introduced in 1972, namely authenticity, autovisuality, credibility, domesticity, essentiality, inventiveness and selectiveness (Krause-Jensen 2013). The 7 CIC emerged as a response to both the rapid growth the company had undergone during the 1960s and the closer collaboration with the retailers (Krause-Jensen 2013). The 7 CIC were to help create a shared understanding of the company and the products between B&O, the retailers and the market, and they were especially used as part of the marketing strategy (Krause-Jensen 2013). However, they also described the attributes of the products (Krause-Jensen 2013).

Since they began collaborating with designers, B&O have primarily used external designers (Krause-Jensen 2013). In the beginning, the design consistency and long-term planning of different products was the task of two concept groups (Krause-Jensen 2013). One of these focused on the audio and had Jacob Jensen as the chief external designer (Krause-Jensen 2013). The other group was the video group, with external designer David Lewis (Krause-Jensen 2013). David Lewis has also played an important role in B&O, leading the design team from the mid-1980s (Krause-Jensen 2013). At the beginning of the 1970s, idealand emerged from the two concept groups (Krause-Jensen 2013). Idealand consisted of seven engineers and technicians who worked in close collaboration with the external designer, developing the initial idea of the designer into a workable product concept (Krause-Jensen 2013). Afterwards, the product concept was presented to the senior management group, who then could accept or reject the product concept (Krause-Jensen 2013). However, the product concepts were almost always accepted and idealand had a strong position in the organisation (Krause-Jensen 2013). After the product was accepted by senior management, the product development then made the product concepts into full prototypes in close collaboration with idealand (Krause-Jensen 2013). It was then again presented to senior management, who gave a final "okay" before the prototypes were sent to operations for production (Krause-Jensen 2013). Idealand had a special and powerful place in the organisation and their decisions were almost never questioned (Krause-Jensen 2013). Their strong position was also linked to the fact that design was very important for B&O (Krause-Jensen

2013). Design was what made the consumer buy a B&O product instead of a competitor's product and it is what attracted the consumers (Krause-Jensen 2013).

In 1977, B&O was quoted on the stock exchange, but the founding families still maintained financial control (Krause-Jensen 2013). The quoting on the stock exchange was done to finance an international expansion and research and product development (Krause-Jensen 2013). During the 1980s, B&O received several prestigious design awards and gained international recognition, and during this period their image as luxury brand emerged (Krause-Jensen 2013). However, the costly investments in product development and the prioritization of design lead to a growing deficit in the 1990s (Krause-Jensen 2013). Therefore, in 1993 a program, *Breakpoint 1993*, was launched by the new CEO Anders Knutsen, with the idea of making B&O slimmer and stronger (Krause-Jensen 2013). It materialised in structural changes aimed at reducing costs, including the dismissal of 700 employees, constituting more than a quarter of the workforce, the closing of a factory, the delaying of the managerial level and a restructuring of the factory (Krause-Jensen 2013). A "just-in-time" inventory strategy was launched, releasing capital (Krause-Jensen 2013). In this period, Phillips also brought 25% of the shares (Krause-Jensen 2013). *Breakpoint 1993* also challenged idealand and the sanctity of design (Krause-Jensen 2013). Management turned down product concepts because they were not viable, a practice that had previously been almost inconceivable (Krause-Jensen 2013). Hence, idealand's elevated position within the organisation was challenged (Krause-Jensen 2013). It also meant that the development of new products was to be faster (Krause-Jensen 2013). Anders Knutsen also set up Storylab, a think tank with the purpose of reflecting upon, conceptualising and developing corporate identity (Krause-Jensen 2013, 38). Anders Knutsen managed to turn the company around (Christensen 2012). In the financial year 1993/1994, B&O made a solid profit (Christensen 2012). The turnover increased to 2 bn DKR. in the financial year 1990/1991 and to 4 bn DKR in 2001/2002. With some setbacks, the turnover stayed around 4 bn DKR until 2008 (Christensen 2012).

In 2001, Torben Ballegaard followed Anders Knutsen as CEO (Berlingske Business 2012). Under Torben Ballegaard, B&O Automotive arose as a business unit that developed exclusive sound systems for high-end car manufactures (Berlingske Business 2012). In 2005, they launched their first car audio system. Automotive have subsequently proven to be quite profitable (Berlingske Business 2012). During this period turnover decreased, but profitability increased (Berlingske Business 2012). In 2008/2009, the turnover dropped to 2.8 bn DKR and stayed at this level over the following years, and for the first time in many years B&O had a small deficit (Christensen 2012). The drop in turnover was linked to the global financial crises. Due to the poor financial result, Ballegaard was fired in 2008, and Kalle Hvidt Nielsen took over (Berlingske Business 2012). In order to turn things around, in 2008 management launched a new strategy called Pole Position (Christensen 2012). The purpose was to focus on their core competences, namely audio and visual products (Christensen 2012). A shared platform was developed as the outset for all products to reduce product development cost, while several activities were outsourced and the number of suppliers reduced (Christensen 2012). B&O received most of their components from suppliers and did the assembly in Struer and the Czech Republic (Christensen 2012). However, the new strategy did not change B&O's core values of design and quality (Christensen 2012).

In 2011, Tue Mantoni took over from Kalle Hvidt Nielsen (Hansen 2011). Kalle Hvidt Nielsen had ensured the streamlining of B&O and turned a deficit into a small profit, but now they wanted a CEO who could ensure a growth in sales (Hansen 2011). Tue Mantoni introduced the strategy *Faster, Leaner and Stronger* with the ambition of increasing turnover to 8-10 bn DKR (Børsen 2012). Part of the strategy was to introduce a new brand, BEOplay, to the product portfolio (Gullev 2012). The new product line would be cheaper than their core products and target a new, younger consumer group (Gullev 2012). The idea was to get a new consumer groups interested in B&O's products and, over time, get them to buy B&O's core products (Gullev 2012).

9.2 CURRENT SITUATION

Tue Mantoni did not manage to turn around the development at B&O or reach the promised increase in turnover. Therefore, in 2015 an attempt was made to sell B&O, however this failed (Børsen 2016). To raise capital, B&O sold off several businesses. In March 2015, Automotives was sold to HARMAN and B&O entered into an Automotive brand licencing agreement with HARMAN (Bang & Olufsen 2015b). In March 2016, B&O formed a strategic partnership with LG. In the future, LG will be responsible for the product development and production of B&O televisions (Euroinvestor 2016). However, B&O will still be responsible for the concept development (Environmental Consultant 2016b). The strategic partnership resulted in a reduction in employees, including the environmental consultant at B&O. In April 2016, B&O sold off ICEpower (Bang & Olufsen 2016b). In April 2016, Henrik Clausen replaced Tue Mantoni as CEO at B&O. The strategy is now to change B&O into an innovation centre, but the actual implications are not yet clear (Environmental Consultant 2016b). Today, B&O consists of the two core businesses, namely BEOplay and B&O's core products, divided into five business units, as the two additional businesses (Automotive and ICE Power) were sold off in 2016.

9.3 ORGANISATIONAL STRUCTURE

As mentioned above, B&O is in a transition phase and large changes are expected as they transit to an innovation centre during 2017. As the implications for the organisational structure are unknown, the outset for this introduction to B&O's organisational structure is how the company was organised in 2013, when the projects began. However, ICE Power and Automotive are omitted as they have been sold off. On overview of the organisational structure is provided in figure 9-1.

Until 2011, B&O had a separate environmental department. However, in connection with the downsizing of the organisation in 2011 as part of "*the leaner, faster, stronger*" strategy, the environmental department's responsibility for environmental aspects has been divided between different departments (Huulgaard 2015). Since 2011, the numbers of employees working with environmental aspects and work environment has also been reduced. In 2013, there were two employees responsible for environmental aspects and work environment (Environmental Consultant, Environmental Manager 2013). An environmental consultant is responsible for the product environment and an environmental manager is responsible for the environmental aspects in connection with the production and work environment (Environmental Consultant, Environmental Manager 2013). They are both located within Global Quality (Environmental Consultant, Environmental Manager 2013). The environmental consultant responsible for product environment was located within the product quality centre and the environmental manager responsible for the work environment and environmental aspects in connection with the production is located in Group Function (Environmental Consultant, Environmental Manager 2013). In connection with the latest reduction in staff in spring 2016, the employee responsible for product environments was dismissed (Environmental Consultant 2016b). Her tasks will in the future be handled by LG and the external suppliers because B&O will outsource more of their production during the transition to an innovation centre (Environmental Consultant 2016b).

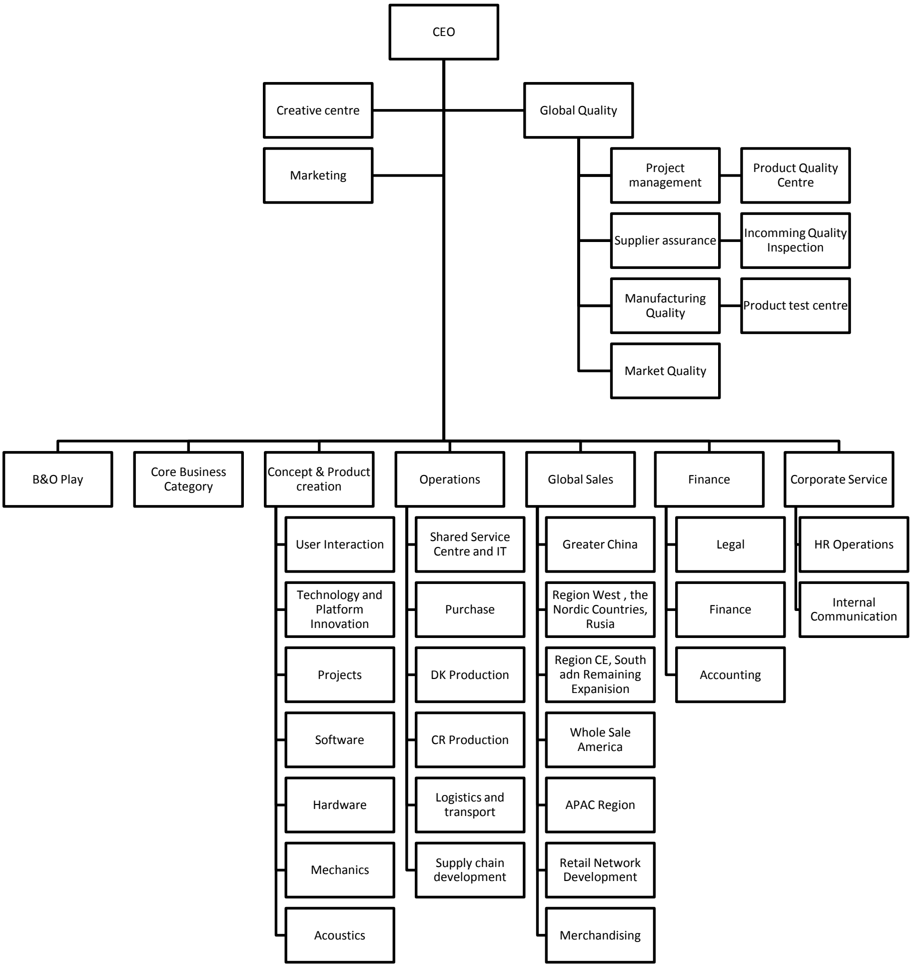


Figure 9-1: B&O's organisational structure 2013, based on Huulgaard (2015) and Environmental Consultant and Environmental Manager (2013).

9.4 PRODUCT DEVELOPMENT

An overview of B&O's product development process is provided in figure 9-2. The first step is called scoping and is prior to the actual product development stage (Huulgaard 2015). In this stage, it is decided what B&O's product portfolio should look like in the coming years (Huulgaard 2015). The scoping is based on, amongst other things, the corporate strategy (Huulgaard 2015). The actual product development follows a classic stage-gate model (discovery stage, scoping, build business case, development, testing and validation and launch) (Huulgaard 2015). In figure 9-2, this process is denoted as business (Huulgaard 2015). A framing and an exploration process support the stage-gate model (Huulgaard 2015). Most of B&O's products build on the same platform technologies (Huulgaard 2015). These platform technologies are developed during the framing process (Huulgaard 2015). The exploration process examines which types of platform technologies should by developed during the framing process, based on the product portfolio decided during the scoping process (Huulgaard 2015). The three processes can happen simultaneously, but typically the exploration process is first followed by the framing process and then finally by the actual product development process (Huulgaard 2015).

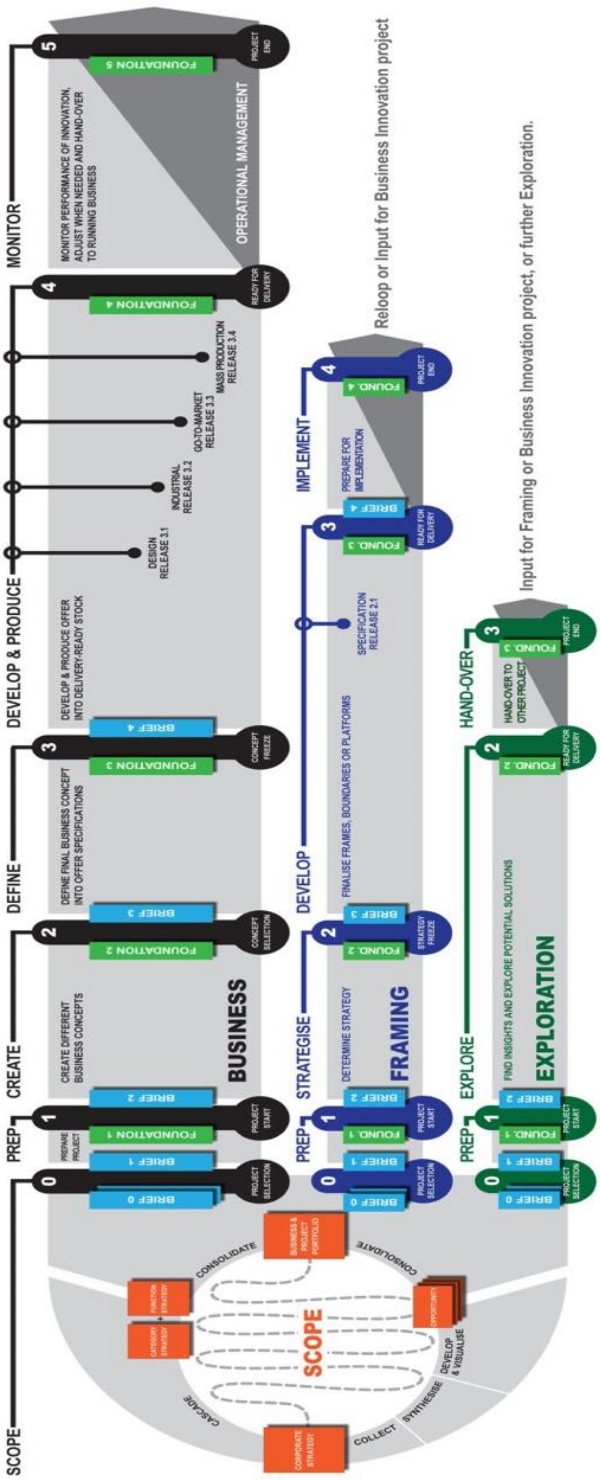


Figure 9-2: B&O's product development process, from Huulgaard (2015).

9.4.1 ENVIRONMENTAL ASPECTS IN PRODUCT DEVELOPMENT

The environmental consultant introduces environmental aspects into the product development process (Environmental Consultant 2013). She begins by introducing all the environmental requirements at the beginning of the product development process (Environmental Consultant 2013). The environmental requirements are collected in a product requirement brief (Environmental Consultant 2013). She then works as a consultant during the product development process (Environmental Consultant 2013). Finally, before the product launch she makes sure that the product complies with the environmental requirements and that the right documentation exists (Environmental Consultant 2013). Previously, B&O had several environmental requirements exceeding legal requirements. However, slowly these requirements have been included in the regulation (Huulgaard 2015). Today, the environmental requirements consist mainly of mandatory market access requirements, such as legal requirements from the WEEE Directive, the RoHS Directive, the Ecodesign Directive and similar legal requirements in other parts of the world. B&O only has a few requirements for chemical content which exceed the legal requirements (Environmental Consultant 2013). However, these substances might also be covered in the latest expansion of substances included in the RoHS Directive from 2015 (European Commission 2015d).

9.5 SUB-CONCLUSIONS

B&O is an old company dating back to 1925. Almost from the beginning, B&O has had a strong focus on design and quality and this focus persists today. B&O's image as a producer of luxury products was established in the 1980s. The designers have held a strong position in the organisation. Nevertheless, their position was weakened in the 1990s with the *Breakpoint 1993* strategy launched by Anders Knutsen. Until 2016, two employees handled environmental aspects, both located in the Global Quality department. The environmental manager handled the environmental aspects and health and safety at B&O's facilities, and the environmental consultant handled environmental aspects in relation to the product environment. In 2016, the environmental consultant was dismissed, partly because the television production was outsourced to LG. Until 2016, the environmental consultant had been responsible for the introduction of environmental aspects into product development. Since 2016, Global Quality has been responsible for any environmental requirements set by regulation and the business units are themselves responsible for any environmental aspects beyond legal compliance. B&O has faced several financial crises, which has led to a slimming down of the organisation and the outsourcing of production. The most recent began with the latest financial crisis and B&O has not yet managed to turn things around.

CHAPTER 10 CAN LUXURY PRODUCTS DRIVE THE CIRCULAR ECONOMY? A CASE STUDY OF BANG & OLUFSEN

Bang & Olufsen is not known for its progressive environmental strategy. Instead, environmental aspects are considered to be embedded within the quality dimension of their products. In the initial mapping of B&O's environmental efforts, a number of activities and characteristics were identified important for closing the loops in the circular economy. This led me to consider B&O's initial motivation, if indeed these activities were not a result of an environmental strategy. I therefore set out to understand where these activities and characteristics had originated.

The end result was the article titled "*Can Luxury Products Drive the Circular Economy - a Case Study of Bang & Olufsen*", written by Anja Marie Bundgaard and Rikke Dorothea Huulgaard. The article examines the links between luxury products and the circular economy and develops a conceptual framework describing these links based on a literature review. The conceptual framework is then used to examine the Bang & Olufsen case. The study only examines B&O's core products. The article has been submitted to the Journal of Cleaner Production and is currently under review.

Not included for online publication

CHAPTER 11 DESIGNING FOR IMPROVED RECYCLABILITY

Bang & Olufsen took part in the project *Designing out Waste* financed by the Environmental Protection Agency. The purpose of this project was to test different ecodesign approaches which could help improve companies' resource efficiency and develop communication and forms of co-operation between the producers and recyclers. The study examines both B&O's core products and their BeoPlay products.

Bang & Olufsen wanted to improve the recyclability of their products, however they lacked the necessary knowledge to make these changes. A workshop was set up to approach this issue. The purpose of the workshop was to facilitate a knowledge exchange between the recyclers and Bang & Olufsen and thereby develop design for recycling requirements. An account of the workshop is provided in chapter 11 *Designing for improved recyclability*.

11.1 IDENTIFICATION OF THE PROBLEM AREA AND PROBLEM FORMULATION

The objective of this chapter is to examine *how the recyclability of B&O's products could be improved with the current recycling processes and how a workshop could be used to facilitate knowledge exchange between the waste treatment sector and the producers*. Recyclability was selected as a focus area for B&O because their activities targeting recycling are less developed and less embedded within the company's value and identity. B&O has previously worked with recycling primarily through their disassembly test, the marking of plastics and a negative list. B&O marks all plastic components with a weight above 25 grams. B&O has a negative list of hazardous substances which are not allowed in B&O's products. Many of these substances are now subject to mandatory legal requirements.

In the beginning, B&O conducted disassembly tests in-house as a public event (Director Research 2014). However, this changed when B&O started collaborating with waste manager HJ Hansen, because they informed B&O that the disassembly time was not that important due to the automatic and destructive methods applied by the waste treatment processes. Hereafter, HJ Hansen took over the disassembly tests and compiled reports for B&O which contained the recycling percentages. However, the results of these reports were mainly used by the environmental consultant (1999-2013) and not disseminated to the rest of the organisation. This is in contrast to when the disassembly tests were performed as a public event. When B&O shifted from HJ Hansen to Stena, the environmental consultant (1999-2013) took over the disassembly tests and the calculations of the recycling percentages (Environmental Consultant 2013). Now, the disassembly tests are no longer done systematically.

It was identified during the interviews with the environmental consultant (1999-2013) that B&O had a lack of knowledge when it came to design for recycling. As she expressed during one of the interviews,

> "We do not know what happens to our products the day they are disposed. We may think what we are doing is smart, but then we might have put two materials together which are not compatible, or we might have done something which is completely irrelevant like making it easy to separate two material factions that can easily go together in the waste streams. In principle, we do not have the knowledge today. We cannot find this knowledge in literature because the knowledge is out-dated. A lot has happened during the last 10 to 15 years." (Environmental Consultant 2013, 1)

The environmental consultant (1999- 2013) feels that her knowledge of design for recycling is outdated because the waste treatment process in Europe has become increasingly automatic and destructive. This also implies that her existing knowledge of design for recycling may no longer be relevant. Therefore, the idea of the workshop was to re-establish a knowledge link between the waste managers and the producers and to ensure that the knowledge was shared between the waste managers and the producers on how to improve the recyclability of their products. The fact that this link and knowledge exchange between the producers and the waste mangers is today almost non-existent was also evident during the interviews with representatives from the waste treatment sector (Ellegaard 2013, Halvarsson 2013, Zonneveld 2014). As expressed by the executive secretary of the European Electronic Recycler Association (EERA),

> "I have only very few times in the ten years that I have been involved in the association been asked to come to producers and to discuss about what they can do, how shall we do, what is best to do for you, etc. That is the reality, basically, on what our contact with producers is." (Zonneveld 2014)

Neither the two largest recycling facilities in Denmark nor the executive secretary from the EERA are experiencing interest from producers to design products with better recyclability, emphasising the importance of bridging the knowledge gab between producers and waste handlers. However, this lack of interest from the producers in designing products that can be recycled more easily is also a result of the lack of incentives for the producers to approach the challenges that their products might offer at their end-of-life. The WEEE Directive has tried to approach this issue by implementing producer responsibility, making the producers responsible for the end-of-life of their products. However, the way the directive has been implemented in many countries through collective schemes has not provided the incentive for the producers to design products for end-of-life. Therefore, there is currently no incentive for the producers to approach this issue. Despite this, the environmental manager at B&O wanted to address this issue.

11.2 THEORETICAL FRAMEWORK – KNOWLEDGE BOUNDARIES AND BOUNDARY OBJECTS

Transferring knowledge between departments within an organisation is in itself a complex task. Transferring knowledge between two organisations as different as a manufacturer of high-end audio and visual equipment and the waste treatment sector is even more complex. In order to conceptualise the challenges of knowledge transfer and knowledge boundaries, I have used the theoretical framework developed by Carlile (2002, 2004).

Innovation often happens at the boundaries between specialised domains and therefore it is essential to manage knowledge across boundaries. However, deeply specialised knowledge can also hinder problem-solving across different functions, creating a knowledge boundary (Carlile 2002). According to Carlile (2002), knowledge can be described as localised, embedded and invested in practice. Knowledge is therefore in practice specialised and path-dependent. This path-dependent nature of knowledge has positive effects when the differences and dependencies between the actors and their knowledge are known. However, when the novelty increases and the differences and dependencies change, then the path-dependent nature of knowledge can be problematic because the common knowledge used previously may no longer be able to represent the new situation (Carlile 2004). These facts make it increasingly difficult to work across functional boundaries and accommodate knowledge developed in another practice, especially as novelty increases (Carlile 2002).

Carlile (2004) operates with three different types of knowledge boundaries: the syntactic, semantic and pragmatic knowledge boundaries, depending on the degree of novelty (see figure 11-1). At the bottom of the triangle, where novelty is low and the differences and dependencies are known, a syntactic transfer of knowledge is sufficient to convey knowledge across boundaries. However, as novelty increases and the difference and dependencies are no longer known, then a semantic translation or a pragmatic formation of knowledge is necessary to overcome the knowledge boundaries. However, we still need the capacity of the boundaries below to overcome the more complex boundaries above.

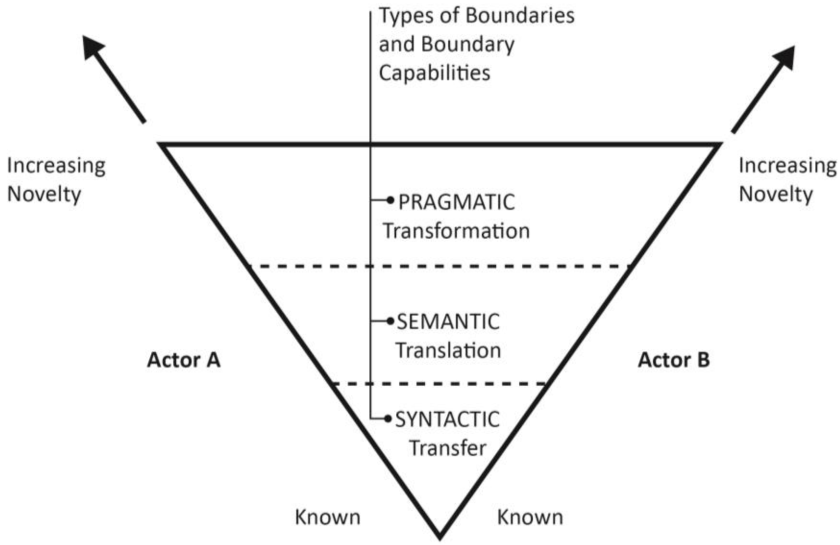


Figure 11-1: Categories of knowledge boundaries (Carlile 2004, 558).

When only a syntactic knowledge boundary exists, then a common lexicon is enough to ensure the transfer of knowledge from one function to another function. If a stable and shared syntax exists across a boundary, it ensures a quality information exchange (Carlile 2002). However, it requires that the common lexicon sufficiently specifies the differences and dependencies at play at the knowledge boundary (Carlile 2004).

When novelty arises, the simple transfer of knowledge can become a problem because the current lexicon is no longer enough to sufficiently represent the differences and dependencies (Carlile 2004). The novelty makes some of the differences and dependencies unclear or some meaning confusing (Carlile 2004). When this happens, we have a semantic knowledge boundary. The semantic approach acknowledges that a common syntax is not always enough to ensure communication between actors. Actors will interpret the knowledge differently when coming from different fields (thought worlds), making communication and knowledge exchange difficult (Carlile 2002, Dougherty 1992). When faced with a semantic boundary, the actors should learn about each other's domain-specific knowledge and translate their own domain-specific knowledge to establish a common meaning, making it possible for actors to share and assess their own knowledge (Carlile 2004). It is important to establish an understanding through communities where the individual can interact and work past the semantic differences by making their tacit knowledge explicit (Carlile 2002).

If novelty results in differences in the interests of the actors involved, then we might be faced with a pragmatic boundary (Carlile 2004). Interests that are in conflict imply that knowledge from one area will result in negative consequences in another area (Carlile 2004). These negative consequences will impact the actors' willingness to make changes, even though they are faced with a new situation that requires new knowledge (Carlile 2004). People can be reluctant to change their knowledge and skills because they have invested resources in developing their skills and knowledge (Carlile 2002). It will therefore be costly for them to change these (Carlile 2002). Hence, when knowledge is at "stake", people can be reluctant to change. When faced with a pragmatic boundary, a transformation of the common knowledge and the domain-specific knowledge used in the past is necessary to ensure that knowledge can be moved across the boundary (Carlile 2004). To resolve the consequences of a pragmatic knowledge boundary, the knowledge needs to be transformed in a process where individuals represent, learn, negotiate and change their current knowledge and new knowledge should be created to mitigate the consequences identified (Carlile 2002).

Carlile's conceptualisation of knowledge and knowledge boundaries builds on various existing theoretical approaches. In relation to knowledge transfer, he builds on information processing theory (Shannon, Weaver 1949, Lawrence, Lorsch 1967). The ideas about knowledge translation derive from learning theory and theory on communities of practice and creating shared meaning (Dougherty 1992, Nonaka 1994). The notions on knowledge transformation have their origin in the theory on creative abrasion by Leonard-Barton (1992) and the theory on negotiating practice by Brown and Duguid (2001).

11.2.1 BOUNDARY OBJECTS

To mitigate some of the challenges of exchanging knowledge across boundaries, boundary objects can be used. Boundary objects can be described as "*objects that are shared or sharable across different problem solving contexts*" (Carlile 2002, 451). The use of boundary objects can be an effective way of representing the interests of actors from different contexts and ease the process of negotiation and the transformation of knowledge in product development (Carlile 2004). Boundary objects can be objects such as drawings, prototypes or trade-off methodologies (Carlile 2004). Carlile (2002) differentiates between three types of boundary objects, namely repositories, standardized forms and methods, objects or models and maps of boundaries. Examples of repositories are cost databases, parts libraries or CAD databases (Carlile 2002). Repositories provide a shared reference point of data, labels or measurements across different functions, which can offer shared definitions and values for problem-solving (Carlile 2002). Standardised forms and methods offer a shared format for solving problems across different functions (Carlile 2002). Objects or models can be sketches, assembly drawings, prototypes, parts mock-ups or computer simulations (Carlile 2002). The objects and models are complex or simple exemplifications which can be used and observed across different functions (Carlile 2002). When selecting a boundary object, it is important to keep in mind which type of boundary is faced (Carlile 2004). Table 11-1 provides an overview of which types of boundary objects are relevant when faced with a syntactic, semantic or pragmatic knowledge boundary.

Type of knowledge boundary	**Category of boundary objects**	**Characteristics of boundary objects**
Syntactic	Repositories	Representing
Semantic	Standardised forms and methods	Representing and learning
Pragmatic	Objects, models and maps	Representing, learning and transforming

Table 11-1: Types of knowledge boundary, category and characteristics of boundary objects (Carlile 2002, 453)

Not all objects will be able to work as a boundary object and even fewer will be effective boundary objects. The effectiveness of a boundary object depends on the actors' ability to use its capacity as a kind of common knowledge. Carlile (2002) provides three characteristics of objects, methods or tools that make an effective boundary object. Firstly, the object needs to establish a shared language which the actors can use to represent their knowledge. Secondly, it needs to provide a way for the actors to learn and specify their differences and dependencies across a given boundary. Thirdly, it should make it possible for the actors to collaboratively transform their knowledge.

11.2.2 THE WORKSHOP

The idea of the workshop was to provide B&O with the knowledge for designing products with improved recyclability. The recyclers of electrical and electronic waste are those with the knowledge of the challenges faced when recycling electrical and electronic waste, and how the products could be designed differently to mitigate some of these challenges. Therefore, the idea was to create a knowledge exchange between the recyclers of electrical and electronic waste and B&O through a workshop. However, as the theoretical framework has illustrated, the exchange of knowledge can be difficult because of the path-dependency and context dependent nature of knowledge. The idea was to transfer, translate or transform the recyclers' knowledge (the operations manager at Averhoff) to the product developers at B&O. The operations manager at Averhoff and the product developers at B&O are from two very different fields and have very different backgrounds. Due to these differences, the product developers and the operations manager at Averhoff belong to two different thought worlds. Therefore, both a high degree of novelty and a syntactic and semantic knowledge boundary might be expected. Design for recycling at B&O would potentially set restrictions on product developers, and therefore the knowledge boundary is very likely to be a pragmatic boundary.

11.3 DESIGN OF THE WORKSHOP

11.3.1 THE PROPOSED WORKSHOP:

In collaboration with the environmental consultant (1999-2013) from B&O, a program for the workshop was developed and the participants were selected. It was decided that the participants from B&O should be the environmental consultant (1999-2013), the manager of technical products and services, and the design engineers. The environmental consultant (1999-2013) should participate because she takes part in the product development process and ensures that the environmental requirements are taken into consideration. The manager of technical products and services was included because he has very detailed knowledge of the recyclability of B&O's products as he is responsible for the recycling of the prototypes. The design engineers were selected because they are the ones who make the final detailed design and assembly of the products. Therefore, they have a large influence on the recyclability of the product. Then, a representative from the waste treatment sector should participate, providing the knowledge from the recycling sector. Finally, a representative from Aalborg University should participate in facilitating and documenting the process and providing knowledge on ecodesign and the circular economy.

The idea was to start with an introduction to ecodesign and the circular economy, conducted by Aalborg University. This was followed by an assignment, whereby the employees at B&O were to map their current practice with ecodesign requirements according to the four circles in the circular economy. Afterwards, the representative from the waste treatment sector made an introduction to the recycling of WEEE. The purpose of this part of the workshop was to help develop a common lexicon and start a process whereby the actors could learn about and translate their domain-specific knowledge to a shared knowledge between the different practises. This was to help overcome the syntactic and semantic knowledge boundaries.

After the introductory presentations, the participant were to work on separating three B&O prototypes. The prototypes were at the gate level and therefore it was not possible to make design changes to the prototypes. Instead, the idea was that the new knowledge developed was to be used in future product development. The purpose of this part of the workshop was to use the dismantling of the prototypes to illustrate and facilitate a discussion of some of the challenges the recyclers face when receiving the products at their end-of-life. Based on these discussions, the participants were to co-operatively develop design for recycling requirements relevant to B&O. The prototypes and their separation were intended to help overcome the design engineers' reluctance towards additional design requirements by starting a process of negotiation and learning, whereby the design engineers would understand the importance of their design decisions for the recyclers and the recyclers could understand why the designers did as they did, thus creating a shared understanding. Based on this mutual understanding, they could mitigate some of the challenges faced by the recyclers by developing design for recycling requirements (new knowledge). Hence, a process of negotiation was to be started in order to develop specific design for recycling requirements overcoming the pragmatic knowledge boundary. Because it was a pragmatic knowledge boundary, we wanted a boundary object within the category *objects, models and maps* and the separation of the prototypes could work as a boundary object. It could help illustrate the problems faced by the recyclers - show what is "at stake". Finally, the prototypes were something that was "shared" by all actors involved. The design engineers developed the products and the waste managers deconstructed it. Hence, the product could help create shared meaning. The question is whether the prototypes would be an effective boundary object.

11.3.2 THE ACTUAL DESIGN OF THE WORKSHOP

In the middle of the planning process, the environmental consultant (1999-2013) changed jobs and a new environmental consultant (2013-2016) was employed. This led to a reduction in the participants included in the workshop. Only the environmental consultant (2013-2016) from B&O, a representative from the recycling sector (Averhoff) and researchers from Aalborg University would participate. The manager of technical product service from B&O also participated in part of the disassembly assignment. Hence, the design engineers, who make the actual design decisions, did not participate. In this set-up, the environmental consultant (2013-2016) from B&O was to ensure that the new knowledge developed during the workshop would be disseminated among the rest of the organisation through her role in product development. Aalborg University would sum up the learning from the workshop in a small report which the new environmental consultant (2013-2016) could then use during product development. The program was reduced and the section on ecodesign and circular economy was omitted. The environmental consultant (2013-2016) would thus work as a knowledge broker within B&O. A knowledge broker can be defined as *"people or organisation that move knowledge around and create connections between researchers and their various audiences"* (Meyer 2010: 118). Hargadon (2002) has also emphasised the importance of knowledge brokering for innovation in companies and organisations in his process model for knowledge brokering. Hence, the environmental manager (2013-2016) plays a key role, ensuring that knowledge is shared within the organisations and leads to actual design improvements. It could be argued that the environmental consultant already functions as a knowledge broker as she provides the product developer and designers with information on B&O's environmental requirements.

11.4 THE RESULTS OF THE WORKSHOP

Despite the downsizing of the workshop, the set-up facilitated a constructive dialogue and resulted in several ecodesign recommendations which could improve the recyclability of B&O's products. The following section provides an account of the design recommendations that came up and were discussed during the workshop. We worked on the separation of a television, a remote control and a loud speaker. The section begins with an analysis of the design challenges discussed during the workshop and is followed by the design recommendations that came up during the disassembly of each of the three products.

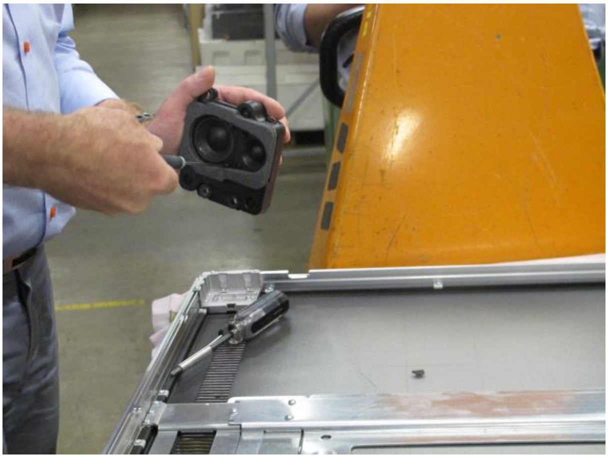
11.4.1 GENERAL DISCUSSIONS

Rare earth elements and precious metals

The recovery of rare earth elements and precious metals requires special treatment processes to ensure a good recovery of these materials(Chancerel et al. 2011). Many precious metals are lost if the components are shredded (Chancerel et al. 2011). Therefore, the components containing these materials need to be easily identified, removed and treated separately. However, the waste handlers often do not know which components contain rare earth elements and precious metals, and they need to rely on their experience and their network to locate the components with these metals. This was also illustrated during the workshop, where the employee from Averhoff noticed a loud speaker in the containers. He knew from experience that these small loud speakers might contain neodymium, but was not able to verify it visually, and therefore began to dismantle it (pictures 11-1). It turned out not to contain neodymium, however this illustrates one of the problems experienced by waste handlers, namely that it is often difficult to locate components containing rare earth elements and precious metals. This is also the case for components containing hazardous substances that can contaminate the materials and require special treatment. Therefore, the following recommendations can be made:

- Mark components that contain rare earth elements and precious metals and make it easy to disassemble the component.
- Mark components that contain hazardous substances that require special treatment and make it easy to disassemble the component.

How the specific marking system could be made is not further examined in this study. However, it is recommended to make such a marking system in close collaboration with waste handlers.



Picture 11-1: Employee from Averhoff working on disassembling a loudspeaker during the workshop to examine whether it contains neodymium.

Batteries

Batteries need to be removed according to the WEEE Directive because they contain various hazardous substances which need special treatment. Therefore, it has to be easy to both manually remove inbuilt batteries and identify those products containing batteries.

- Make it easy to manually remove inbuilt batteries.
- Mark products that contain batteries.

Information

A general aspect discussed during the workshop was the recyclers' lack of access to information relevant for the recycling and recovery process. Generally, the recyclers lack information from the producers that could help optimise the recycling of the products and the recovery of the materials. This could be in the form of a marking system of the product that would link to a database with information relevant for the recyclers on how to recycle the product and recover the materials in the best possible way. One of the possibilities that has been discussed is the use of radio-frequency identification (RFID). It is not within the scope of this study to give a full account of the information that would be relevant for the recyclers and which solution would be the best. This requires further study and collaboration with the recyclers. However, some recommendations could be made:

Make information easy accessible for the recyclers regarding:

- How to disassemble the product.

- The content and location of hazardous substances, precious metals, rare earth elements and batteries.

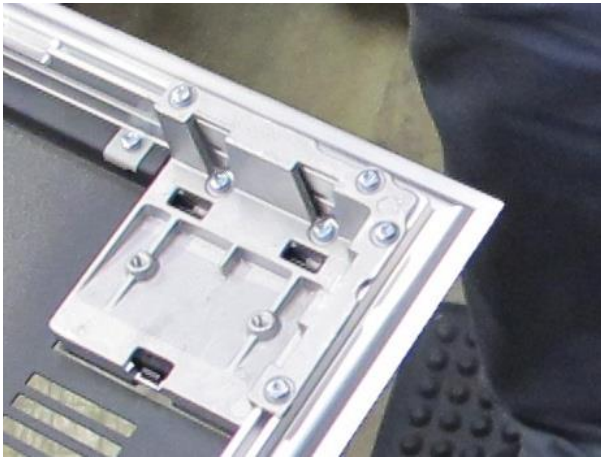
11.4.2 DISASSEMBLY OF THE TELEVISION:

Screws and different slots

The process of separating the television showed that the television is assembled using many screws which have many different slots (picture 11-2). According to the employee from Averhoff, there are around 300 screws in a flat screen television, depending on the producer. This is a problem if the television is to be disassembled manually because it increases the time consumed, making the recycling of the product less profitable. In addition, screws cause problems if the product is disassembled destructively in a shredder because they can contaminate the fractions they are holding together. For example, if a steel screw is used to hold pieces of aluminium together (picture 11-3), it can happen that the aluminium parts break in the shredder while the screw is still attached to the aluminium and thus a part or the whole of the steel screw can contaminate the aluminium fraction. Hence, the use of many screws and many different slots is a problem during manual disassembly and can be a problem during destructive disassembly. Therefore, the following recommendation is made:

- Reduce the number of screws used to assemble the product and, where possible, use the same slots for all screws.

Picture 11-2: A picture of some of the different screwdrivers used to separate the television.

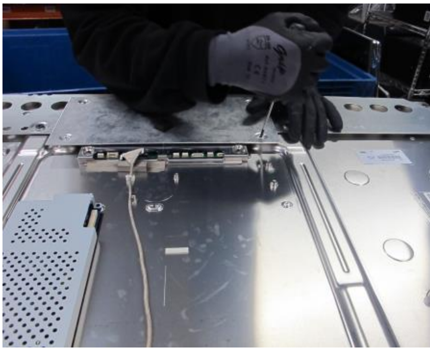


Picture 11-3: A picture of aluminium parts assembled using steel screws.

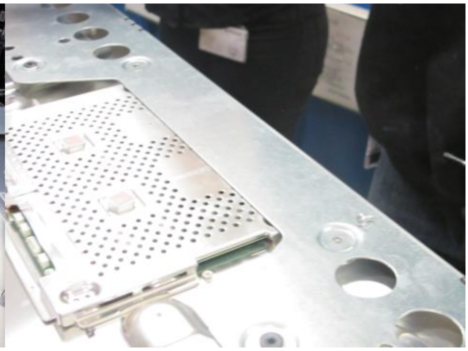
Printed circuit boards

The disassembly of the television also revealed that the manual removal of printed circuit boards is complicated because they were sealed off below several metal plates that were held together with screws (see pictures 11-4 to 11-7). This makes it both difficult and time consuming to remove the printed circuit board manually and without damage, and it is therefore often not cost-effective for the waste treatment facility. Averhoff does not remove the printed circuit boards manually; they end up in the shredder and are then separated afterwards. However, studies have shown that a better recovery of the precious metals in the printed circuit boards can be achieved if the printed circuit boards are disassembled manually and treated separately, avoiding shredding (Chancerel et al. 2009, Chancerel et al. 2011, Cui, Forssberg 2003). Therefore, making the printed circuit boards easily accessible and easy to remove manually could potentially improve the recovery rate of the precious metals in the printed circuit board, especially gold. Furthermore, the reparability of the product may also be improved. One way to improve easy disassembly and the removal of the printed circuit board could be to ensure in the case of this television that the three different metal plates placed on top of the printed circuit board were fastened with the same screws. Thus, if the screws in the first metal plate were removed, then the other metal plates would also be free (see pictures 11-4 to 11-7). A recommendation therefore is:

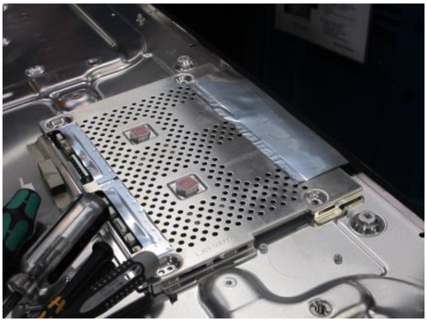
- Make the printed circuit board easy to remove manually during the recycling process to facilitate the better recovery of precious metals in the circuit boards.



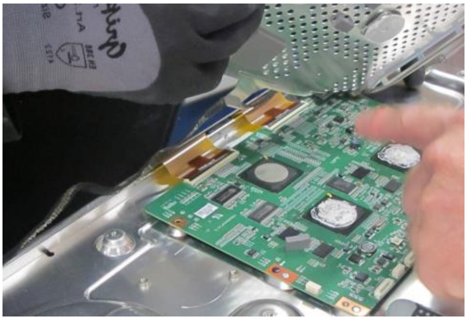
Picture 11-4: Disassembly of the television; the printed circuit board is sealed off by several metal plates held together by screws and it is therefore both time consuming and difficult to remove them manually



Picture 11-5: Same as picture 11-4.



Picture 11-6: Same as picture 11-4.



Picture 11-7: Same as picture 11-4.

Easy disassembly

The disassembly of the television also revealed other issues related to easy disassembly which could be improved. Returning to the example of the casing around the printed circuit board, the different metal plates were assembled in a way that made it necessary to remove the plates one at a time because the plates were covering the screws below. Again, this made it more time consuming and expensive to disassemble the products. This problem is illustrated in picture 11-8, where the top plate covers the screw in the bottom plate, making it more complicated to separate the product. Hence, a recommendation could be:

- Make screws easy accessible and avoid covering them.

Picture 11-8: Screw covered by metal plate, making disassembly difficult.

Recycling of glass in the televisions

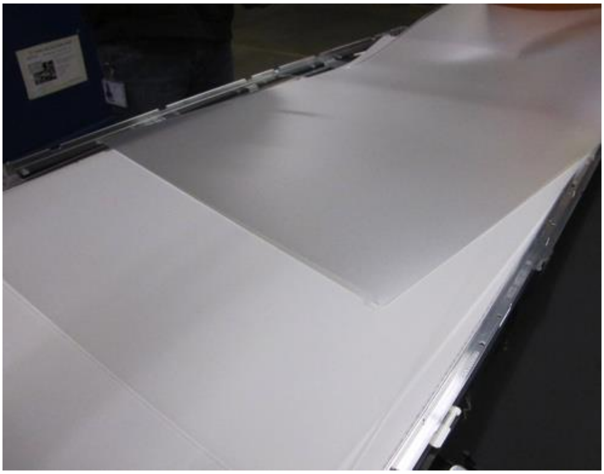
An important aspect of Bang and Olufsen televisions is the glass screen. However, the coating of the glass currently used in conjunction with 3D technology implies that the glass cannot be recycled (picture 11-9).

Picture 11-9: Glass front of B&O's television; this cannot be recycled.

Plastic back screens

Part of the television's flat screen is made of plastic pieces which are used to diffuse the light from the LEDs (see picture 11-10). These plastic pieces are made of acrylic and have a considerable recycling value. In the examined television, these parts of plastic were easy to disassemble and sort into the correct fraction because they were not fixed to anything (e.g. glued together or adhering to other components). Therefore, this was a good ecodesign example and a recommendation is:

- Continue to make the plastic pieces in flat screens easy to disassemble and avoid using glues or other materials that could hinder easy disassembly.

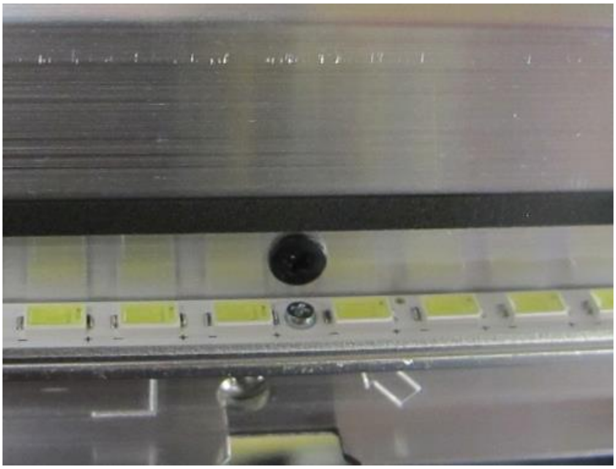


Picture 11-10: Plastic pieces used to diffuse the light from the LEDs.

The use of glue:

The LEDs was fastened with screws and not with glue (picture 11-11). This was emphasised by the waste manager as positive because the glue usually used to fasten the LEDs was under suspicion of causing environmental problems. However, this has not yet been verified. Therefore, a recommendation is:

- Avoid the use of glues that are suspected to cause environmental problems. This could be linked to the REACH classifications.

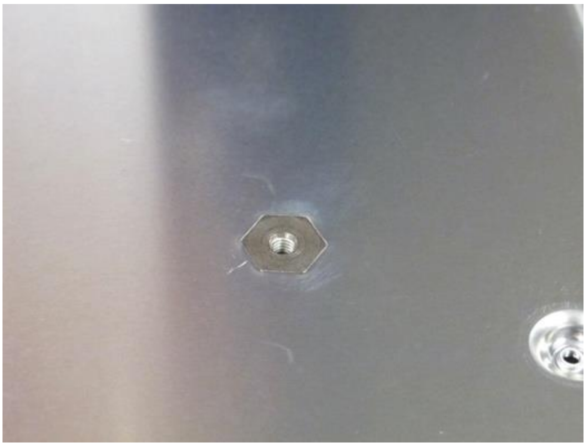


Picture 11-11: LEDs fastened with screws.

Contamination of materials

Another possible design challenge identified was the screw threads made of iron or stainless steel which were embedded in the aluminium elements (see pictures 11-12 and 11-13). The problem with these threads of a different material is that they can contaminate the aluminium fraction in this case. Therefore, a recommendation is:

- Avoid mixing materials, for example the embedding of iron or stainless steel threads in aluminium elements.



Picture 11-12: Screw thread made of iron or stainless steel embedded in aluminium.

Picture 11-13: Screw thread made of iron or stainless steel embedded in aluminium.

11.4.3 REMOTE CONTROL

During the workshop, we worked on separating a remote control. This remote control represents an excellent example of how a product could be designed to facilitate easy disassembly. However, the environmental department had not been involved in the work, and it was not clear whether easy disassembly had been a priority during the design process or whether it was merely fortuitous. The remote control is presented in picture 11-14. On the back of the remote control there was a small hole (picture 11-14), and if a sharp small object was inserted into this hole, it was possible to easily separate the three main components of the remote control. In a small test, it was possible to separate the remote control into its three parts in less than 10 seconds. The three main fractions which the remote control can be separated into are: (1) the aluminium casing, which can go directly into aluminium recycling without any materials contaminating the fraction and is therefore a clean fraction; (2) the components containing the batteries which, according to the WEEE Directive, need to be separated and treated separately because they contain hazardous substances; (3) the components containing the keys and the printed circuit board elements, which also can go into the same recycling process. Hence, the remote control is designed in a way that makes it easy to separate into three main fractions which enter different recycling processes, making the remote control a good example of a product designed for the recycling of the material fractions. Based on the dismantling of the remote control, the following recommendation can be made:

- Make the product easy to dismantle into material fractions that require the same recycling process. This can increase the value of the different fractions.

Picture 11-14: The remote control and its disassembly.

11.4.4 LOUDSPEAKER

Easy disassembly

The disassembly of the front of the loudspeaker (picture 11-15 and 11-16) was a time consuming process because it was assembled using approximately 30 screws with different slots. Furthermore, some screws were submerged in the plastic front, making them difficult to remove (see pictures 11-17 and 11-18). As it takes too much time to disassemble the loudspeaker, it is not separated manually at the waste treatment facility unless there are components within it which need to be removed according to the WEEE Directive. Instead, the product more or less directly enters the destructive and automated separating processes. As mentioned previously, different studies have shown that a better recovery of the precious metals in printed circuit boards, for example, could be achieved if they were separated before the product enters the more automatized and destructive processes (Chancerel et al. 2011). Hence, if it were easier to separate those components that need different recovery processes, a better recovery of the materials could be achieved. Moreover, it was difficult to determine which components to separate in order to dismantle the product or remove certain components. To address this concern, a marking system, such as arrows, could be used to indicate which parts, such as screws, to remove. Therefore, the following recommendations can be made:

- Make the product easy to disassemble so that printed circuit boards or other components that need special treatment can be removed before the products are dismantled destructively.
- Reduce the number of screws.
- Use screws with the same slots.
- Make the screws easily accessible.
- Use a marking system to make it easy to determine which screws to remove to disassemble the product or component.

Contamination of the plastic or metal fractions

The fact that the screws were submerged in the plastic front or enclosed in plastic (see pictures 11-17 to 11-19) may also result in the screws not being separated from the plastic fractions during the destructive disassembly process. Hence, the screws could end up in the plastic fraction and contaminate it, decreasing its value. Or the plastic could end up in the metal fraction by being stuck to the screws, and thus contaminate the metal fraction, decreasing its value. The following recommendation can be made:

- When using metal screws to assemble plastic parts, design these assemblies in such a way that the plastic and screws are separated during the destructive disassembly process, such as by avoiding having screws submerged or enclosed in plastic.

Contamination of the recyclable fractions by the soundproofing material in the loudspeaker

A problematic fraction for the recyclers when disassembling loudspeakers using destructive and automatic processes can be the soundproofing materials used in loudspeakers. In this case, some sort of foam made of plastic was used (see picture 11-20). When this type of material enters the destructive disassembly process, it disintegrates and small bits of the foam end up in all the other fractions and contaminate them, decreasing their value. However, foam made of plastic is not the only soundproofing material that can cause problems for the automatic and destructive disassembly processes; other soundproofing materials cause similar problems. Therefore, the following recommendation can be made.

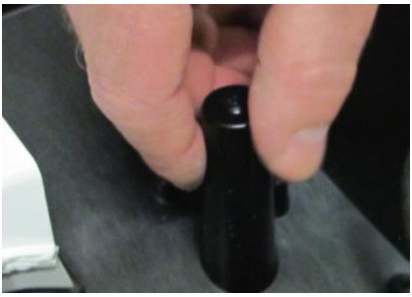
- Avoid soundproofing materials that disintegrate during destructive and automatic disassembly and thus contaminate the other fractions; or make these very easy to remove beforehand.

Picture 11-15: Picture 17: The loudspeaker before disassembly (Recordere 2015).

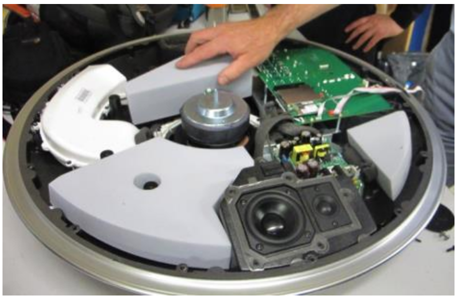
Picture 11-16: The loudspeaker before disassembly

Picture 11-17: Screw submerged in plastic.

Picture 11-18: Screw submerged in plastic.



Picture 11-19: Screw enclosed in plastic.



Picture 11-20: The soundproofing material found in the loudspeaker.

11.5 DID THE WORKSHOP FACILITATE THE KNOWLEDGE TRANSLATION AND EXCHANGE?

The actual design of the workshop resulted in a different set-up than was initially intended. Figure 11-2 provides an overview of both the proposed and the actual process. The proposed workshop included an introduction to circular economy, ecodesign and the treatment of WEEE. This was followed by an event where the participants were to dismantle three B&O products, namely a television, a loud speaker and a remote control. Finally, the participants were to collaboratively develop design recommendations for future product development. The participants included the environmental consultant (2013-2016) from B&O, the manager of product and service from B&O, design engineers from B&O, a representative from the waste treatment section, and a researcher from Aalborg University. However, the actual process was downscaled due to changes in the staff at B&O. This included a small reduction in the program and the fact that the design engineers were not engaged in the workshop. Thus the design recommendations were developed by a researcher from Aalborg University based on recordings and pictures from the workshop. It was then the responsibility of the environmental consultant (2013-2016) at B&O to incorporate the learning from the workshop into product development. One of the projects developed after the workshop was the screw product, which was implemented into SAP (System Application and Products). SAP is a software that can be used to manage among other things production operations and materials and customer relations. However, the project was discontinued before it was finalised. Despite the downsizing of the workshop, it did help to translate and disseminate knowledge between the waste managers and B&O.

The knowledge dissemination began prior to the workshop. It was evident from the interviews leading up to the workshop that knowledge on the disassembly and recyclability of B&O's products was already embedded within the organisation. The manager of technical product service at B&O was responsible for the disassembly and recycling of their prototypes and he therefore had extensive knowledge of the challenges faced when dismantling and recycling their products. The environmental consultant (1999-2013) and the manager of technical product service had not previously exchanged knowledge on this issue. However, the environmental consultant (1999-2013) participated in the interview we conducted with the manager of technical product service and thus became aware of the existing knowledge embedded within the organisation. This was the first step in breaking down the knowledge boundaries and exchanging knowledge within the organisation. However, the manager of technical product service did not have any knowledge on the recycling process the product undergoes after they leave B&O's facilities. Therefore, it was still important to involve the recycling sector.

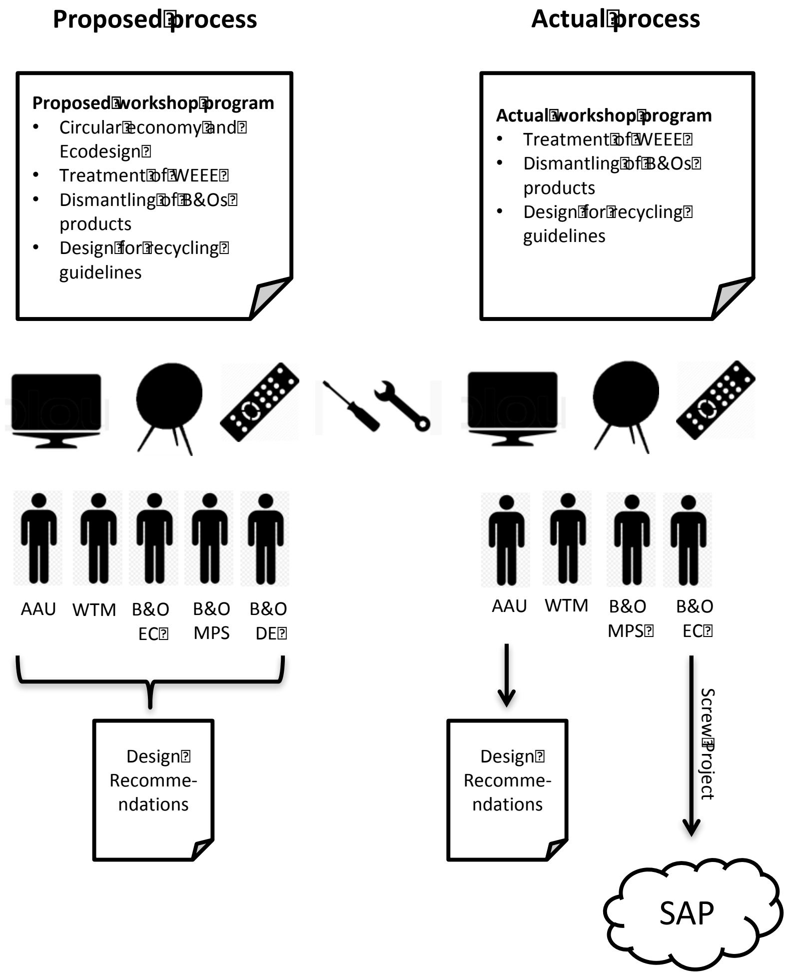


Figure 11-2: Overview of the proposed processes and the actual process at B&O. Abbreviations: Aalborg University (AAU), Waste Treatment Manager (WTM), Environmental (2013-2016) (EC) at B&O, Manager Technical Product Service (MTS) at B&O and the Design Engineers (DE) at B&O.

The first part of the workshop, where the representative from the waste treatment sector presented the electrical and electronic waste treatment processes, worked well towards creating a shared knowledge basis. It helped overcome some of the semantic knowledge boundaries which are present when the actors are from different fields. The waste manager included and brought with him B&O products which had previously caused problems in their operations. The two objects were a counterweight, which B&O had incorporated in their old televisions, and isolation material from their old loudspeakers, which if not removed would damage the machinery at the waste treatment facility. These objects, in combination with the presentation of the waste treatment processes, made it possible for B&O to learn about the problems their products tend to cause for the recycling operations, thereby giving them access to the domain-specific knowledge of the waste treatment sector. At the same time, it illustrated to B&O the problem as well as their role in creating the problem.

In the second part of the workshop, we disassembled three B&O prototypes while discussing the various problems the design of the products may cause for the recycling operations. This practical dimension, whereby we worked together to separate the products, helped illustrate problems which may otherwise have been difficult to comprehend. The disassembly of the prototypes facilitated a dialogue whereby the waste manager was able to explain the problems caused by a certain design solution, and the representatives from B&O could explain why they had made that particular design (if they knew). Based on this, a negotiation of what could be done differently was initiated, developing new knowledge in the form of design requirements. Hence, the practical disassembly worked as an effective boundary object because it helped establish a shared language, gave the actors the possibility to learn and share their context specific knowledge, and finally helped transform the knowledge into design recommendations. However, it should be acknowledged that the degree of novelty for the participants in the actual workshop was lower than it would have been in the original workshop set-up, whereby the design engineers should have been included.

What did not work that well in the workshop was the composition of the participants. It was the intention in the proposed set-up of the workshop that the design engineer should be included in the process, thus making it possible to start a process of negotiation and the translation of knowledge from the waste treatment sector and the design engineers into a shared new knowledge in the form of design requirements. However, the design engineers were not included in the actual set-up of the workshop. This presented some challenges during the dismantling of the products because we came across design solutions which the representatives from B&O could not explain. An example was during the disassembly of the television. The printed circuit board in the television was covered by several metal plates which were screwed together with different types of screws. However, the environmental consultant (2013-2016) did not know why this design was chosen and whether it was due to safety issues. The knowledge from the design engineers or from other representatives from product development was missing in the discussions. Therefore, it would have been beneficial if employees from different departments at B&O working with product development had had the possibility to participate to ensure that their knowledge came into play during the discussions and that they took part in the negotiation and transformation of the new knowledge into design requirements. It also had a large influence on knowledge dissemination within the organisation afterwards. It was the initial idea that the new knowledge produced during the workshop would be embedded amongst the participants, and that the design engineers would be able to apply this new knowledge when designing new products. The intension was to develop a physical design guideline, however the participants were to play an important role in spreading the knowledge to the rest of the organisation, thus working as knowledge brokers. This was significantly changed with the new workshop set-up. In this set-up, the environmental consultant (2013-2016) was responsible for translating the knowledge to the rest of the organisation. She was to facilitate the implementation through her role in product development and by setting up new projects acting as a knowledge broker.

11.5.1 THE SCREW PROJECT

One of the new projects initiated by the environmental consultant (2013-2016) after the workshop was the screw project. An issue highlighted during the disassembly of the television and the loudspeaker was the many screws with various slots used to assemble the products. These screws with different slots made manual dismantling difficult and time consuming for the recyclers. Therefore, it was likely that the products went directly to automatic and destructive disassembly, unless some components needed to be removed due to legislative requirements or for safety reasons. However, the recycling of certain factions could be improved if separation of the different components were to be increased before they are separated destructively(Chancerel et al. 2011). Therefore, the environmental consultant (2013-2016) initiated a project to reduce the numbers of different screws with different slots used in the products (Environmental Consultant 2016b). The purpose of the project was to reduce their broad span of screws and to avoid the need for special B&O screws, which were both costly and time consuming to remove. The project was to support the design engineers in selecting standard screws. The system was set up in SAP, a software used in B&O to share and access knowledge. The SAP system had a preference indicator which makes it possible for the design engineer to select the most commonly used screws. The idea was to measure how many standard screws were used in a specific product and then, in the future, to set up specific goals regarding the numbers of different screws used in a product. However, the environmental consultant (2013-2016) terminated the project before it was fully implemented for two reasons. Firstly, these types of projects are in fact within the remit of the value engineers and those making the platforms. Secondly, she faced resistance from the design engineers. As expressed in the interview with the environmental consultant (2013-2016),

> "The designers [design engineers] are creative people who do not really think it is fair that they have to work within certain limits. I can understand that. However, when they are paid to do a job, they also need to keep within the limits laid down. Then there is also the natural and fundamental reluctance towards change. But, it is also fun to experience

> this issue with the designers' freedom - I think." (Environmental Consultant 2016b)

This resistance from the design engineers might have several explanations. Firstly, there is a strong design culture within B&O and the designers have had a strong position within the organisation. In contrast, the environment has not enjoyed as strong a position within the organisation as the designers. Secondly, the resistance could also partly be explained by the way the changes were implemented within the organisation. The new system to reduce the number of different screws used in B&O products sets restrictions for the design engineers. The design engineers, on the other hand, want to keep their design freedom. Hence, there is a conflict of interest between the design engineers and the environmental consultant (2013-2016). Combined with a high degree of novelty, it is very likely that a pragmatic knowledge boundary exists. The changes were implemented through SAP, a software used in B&O to share knowledge across the organisation. Therefore, in this case SAP should work as a boundary object translating knowledge from the environmental consultant (2013-2016) to the design engineers. SAP is a boundary object belonging to the group standardized forms and methods, which is applicable when faced with a semantic knowledge boundary. This type of boundary object is well suited to the representation and learning of new knowledge. However in this case, the environmental consultant (2013-2016) was faced with a pragmatic boundary because there was a conflict of interests. Therefore, she needed a process of translation and negotiation. Because the design engineers were not included in the workshop, they did not take part in the translation and negotiation of the new knowledge provided by the recycler. Therefore, they did not learn why these design changes were important nor did they have the chance to explain why, for instance, the large variety of screws was important. Hence, the process of translation and negotiation of the new knowledge between the design engineers, the environmental consultant (2013-2016) and the recyclers was not initiated and this might be part of the reason for the resistance by the design engineers towards the new knowledge.

11.6 SUB-CONCLUSION

11.6.1 MITIGATING KNOWLEDGE BOUNDARIES

There exists a knowledge gap between B&O and the recyclers of electrical and electronic equipment. The producers do not know how they could design their product differently to improve recyclability and the recyclers are not experiencing any interest from the producers regarding how to access this knowledge. Therefore, the objectives of the workshop at B&O was firstly to examine how B&O could practically improve the recyclability of their products and secondly to examine how to facilitate a knowledge translation between the recyclers and B&O.

The proposed design of the workshop was not fully tested as the design engineers were not included. Nevertheless, it can be concluded that the workshop did manage to facilitate a knowledge translation between the recyclers and B&O, overcoming both semantic and pragmatic knowledge boundaries. The introduction to the recycling processes and the B&O products that are problematic for the recycling processes, which the recycler included in the introduction, created a shared knowledge base and made the problems caused by their products evident to B&O. Thus, the introduction helped break down the syntactic and semantic knowledge boundaries.

The disassembly of the prototypes worked as an effective boundary object facilitating the negotiation and transformation of the knowledge of the recyclers and the producers. However, the exclusion of the design engineers in the workshop had negative implications for the workshop as their knowledge was missing during the discussions, making it more difficult to understand some of the design solutions and how these could be changed. Furthermore, it had implications for the subsequent knowledge dissemination. Instead of the design engineers working as knowledge brokers in future design processes, it was the responsibility of the environmental consultant (2013-2016) to ensure that this was introduced into product development.

The possible consequence was illustrated in the screw project which the environmental consultant (2013-2016) developed after the workshop. The purpose of the project was to encourage the designers to used standards screws, thus reducing the numbers of different screws used in their products. When trying to implement the project into SAP software, she faced resistance from the design engineers because they did not want to have their design freedom restricted. The design engineers had not been part of the workshop, and had therefore not taken part in the translation and transformation of the knowledge of the recyclers into design requirements. Therefore, the environmental consultant (2013-2016) faced a new pragmatic knowledge boundary when trying to impose the new design requirements onto the design engineers. She used SAP software to implement the design requirements across the organisation by identifying standard screws in SAP. The design engineers were to then preferentially use these screws. The SAP software is a boundary object that is relevant when faced with a semantic knowledge boundary. However, in this case she faced a pragmatic knowledge boundary due to the conflict of interest. The design engineers wanted design freedom and the environmental consultant (2013-2016) wanted the designers to use standard screws. Thus there was a conflict of interest between the design engineers and the environmental consultant (2013-2016). Therefore, a recommendation for future workshops is to include those actors who might be affected by the new knowledge to ensure that they participate in the negotiations and translation of knowledge.

11.6.2 THE DESIGN FOR RECYCLING RECOMMENDATIONS

Besides testing the workshop design, the workshop also resulted in specific design recommendations which B&O could implement in their product development. The design recommendations are listed in table 11-2. In chapter 2 and appendix A, generic ecodesign recommendations for closing the loops were identified in the Ecodesign Pilot, the ECMA 341 Standard and in Ijomah et al. (2007a). Here, designs for recycling and design disassembly were identified as relevant strategies to improve the recyclability of products. In table 11-2, a comparison is made of the specific recommendations identified in the case study and the generic ecodesign recommendations.

The comparison reveals that many of the design recommendations found in the case study already existed in the guidelines. Six of the fifteen recommendations from the workshop were already covered by the guidelines. Seven of the fifteen recommendations from the workshop were partly covered by the existing recommendations, but the recommendations from the workshop were more detailed and/or product specific compared to those found in the existing guidelines. Two recommendations were identified in the workshop which were not covered by the existing guidelines.

The recommendations from the workshop which were more detailed was marking components containing rare earth elements, whereby the generic ecodesign recommendation simply requires the simple extraction of valuable substances to be ensured. According to the recycler, rare earth elements are difficult to extract because they are found in the products in small amounts and because their recovery can be destroyed during pre-processing (Workshop B&O 2014). Therefore, a specific focus on rare earth elements in the product specific recycling recommendations is necessary. A recommendation from the workshop was also to mark components containing hazardous substances, whereas the guidelines propose the provision of this information in the disassembly plan. However, direct marking using RFID or a similar concept would ease the recycling process compared to locating the information in disassembly plans, especially when the recycler treats many different types of products from many different producers.

The workshop also suggested facilitating the easy removal of components that need special waste treatment, whereas the guidelines suggest the disassembly down to module level and to enable a possible separation of materials for recycling. This further detailing of the recommendation in the case study is important for the recycling process because a module can comprise parts requiring different recovery processes, or several modules could enter the same recovery process. In the workshop, a marking system for the product was also suggested, making it easier to locate those screws that need to be detached to dismantle the different components. This was also a more detailed recommendation compared to those found in the guidelines on how to avoid the contamination of the iron fractions with plastic, whereby it was also more detailed than the existing guidelines in providing a specific suggestion regarding what to avoid.

Two recommendations were also identified in the workshop which were not found in the existing ecodesign guidelines. One was the recommendation to avoid embedding iron or stainless steel threads in aluminium elements. If the recovered aluminium contains more than 2% impurities, then the price decreases as it is no longer considered to be pure aluminium (Workshop B&O 2014). This recommendation is mainly relevant in the automatic and destructive recycling process. The other recommendation was to avoid soundproofing materials that disintegrate during the destructive and automatic disassembly and contaminate the other fractions, or to make these very easy to remove beforehand. This is a product specific recommendation mainly relevant when designing loudspeakers. It is, however, a relevant recommendation as the material can potentially contaminate a lot of recovered materials.

Recommendations from the case study	**Covered**	**Generic ecodesign recommendations**
Mark components that contain rare earth elements and precious metals and make it easy to disassemble the component.	Partly (MD)	Ensure simple extraction of harmful and valuable substances (Ecodesign Pilot).
Mark components containing hazardous substances that require special treatment and make it easy to disassemble the component.	Partly (MD)	Ensure simple extraction of harmful and valuable substances (Ecodesign Pilot). Make disassembly plans that include information on disassembly, identification of potentially valuable and/or reusable parts, identification of parts containing hazardous substances and special handling and disposal precautions. (ECMA)

Mark products that contain batteries.	Yes	Batteries should be easy to identify and remove (ECMA).
Information on how to disassemble the product.	Yes	Make disassembly plans that include information on disassembly, identification of potentially valuable and/or reusable parts, identification of parts containing hazardous substances and special handling and disposal precautions (ECMA).
Information on the content and location of hazardous substances, precious metals, rare earth elements and batteries.	Yes	Information on batteries should be made available (ECMA). Make disassembly plans that include information on disassembly, identification of potentially valuable and/or reusable parts, identification of parts containing hazardous substances and special handling and disposal precautions (ECMA).
Make the product easy to disassemble to facilitate the easy removal of components that need special treatment, such as printed circuit boards, batteries and components containing hazardous substances, before the products are dismantled destructively.	Partly (MD)	Disassembly down to the module level (e.g. power supply, disk drive, circuit board) shall be possible using commonly available tools and all such parts shall be accessible (ECMA). Make possible separation of materials for recycling (Ecodesign Pilot).
Reduce the number of screws used to assemble the product and where possible use the same slots for all screws.	Yes	Reduce the number and variety of connections (e.g. fastener and screws) (ECMA).
Make screws easy accessible and avoid covering them.	Yes	Ensure easy access to connecting parts for disassembling tools (Ecodesign Pilot).
Make the plastic pieces used to diffuse the LED light in flat screens easy to disassemble and avoid using glues or other materials that could hinder easy disassembly.	Partly (PS)	Make possible the separation of materials for recycling (Ecodesign Pilot).
Make the product easy to dismantle into material fractions that require the same recycling process.	Yes	Make possible the separation of materials for recycling (Ecodesign Pilot).
Use a marking system to make it easy to determine which screw to	Partly (MD)	Use easily detachable connections (Ecodesign Pilot).

remove to disassemble the product or certain components.		Ensure easily visible access to connections for disassembly (Ecodesign Pilot).
Avoid the use of glues that are suspected of causing environmental problems.	Partly (MD)	Avoid raw materials and components of problematic origin (Ecodesign Pilot). Avoid or reduce the use of toxic materials and components (Ecodesign Pilot). Limitations to chemical content (ECMA).
Avoid embedding iron or stainless steel threads in aluminium elements.	No	
When using metal screws to assembly plastic parts, design these assemblies in a way that the plastic and screws are separated during the destructive disassembly process by e.g. avoiding submerged or enclosed screws in plastic.	Partly (MD)	Avoid the use of metal inserts in plastic parts (unless easily removable with common tools) ECMA
Avoid soundproofing materials that disintegrate during the destructive and automatic disassembly and contaminate the other fractions, or make is very easy to remove these beforehand.	No (PS) Loudspeaker	

Table 11-2: Comparison between the recommendations found during the workshop and the recommendations from the existing guidelines in appendix A. PS: product specific. The colon in the middle indicates whether the recommendation was covered by the existing guidelines. MD: more detailed than the one found in the guidelines.

Based on this comparison, it can be concluded that the existing guidelines include many relevant recommendations. However, the workshop also provided a number of more detailed recommendations on how to design electrical and electronic equipment for improved recyclability as well as two new recommendations. The workshop therefore succeeded in creating more detailed and product specific recommendations on how the company could design their products for improved recyclability. As mentioned in section 2.2.2, specific ecodesign guidelines have been identified as a success factor when implementing ecodesign into companies. Hence, this specification of the more generic ecodesign guidelines is important and the workshop succeeded in creating more detailed company specific guidelines than those found in the literature.

CHAPTER 12 BARRIERS AND DRIVERS FOR CIRCULAR ECONOMY IN B&O

The following section discusses the barriers and drivers in B&O's work with closing the loops in the circular economy based on the three previous chapters and the barriers and success factors identified in chapter 2 on the integration of ecodesign into companies.

12.1 LUXURY, QUALITY AND DESIGN AS THE DRIVER

The mapping of B&O's environmental activities revealed that they had a number of activities and product attributes which could help close the material loops in the circular economy. A further scrutiny of these activities revealed that they were not driven by a deliberate environmental strategy or because B&O had developed a circular business model. Instead, these activities and product attributes were a result of their focus on design and quality when producing their luxury core products. B&O's focus on design and quality and their image as a luxury brand are rooted in their history. Their first official slogan was "*Bang and Olufsen - the Danish Hallmark of Quality*" (Krause-Jensen 2013: 90) and their focus on design began during the 1960s. Hence, their primary selling point for their core products has been and still is design and quality. Furthermore, designers have had a central position in the organisation. This image as a producer of luxury products was established during the 1980s. Hence, these aspects of quality, design and luxury products are values that are deeply integrated into B&O.

Links between the core characteristics of luxury products and how consumers perceive luxury products and the circular economy were identified in chapter 10 and include high quality, durability, service schemes, extended warranties and large aftermarkets. These links were also evident in the case of B&O. B&O's activities and their product attributes, such as a long lifespan, extended warranties, repair and service schemes, spare parts availability for eight years, aftermarkets and leasing schemes, were driven by their desire to produce products with a high level of quality. B&O core products are exclusive luxury objects, and therefore a certain quality is expected by the purchaser of the products. Hence, B&O's activities in the inner loops in the circular economy were driven by the fact that they produce luxury products with a high level of quality. These conclusions are however only applicable for their luxury core products. The B&O BeoPlay series represents another category of products targeting another price level and a broader consumer group. The design and quality dimensions are still important elements for B&O in the BeoPlay products. However, these are not luxury products in the way that their core products are. The study has not examined whether the BeoPlay series has the same qualities as the more expensive luxury products in their core series.

12.2 MANAGEMENT COMMITMENT

One of the factors identified in the review by Boks (2006) as being important for the dissemination of ecodesign into an organisation is management commitment and support. Quality and design are the core values of B&O and these aspects have management commitment and support. Therefore, the circular activities, which are related to these aspects of a timeless design, longevity, quality and reparability, also have management commitment and support because they are related to the core values of the company. It is therefore a driver of these activities and product attributes. Environmental aspects in B&O have in general always been considered as something embedded within the quality of the product, but not as a parameter they can use to differentiate themselves from their competitors (Environmental Consultant 2013). Consequently, the circular aspects and those product attributes which are not driven by quality, design and luxury do not have the same commitment from management as those related to the core values of the company. This includes aspects in the outer circles in the circular economy such as their negative list, the marking of plastics, dismantling tests, and the reuse and remanufacturing of components.

12.3 SPECIFIC ECODESIGN GUIDELINES

Another factor important for the integration of ecodesign into companies identified by the review by Boks (2006) was the existence of specific ecodesign tools and guidelines. The purpose of the workshop at B&O was precisely to develop company specific ecodesign guidelines targeting the improved recyclability of their product. The workshop succeeded in creating specific design recommendations, but the actual implementation of these design recommendations was limited. Evidently, it is not enough to develop a company specific guideline, it also needs to be implemented into the standard working procedures of the company. The environmental consultant (2013-2016) did try to incorporate some of the recommendations developed during the workshop into B&O's SAP system in the screw projects. The purpose of the screw project was to support the design engineers in selecting standard screws, and the system was set up in SAP, a software used in B&O across the different departments to exchange knowledge. However, she faced resistance from the design engineers, although this resistance might have been reduced if the design engineers had been included in the workshop and had participated in creating the new knowledge.

12.4 ENVIRONMENTAL VISIONS AND GOALS

One barrier identified by Boks (2006) is the lack of vision and goals regarding the product environment. As presented in the article in chapter 10, B&O has previously had several visions, goals and activities related to the product environment. In previous CSR reports, they have had sustainable design as a topic in their CSR activities and objectives (Bang & Olufsen 2014). As outlined in the article, they have also conducted several activities in relation to the product environment, including the marking of plastics, dismantling tests and a negative list. However, many of these requirements have over the years been included in the European product regulation, and newer, more progressive product requirements have not been developed. This also implies that B&O today have very few environmental product requirements which go beyond legal compliance (Huulgaard 2015, Environmental Consultant 2016b). According to Huulgaard (2015) they have a few chemical requirements which go beyond legal compliance. However, because the list of restricted substances in the RoHS Directive has been expanded, these chemical requirements might also be included in the regulation (European Commission 2015d).

In B&O's CSR report for 2016, they have included product environment in one of their focus areas under environment climate, whereby they aim to "*prevent negative environmental and climate impact from use of products as well as maintain high focus on developing sustainable products*" (Bang & Olufsen 2016c: 10). However, no activities were included in the CSR report regarding product environment (Bang & Olufsen 2016c). Therefore, in 2016 environmental product requirements for B&O products are mainly requirements to ensure legal compliance. With the recent reorganisation of B&O, the quality department will still ensure that the products follow the legal requirements, also in relation to product environment, while the individual business units can choose to implement environmental aspects beyond legal compliance. The fact that B&O has not identified activities to achieve their environmental visions and goals can prove a barrier to reaching these. Therefore, this can also prove to be a barrier for further developing B&O's circular activities in the outer circles, which are driven by an environmental agenda such as the marking of plastics, dismantling tests and B&O's negative list.

12.5 NO MARKET DEMAND

The literature review of sustainable luxury consumption has suggested that the consumers of luxury products are becoming increasingly aware of and concerned about sustainability. However, so far this is not something that B&O has experienced, as expressed by the environmental consultant (1999-2013),

> "At the end of the day there is no customer who demands it (environmental aspects) and we can sell more products by being green. It will not sell more loudspeakers."(Environmental Consultant 2013)

Thus B&O is not experiencing any demand from the market for greener products. A lack of demand from the market was also identified in the review by Boks (2006) as one of the important barriers to the integration of ecodesign in companies. This also has implications for the integration of aspects in relation to closing the material loops, which is not related to the dimension of luxury and quality but is driven by an environmental agenda. This includes amongst others the recyclability of their products, which was the focus point of the workshop. Improving the recyclability of products will not increase sales because it is not linked to design and quality, which differentiate them from the competitors. Hence, a lack of market demand for sustainable luxury products can be a barrier to the integration of circular activities and circular product attributes in B&O driven by an environmental agenda.

CHAPTER 13 TIER1ASSET - DESIGNING FOR RECONDITIONING

The reconditioning and resale of electrical and electronic equipment is important to ensure multiple life cycles of a product, thereby prolonging its total use time. Many electrical and electronic products are replaced even though they are still funtional, such as up to 60% of discarded flat sceen televisions (Prakash et al. 2015). Thus there is a great potential for the reconditioning and remanufacutring of electrical and electronic equipment for reuse and resale. This chapter presents a case study of Tier1Asset, a reconditioner of computers, smartphones and tablets. The following research question will be answered,

> Which non-technical and design barriers are Tier1Asset facing when reconditioning computers?

Based on these design barriers, recommendations are proposed to improve the reconditioning of computers. Subsequently, these design recommendations are discussed in relation to the design recommendations identified in chapter 2 and appendix A, and the non-technical barriers are discussed in relation to non-technical barriers identified in the literature. Reconditioning was defined in chapter 2 as "*the process of returning a used product to a satisfactory working condition inferior to the original specifications*" (Ijomah, Childe 2004, 8). Typically, the warranty of a reconditioned product is also less than that of a new product (Prakash et al. 2015). Reconditioning requires less work than remanufacturing, but it includes many of the same steps such as sorting, inspection, disassembly, cleaning, reprocessing and reassembly, the replacement of components and final testing (Hatcher et al. 2011). Tier1Asset mainly replaces components, makes cosmetic changes and performs data erasure. The amount of actual repairs is limited. Therefore, the design challenges identified will mainly relate to replacing components and cosmetic changes. The chapter starts with a description of the methods applied and an introduction to the case company and their main processes. It is followed by a description of some of the non-technical Tier1Asset is facing and of the design challenges they are facing in their operations. Finally, suggestions are made for how the products' reconditioning potential can be improved, and these are later discussed in relation to the design recommendations for remanufacturing identified in appendix A.

13.1 RESEARCH DESIGN AND METHOD

The study was designed as a single case study of the company Tier1Asset. Case studies enable the researcher to make an in-depth study of the research object and thereby gain a profound understanding of the object (Flyvbjerg 2006). Case study research also makes it possible to study a phenomenon in society on its own terms

(Flyvbjerg 2006). According to Flyvbjerg (2006), whether or not you can generalise based on one or a few case studies depends on how the case study is selected. The Tier1Asset case study was selected as an information-oriented sample (Flyvbjerg 2006). It implies that the case was selected to gain the most information from the single case study (Flyvbjerg 2006). Computers are a product category categorised by a high turnover of devices due to the short innovation cycles of the hardware (Robinson 2009). It is therefore a product group more difficult to recondition and resell than, for example, household washing machines or pumps. Consumer electronics is also a technically complex product category. The case can therefore be considered an extreme or deviant case according to Flyvbjerg's (2006) definitions. The purpose of an extreme or deviant case is *"to obtain information on unusual cases, which can be especially problematic or especially good in a more closely defined sense"* (Flyvbjerg 2006: 230). Thus Tier1Asset reconditions computers, a category more prone to technical obsolescence as well as being a complex product category. Therefore, reconditioning can be especially problematic. It could be expected that the non-technical barriers and design barriers identified in this case study might be more comprehensive than when examining the reconditioning of a less complex product category which is less prone to technological obsolescence. There are some limitations to the comprehensiveness of the case study. Tier1Asset mainly performs the replacement of components, data deletions and cosmetic changes. Therefore, all the design barriers and non-technical barriers in relation to repair are not fully illustrated in this case study.

13.1.1 QUALITATIVE RESEARCH INTERVIEWS

The main method applied for the collection of information was qualitative research interviews with employees from Tier1Asset. Table 13-1 provides an overview of the interviews conducted along with the purpose of the interview, the format and documentation. In the study, I have used Steiner Kvale's (1996) understanding of qualitative research interviews as a site of knowledge creation through the interaction between the interviewer and interviewee and his seven-stage model of interviewing. Kvale proposes seven stages when preparing, conducting and treating interviews and these steps include thematizing, design, interviewing, transcribing, analysing, verifying and reporting. All interviews were semi-structured. An interview guide was prepared for all interviews and included the purpose of the interview, teams and the specific questions, however the interviewers were free to deviate from them during the interviews. All the interviews were conducted by me in collaboration with a colleague and were recorded. Afterwards, the interviews were transcribed and analysed. The knowledge obtained was sent for verification by the head of operations.

The process started with a meeting with the head of operations, where the project was introduced and discussed. This was followed by a presentation by the company and a guided tour of the facility. This provided a good insight into the company, their operations and business plan. It was followed by qualitative research interviews with key employees from all major process steps at Tier1Asset to identify the main aspects that had an impact on the reconditioning of the product and its reuse and resell potential. A specific focus was on the design challenges that Tier1Assset experiences when they recondition the used products. In total, six employees were interviewed.

Interviewees	**Purpose**	**Documentation**
Two employees from production working with cleaning and changing components	To map their experience with reconditioning and possible design improvements.	Recorded and transcribed
Employee responsible for the grading of the products	To map their experience with reconditioning and possible design improvements.	Recorded and transcribed
Employee from service working with the repair of sold products	To map their experience with reconditioning and possible design improvements.	Recorded and transcribed
Employee responsible for software	To map their experience with reconditioning and possible design improvements.	Recorded and transcribed
Head of operations	To gain a detailed understanding of the business model and to identify success factors and barriers	Recorded and transcribed

Table 13-1: Overview of the interviews performed at Tier1Asset.

13.2 INTRODUCTION TO THE CASE COMPANY

Tier1Asset is located in Allerød in Denmark and has around 50 employees. Tier1Asset buys used information and communication equipment from private companies, public institutions and schools, for example. They then recondition it and resell it to new customers (see figure 13-1). They recondition up to 600 units a day. They also resell excess spare parts from defect products or spare parts removed from the functioning products to customise them (Tier1Asset 2014c). The company was established in 1999 and their main activity at the time was selling spare parts for IT equipment. From there they began to focus on data deletion, because they found that there was a market for this service.

Tier1Asset buys products from larger companies or organisations because they typically have products of a higher quality and in larger quantities (Tier1Asset 2014c). According to them, it is difficult to achieve a viable business from reconditioning consumer market products due to their lower quality and because they cannot obtain large enough quantities of the same brands and same models

(Tier1Asset 2014c). The supply of used equipment depends on when the producers release new models because that is when large companies and organisations typically change their equipment (Tier1Asset 2014c).

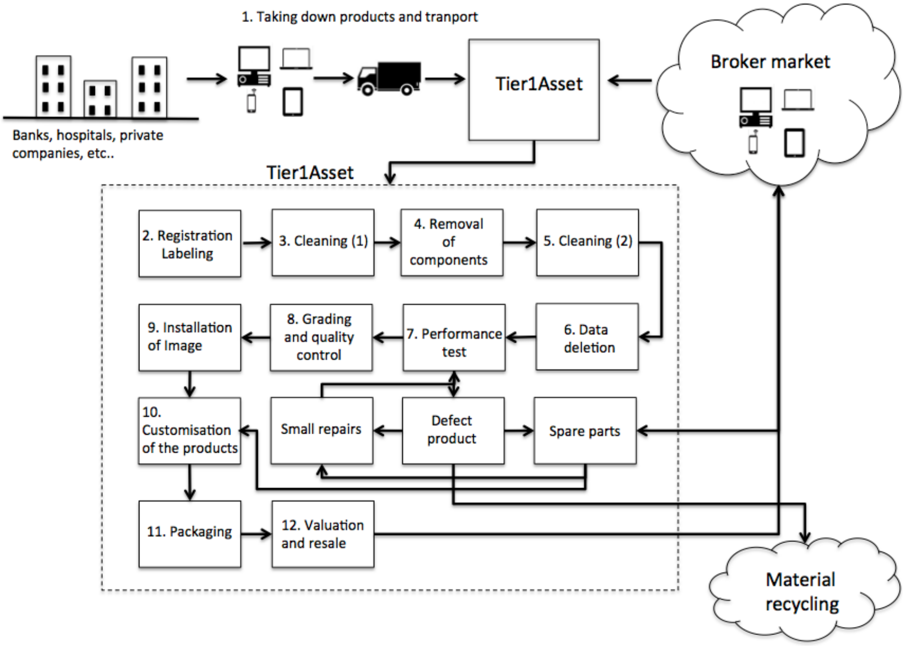


Figure 13-1: Overview of the processes at Tier1Asset, based on (Tier1Asset 2014c, Tier1Asset 2015b).

They recondition desktops, laptops, screens, servers, smartphones, tablets and printers (Tier1Asset 2014c). Printers cause some difficulties because they break down if they are not used over a three-month period. Furthermore, Tier1Asset finds it difficult to resell the printers (Tier1Asset 2014c). The main brands are Lenovo, Dell, HP, Fujitsu, Apple and HTC (smart phones) (Tier1Asset 2014c). The equipment is between 2-3 and 6-8 years old (Tier1Asset 2014d, Tier1Asset 2014a). This implies that some products are still covered by the initial warranty provided by the producer when Tier1Asset receives them (Tier1Asset 2014d). If this is the case, then Tier1Asset has the possibility to have the product repaired by the producer or to obtain spare parts from the producer. In the outset, Tier1Asset has only bought equipment that still functions. Thus if they receive defect products, the seller does not receive any payment for the defect equipment. The seller can then choose to take the equipment back or Tier1Asset can handle data erasure, using degaussing of the defect equipment, and handle the end-of-life recycling of the equipment. According to their head of operations, their recovery percentage is around 90%, meaning that they waste around 10%, including non-functional equipment, batteries and cables. However, the recovery percentage varies depending on the product. Printers have a lower recovery percentage, whereas smart phones have a high recovery percentage (Tier1Asset 2014c).

Data erasure is part of Tier1Asset's core business. They offer data erasure of the equipment without destroying its reuse potential. They use a software called Blancco that erases data and provides a report at the end of the process providing proof of the erasure process (Blancco's Erase-Report-Audit) (Blancco 2015a). Blancco is certified according to the Common Criteria scheme (ISO 15408) and by various organisations (Blancco 2015b). By using Blancco, Tier1Asset can provide the seller of the equipment with a detailed report of the data erasure process through certified software. This helps Tier1Asset's operations gain credibility, which is important because the equipment may contain sensitive data. The seller needs to have confidence in Tier1Asset and their data erasure process. Another way Tier1Asset creates credibility when selling the reconditioned products is by being an authorised Microsoft refurbisher. This also allows them to install new software at a certain (reduced) price. Furthermore, Tier1Asset also collaborates with Lenovo by buying their used products in Europe (Tier1Asset 2014c).

Tier1Asset distinguishes between four grades: gold, silver, bronze and green. The four grades are further described in figure 13-2. According to Tier1Asset, they have a strict grading system. A strict grading of their products ensures high quality products and adds credibility to their brand. Tier1Asset has also just begin using their name on all packaging materials for the reconditioned products because their believe that they have a good and credible brand (Tier1Asset 2014c).

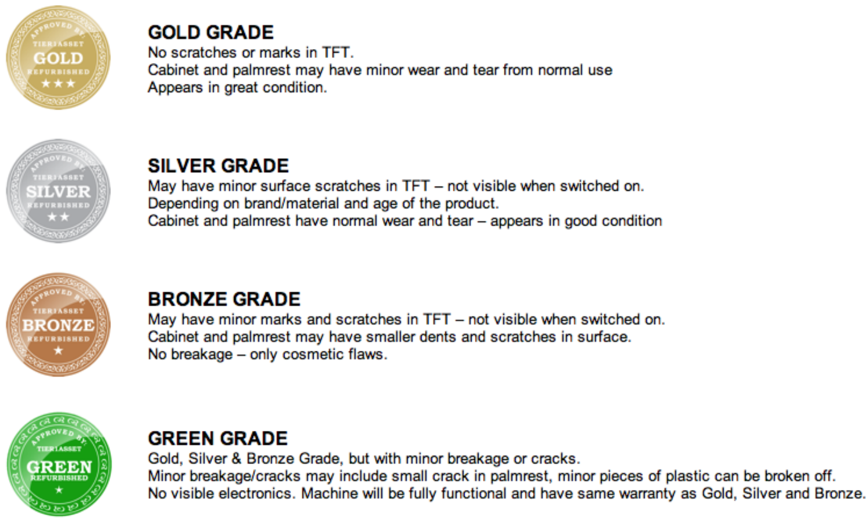


Figure 13-2: The four grades applied by Tier1Asset (Tier1Asset 2015a).

Tier1Asset sells the reconditioned products on a broker market. The broker market sets the value of the equipment depending on supply and demand and whether the market has confidence in the quality of the brand and model. Hence, Tier1assset can experience rises and drops in the prices of the brands and models depending on how the market develops. The equipment is then resold to private customers through external retailers. Some of the main retailers are the British retailer Misco, the German retailer notebookbilliger, while on the Danish market their equipment is sold through brugtecomputer.dk. (Tier1Asset 2014c). Many of their products are sold in England. Hence, there seems to be a larger market for used equipment in England compared to in Denmark.

13.3 KEY PROCESSES

The types of ecodesign requirements relevant for the reconditioning of products depend on the processes the product undergoes. The following section provides an introduction to the reconditioning processes at Tier1Asset. The reconditioning processes encompass cleaning the products, data deletion, performance testing, grading of the equipment, re-installation of Image and customisation of the equipment (Tier1Asset 2014c). A more detailed description of the processes is provided below, focusing on laptops and desktops. The amounts of repair they carry out are limited because from the outset they have only reconditioned functioning products. When Tier1Asset resells the reconditioned equipment, they provide a 1-2 year warranty (Tier1Asset 2014c). Therefore, Tier1Asset also has a unit repairing defect equipment sold by Tier1Asset (Tier1Asset 2014e). The main processes in their value chain are described below and in figure 13-1. The description is based on the information available from their homepage (Tier1Asset 2015b) and a guided tour at the facility (Tier1Asset 2014c).

1. Taking down the products and transportation: Tier1Asset buys the used products mainly from large private companies, hospitals or schools (the seller). They then take the products down, pack them and transport them to their facility. The seller can also chose to take care of these steps themselves. They sometimes also buy used products on the broker market if they have a large order and are in short supply.

2. Registration and identification number: When Tier1Asset receives the products, each product is given a unique identification number that is linked to its serial number. This number is used throughout the entire process and keeps track of the product and the information on the product.

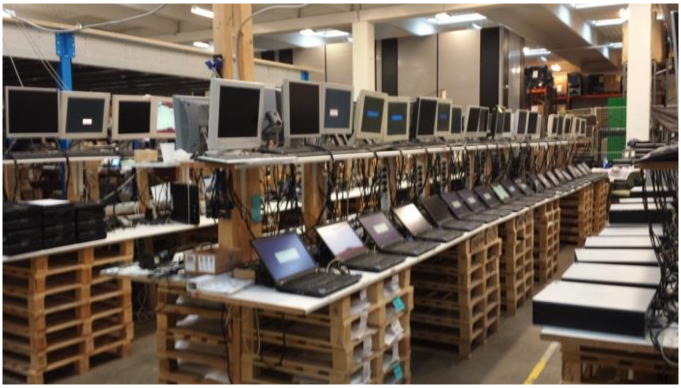
3. Cleaning 1: The first step in the cleaning process is the manual removal of stickers, safety and security tags, and other physical markings.

Picture 13-1: The first step in the cleaning process at Tier1Asset.

4. Removal of components: To standardise the end products, certain components are removed and/or replaced. These components can be graphics cards and RAM modules. During this process, the batteries in the laptops are also removed to ensure that they maintain their performance during the time in storage and do not discharge and break down.

5. Cleaning 2: The next step in the cleaning process is dust removal using air pressure. Desktops are partially dismantled to ensure better dust removal, but laptops are not. Finally, the surfaces, cabinet, screens and keyboards are cleaned using water and soap.

6. Data deletion: The data on the computer is deleted using the Blancco software. Blancco also produces a report documenting the data deletion process which can be given to the seller. In addition to the data deletions, information on the product is registered, such as identification number, serial number, producer, type, processor, and RAM in an AIDA 64 report. This information is used when the product is sold.



Picture 13-2: Data deletion.

7. Performance test: A performance test registers whether the product is in good working condition or is defect. If it is defect, it will also provide a report documenting where the product is malfunctioning.

8. Grading and quality control: If the product is fully functioning, the next step in the process is the grading of the product. The grading of the product is based on the information provided during the performance test and a visual grading made by employees. In the visual grading, certain aspects are considered, such as scratches, wear and tear or dents in the top cover and palm rest, plastic parts that have broken off, broken pixels and wear and tear of the hinges on laptops. During this process, the equipment is also turned on to see whether it works and can start up correctly. Finally, the data provided by the performance test is verified manually.

9. Installation of Image: The next step in the process is installation of Image. Tier1Asset is an authorized Microsoft refurbisher, but if the buyer wants to have another operating system then this is also possible.

Picture 13-3: Installation of Image at Tier1Asset.

10. Customisation of the product: Depending on the buyer, the product is then customised. This typically includes changing the keyboard to fit the relevant language, the addition of extra RAM and changing the hard drive. Keyboards are repainted to fit the selected language and thereby reconditioned and reused. Furthermore, batteries are re-inserted into the laptops. Prior to this, the batteries are tested and graded to fit the grading of the laptops. The grading takes into account the lifetime and quality of the batteries. Then the equipment is supplied with a charger.

11. Packaging: The products are packed into new Tier1Asset packaging materials (picture 13-4).

Picture 13-4: Tier1Asset's packaging material.

12. Valuation and resale: Based on the grading and the characteristics of the product, it is valued and sold.

Defect products, small repairs, spare parts and material recycling: If the product is defect, it is taken aside. If it can be easily repaired, it is repaired and then repeats the test process. However, if it cannot be easily repaired, the product is discarded. Those components that can be used as spare parts are taken out and the rest is separated into fractions for material recycling. The spare parts are then used to repair, customise or upgrade other products. Defect hard drives are physically deleted by degaussing equipment before being sent for recycling. Tier1Asset does a minimum of repairs on the products and only repairs products if the component can be easily changed. However, they believe that they could repair more products that are currently used for spare parts.

13.4 NON-TECHNICAL BARRIERS TO RECONDITIONING

The case study highlighted some barriers that are related to the system and structural context in which Tier1Asset is operating and which thus present non-technical barriers to reconditioning. Ijomah and Childe (2004) have identified non-technical barriers to the remanufacturing of mechanical and electromechanical equipment. The most important barriers identified in the study are listed in table 13-2. It is assumed that some or all of these barriers could also be relevant to the reconditioning of computers. There are evidently differences because Ijomah and Childe (2004) examined another product category and because remanufacturing requires more extensive repairs and replacements compared to reconditioning. Therefore, the following section will describe the non-technical barriers found in the Tier1Asset case study and discuss these in relation to the non-technical barriers found in the literature for remanufacturing.

Barriers	**Description**	**Identified in the study**
Technological advancement	It may not be possible to obtain the required components because they have become obsolete at the time of remanufacturing.	No
Lack of effective remanufacturing tools	Tools used in manufacturing are often specialised and not designed specifically for remanufacturing. Therefore, the remanufacturer must use conventional tools or buy expensive tools from the original equipment manufacturer.	No
Poor customer perception	If the remanufactured product has a poor image, the customers will not buy it, making remanufacturing unfeasible.	Yes
Low demand	If there are no customers then remanufacturing is not viable.	Partly
High selling price	People will only buy remanufactured products if they cannot obtain or afford a new product. Remanufactures therefore reject products that	Yes

	are beyond economic repairs (around 65-70 of new costs).	
High lead-time	If the remanufacturing lead-time is too high, customers may choose to purchase a new product instead.	No
Legislation: banned products, materials and features	If they contain banned materials, the products or components cannot be remanufactured.	No
Intellectual property rights	OEMs might refuse to provide technical information or make changes in the design which could improve remanufacturing and the remanufacturer cannot make these changes due to intellectual property rights.	No

Table 13-2: Important barriers for remanufacturing (Ijomah, Childe 2004).

Tier1Asset did not experience any difficulties in getting the necessary components to conduct repairs or replacements. They primarily utilise used parts from products that could not be reconditioned or buy used components on the broker market. When they need to buy new parts they have not experienced any difficulties acquiring these components. Tier1Asset also did not experience any problems in relation to the availability of effective remanufacturing tools. However, this might be a result of Tier1Asset doing limited repairs and therefore not conducting a total disassembly of the products and components. A high-lead time was not a barrier identified in the Tier1Asset case. However, Tier1Asset has a short lead-time to avoid the products becoming obsolescent or degrading during the time in storage (Tier1Asset 2014c). Neither banned products, materials and features nor intellectual property rights were documented as a barrier in the Tier1Asset case. However, computers are a product group covered by the Ecodesign Directive, the RoHS Directive and the WEEE Directive, hence there could potentially be some issues in the future. A recent study by Larsen et al.(2015) has identified ambiguities in legislation as a potential barrier for the reuse of electrical and electronic equipment. Particularly the differences in the implementation of the WEEE Directive between Member States were identified as a barrier for the reuse of electrical and electronic equipment.

Customer perception and trust is very relevant for Tier1Asset. The buyer of the used equipment needs to have trust in Tier1Asset and in their delivering a high quality product. One of the strategies to obtain this trust from the buyer was their strict grading system ensuring high quality products. Another strategy was becoming an authorised Microsoft refurbisher. Standardised procedures and validated data erasure is also important to ensure the reconditioning of IT equipment. It is also essential that the buyer of the reconditioned product has trust in Tier1Asset and in the quality of their products. Tier1Asset introduced the grading system to ensure a standardised quality and the buyer of the reconditioned products receiving the expected quality. However, this company specific grading system makes it difficult for consumers to compare products from other reconditioners. It is not only the perception and trust of the customer but also that of those selling the used equipment to Tier1Asset. It is central that the seller of the equipment has faith in Tier1Asset and believes that they can ensure a safe and secure data erasure. Therefore, a precondition for the reconditioning of computers, smartphones and tablets is that complete data deletion can be secured and documented.

Another barrier identified by Ijomah and Childe (2004) was low demand. This was partly identified in the case study as a lot of the equipment Tier1Asset sells goes abroad to Germany and England, suggesting that the market for used computers, smartphones and tablets is not as well developed in Denmark (Tier1Asset 2014c).

Ijomah and Childe (2004) also identified a high selling price as a potential barrier as it implies that products that are beyond economic repairs are not remanufactured or reconditioned even when this is possible. It is also a factor relevant for Tier1Asset as they need to make a viable business of reconditioning and reselling the products. According to the head of operations, a potential barrier is also the varying prices on the broker market (Tier1Asset 2014c). Tier1Asset mainly buys functional used equipment and the amount of repairs they conduct is limited. This was emphasised by one employee, who stated that they have a large improvement potential in terms of increasing their repair rates (Tier1Asset 2014a). According to him, they could, with a few small repairs, get more defect products back into the cycle, but they could also utilise the components from the defect product to a greater extent in order to give other products a better grading. (Tier1Asset 2014a) However, this would require a new set-up of their facility. The question is, however, whether this would be a viable business, or whether it would require too high a cost to increase repair rates. Economic obsolescence, whereby the repair costs are so great that it makes more economic sense to buy a new product, is a prevalent problem for electrical and electronic equipment (Prakash et al. 2015). Typical failures in laptops are the battery (33%), main board (23%), screen and fan (19%) and graphics card (13%), while the cost of replacing main boards, processors or graphics chips represent some of the highest costs for laptops (Prakash et al. 2015). Furthermore, real wages are high in Denmark, therefore time consuming repairs may not be viable.

The case study of Tier1Asset also revealed barriers for the reconditioning of computers, smartphones and tablets which were not included in the study by Ijomah and Childe (2004).

One of the barriers Tier1Asset is facing is that they have no influence on the design of the products they recondition. Tier1Asset reconditions products as a third party and therefore does not have the capability to affect the design of the products. They can only try to avoid buying used models that are known to be of poor quality. Therefore, to ensure a sufficient quality of the products, Tier1Asset stick to high quality labels such as Dell, Lenovo, Apple and HTC. However, the quality and the ease with which they can be repaired and dismantled can vary a lot between different models (Tier1Asset 2014b). So far there has been little evidence that reconditioning or remanufacturing is considered during the design process (Hatcher et al. 2014). Hatcher et al. (2014)have documented potential drivers for integrating this into the design process and these include, amongst others, profitability. However, when the producer does not perform the reconditioning or remanufacturing they do not profit from designing the products with these in mind.

Another barrier for reconditioning is the quantity and the quality of the used products Tier1Asset buys. For Tier1Asset to have a viable business, they need a large amount of similar products to standardise their operations. Therefore, they only buy products from larger companies and organisations. Typically, equipment from these organisations also have a higher quality than equipment from the consumer market. However, there is a large unexploited potential in reselling equipment from the private consumer market in Denmark. The quality of the used equipment is also highly dependent on how the first user has treated the equipment, which is again something that is outside of Tier1Asset's control. Tier1Asset also depends on a steady supply of used equipment, something that they are unable to control and which depends on the seller of the equipment and when the producers release new models. Furthermore, Tier1Asset is dependent on how the market for used equipment develops, the supply of and demand for used products, and whether there is faith in the quality of the brands and models.

The first user of the product can also be a potential barrier to reconditioning (Tier1Asset 2014c). According to Tier1Asset, the quality of the product they receive varies considerably depending on which type of organisation has used the product during its first lifecycle. Also, the process where the products are taken down, packed and transported to the Tier1Asset facility significantly affects their resale potential(Tier1Asset 2014c). Ensuring that the products are taken down, packed and transported in a gentle manner can improve their resale potential.

13.5 DESIGN BARRIERS AND RECOMMENDATIONS

Based on interviews with employees from operations at Tier1Asset, several design challenges were identified and design recommendations were made. The following recommendations are mainly relevant for laptops and desktops. However, some are more general aspects which could be relevant for other product categories.

13.5.1 HIGH QUALITY AND LONG LIFESPAN

Tier1Asset mainly buys high-end products because they have a higher quality and thereby a longer lifespan. Hence, a precondition for a product to be reconditioned and resold is that the products have a high quality and a long projected lifespan. This is generally a challenge because ICT equipment is typically less durable and less technically stable compared to other product categories such as pumps, medical equipment and office equipment (Hatcher et al. 2014).

Recommendation:

- Design products of a high quality with a long lifespan.

13.5.2 THE FIRST USER

As mentioned earlier, the first user of the product has an impact on the product's reconditioning and resale potential. Therefore, providing the first user of the product with information on how to keep and maintain the equipment may improve the resale potential and price.

Recommendation:

- Provide the user with information on best use and maintenance recommendations for the equipment.

13.5.3 BASIC INPUT/OUTPUT SYSTEM (BIOS) PASSWORD

A challenge experienced by Tier1Asset is the increased use of BIOS passwords (Tier1Asset 2014d, Tier1Asset 2014a). A BIOS password is authentication information that may be needed to log into a computer or tablet's input/output system to enable the computer to boot up (SearchEnterpriseDesktop 2015). For safety reasons, some companies choose to switch off the camera function or Bluetooth or wireless network capabilities on all their computers using a BIOS password (Tier1Asset 2014d) so that the user of the computer cannot enable these themselves. However, without the password it is not possible for Tier1Asset to reboot the system and thereby reactivate these functions (Tier1Asset 2014d). Therefore, unless the seller of the equipment can provide the password or Tier1Asset can bypass the system, the products must be sold without these functions at a reduced price (Tier1Asset 2014d), resulting in a loss of value of the product and a loss of revenue for Tier1Asset and the company selling the product (Tier1Asset 2014d). In addition, sometimes the entire system is locked using a BIOS password and if Tier1Asset is unable to bypass it or obtain the password, it is not possible to reboot the system. (Tier1Asset 2014d). In these cases, Tier1Asset has no choice other than to use the equipment for spare parts (Tier1Asset 2014d). According to the employee responsible for software at Tier1Asset, around 80% of discarded equipment is unusable due to BIOS passwords (Tier1Asset 2014d).

Recommendations:

- Limit the use of BIOS passwords.

- Make BIOS passwords available to the reconditioner.
- The producers could provide a software that can reset the BIOS password.

13.5.4 EASY DISASSEMBLY

Easy disassembly of the equipment was highlighted as important for the reconditioning process by several employees (Tier1Asset 2014b, Tier1Asset 2014e, Tier1Asset 2014a), in particular the easy disassembly of central components that are often changed during Tier1Asset's reconditioning processes of repairing, customising or updating the products. Components that are typically changed on desktops and laptops are screens, keyboards, RAM modules, processors, graphics cards, batteries, palm rests and covers. Based on Tier1Asset's experience, there can be significant variations between producers in how easy the product is to disassemble, but also between different models from the same producers (Tier1Asset 2014e, Tier1Asset 2014b). Thus, they receive products where these components are easy to remove and others that aren't. Hence, an improvement potential is to make the product easier to disassemble.

What complicate disassembly are products where the use of many screws and many different types of screws requires several changes of screwdriver during the disassembly process (Tier1Asset 2014e) (Tier1Asset 2014b). A robust click system was considered as a good design alternative to screws and is something that producers already use (Tier1Asset 2014b). However, it is important that the click system is robust and that it can be taken apart and reassembled several times without breaking or bending out of shape, which can currently happen (Tier1Asset 2014b).

Another design challenge in relation to disassembly was that it could be quite difficult to figure out intuitively how to disassemble the product or change the components (Tier1Asset 2014e). This type of information is typically available in repair manuals and, according to Tier1Asset, accessible (Tier1Asset 2014e, Tier1Asset 2014c). However, it can take quite some time for Tier1Asset to find this information when they handle many different products. The significant variations in the way that the products are constructed and should be disassembled between different producers and between models from the same producers make it more complex to disassemble the products because it is not always possible to apply experience from older models to the new models (Tier1Asset 2014e). Therefore, a design recommendation could be to make how to disassemble the product or remove certain components more self-explanatory in the design or structure of the product. This could be, for example, a small indication of which screws to remove. A modular design was also highlighted as a good design solution that could ease Tier1Asset's reconditioning process (Tier1Asset 2014e). Some producers already use modular design to some extent, but there is still potential for improvement.

Ecodesign recommendations:

- Make it easier to disassemble the product.
- Make it easy to remove and replace components such as keyboards, RAM modules, processors, graphics cards, batteries, palm rests, screens and covers to ensure that it is possible to upgrade, customise and repair the products.
- Make disassembly intuitive; ensure self-explanatory structures or provide instruction for the repair, customisation and updating of the product.
- Reduce the number of screws and use the same types of screw.
- Where possible, use robust click systems that can be separated and reassembled several times.
- Use a modular design.

13.5.5 SAFETY AND SECURITY TAGS FOR ANTI-THEFT PROTECTION AND OTHER LABELS:

One of the items Tier1Asset removes during their reconditioning process is the safety and security tags for anti-theft protection. These tags are placed on the product according to the wishes of the first user of the equipment. Some tags can be removed easily without damaging the equipment while others are difficult and time consuming to remove and leave permanent marks on the product, decreasing its resale value. Safety and security tags can of course be a necessity as anti-theft protection in order to make it less viable to steal and sell the equipment. However, it can have an effect on the resale value of the product. According to Tier1Asset, safety and security tags or other permanent marks can decrease the value of a laptop by up to 500 DKR (Tier1Asset 2014b). Therefore, the companies buying the product could reconsider whether they need this kind of protection and if they do, then to choose tags that are less likely to leave permanent marks.

In particular, tags that are corroded or burned into the product are difficult to remove and leave permanent marks. In these cases, Tier1Asset is required to sand the marks (Tier1Asset 2014a), resulting in a downgrading of the product because it is less visually appealing than a product without permanent marks from safety and security tags (Tier1Asset 2014a). An approach could also be to place the tags on a less visible place, such as on the bottom of the laptop instead of on the front cover (Tier1Asset 2014a), making the permanent marks less obvious. Furthermore, it can also be time consuming to remove the tags, depending on the type and age of the tag. According to an employee involved in cleaning the products, this can take up to 10 to 15 minutes. This is also an important aspect, because the more time spent on the product, the less money Tier1Asset can earn from its resale, thereby decreasing the product's reuse potential. Additionally, the process also requires the use of chemicals such as benzene, petroleum and alcohol. (Tier1Asset 2014b) Sometimes they need to remove the tags using heat, which can be a problem when the tag is placed on two different materials, such as metal and plastic, because the plastic might melt during the process as it can endure less heat than the metal (Tier1Asset 2014b).

Recommendations:

- Where possible, avoid safety and security tags and other labels.
- Use safety and security tags and other labels that can be removed without leaving a permanent mark; in particular, avoid tags that are corroded or burned into the product.
- Place the marks a less visible place, e.g. on the back of product.

13.5.6 EASY TO CLEAN

Tier1Asset also performs a thorough cleaning of the products by cleaning the surfaces and removing dust using air pressure. According to Tier1Asset, it can sometimes be difficult to clean the product's surfaces if there are many nooks and corners that are difficult to access. Therefore, a recommendation is to make the product surfaces easier to clean and to avoid a design that allows dust and dirt to gather and become difficult to remove(Tier1Asset 2014e) Another step in the cleaning process is the removal of dust from desktops and laptops using air pressure. In this process, the desktops are opened to gain access to the parts that accumulate dust and to secure the fan so that it does not rotate when the air pressure is turned on, since this could potentially break it. Therefore, the desktop should be easy to open and close by removing the sides of the desktop or by other means. The desktops' sides are often fastened using a click system or screws. When using a click system, it has to be robust to ensure that it does not break or bend out of shape during the process. Screws can be a problem because they tend to get lost during the process (Tier1Asset 2014b). Tier1Asset does not disassemble the laptop before cleaning using air pressure, but does use air pressure on the keyboard (Tier1Asset 2014c).

Recommendations:

- Make the surfaces easy to clean.
- Avoid a design where dust and dirt can gather and become difficult to remove.
- Make it easy to remove dust by e.g. easy access to central parts in the desktop and laptop.
- Easy disassembly of the desktop's sides.
- Avoid the use of screws.

13.5.7 SURFACES

Another aspect of importance for the resale potential of the equipment is the product surface and how resistant it is in terms of suffering scratches and bumps. If a product does not present well visually, then it cannot receive a good grading and consequently its sale price falls. According to Tier1Asset, there is large variation in the materials used for the casing of the computers in terms of how resistant they are to scratches and bumps. Particularly surfaces made of aluminium and magnesium are easily scratched (Tier1Asset 2014a). This can also be a problem during cleaning.

Recommendation:

- Use materials for the casing that are resistant to scratches and bumps.

13.5.8 SPARE PARTS AND STANDARDISED COMPONENTS

Based on Tier1Asset's experience, access to spare parts is generally not an issue. Most of the time they use spare parts from defect products or they buy spare parts from their competitors. Occasionally, they buy new spare parts and, according to Tier1Asset, gaining access to new spare parts is usually not a problem. However, it has to continue to be easy to gain access to spare parts. Therefore it is also recommended for the producer to have spare parts available for an extended period(Tier1Asset 2014c) Another aspect important for the reconditioning process is that the components to be changed and standardised between the different producers and models as a reconditioner such as Tier1Asset has to handle many different brands and models. According to Tier1Asset, some components are standardised, such as the hard disk, RAM modules, graphics cards (Tier1Asset 2014a) and drivers (Tier1Asset 2014d). However, other components such as the screens, fans, plastic components (Tier1Asset 2014e) and casings (Tier1Asset 2014c) are individualised between brands and models. Thus there is an improvement potential in using standardised components. Other components that are not standardised between brands and models are power plugs, which complicates Tier1Asset's processes because they have to provide each computer with power before they run Blancco and Image. Therefore, if different power plugs are used, they need to change these when handling different brands and models.

Recommendations:

- Have spare parts available for an extended period.
- Use standardised components.
- Standardise power plugs.

13.6 CONCLUSIONS

The case study revealed some non-technical barriers to the reconditioning of computers which were compared with the non-technical barriers identified in a study by Ijomah and Childe (2004) of mechanical and electromechanical equipment (table 13-3). There was an overlap between the two studies. In both studies, poor customer perception was identified as a barrier and low demand and high selling price were also considered barriers to remanufacturing or reconditioning. As these barriers were identified in both the literature and the case study, it is likely that these are more general barriers faced by the remanufacturing and reconditioning industry.

In the case study of Tier1Asset, it was not possible to document the following barriers identified in Ijomah and Childe (2004): technological advancement, lack of effective remanufacturing tools, high lead-time, legislation and intellectual property rights. However, these barriers might still be relevant when examining other companies, particularly those conducting more extensive repairs. Furthermore, other studies have documented that ambiguities in legislation represent a barrier to the reuse of electrical and electronic equipment (Larsen 2015). The case study of Tier1Asset also revealed some non-technical barriers not identified in the study by Ijomah and Childe (Ijomah, Childe 2004). The barriers were the perception and trust of the first user, the fact that products are not designed for reconditioning, the necessity of a certain quantity of products, the first user and the handling and transport of the products. As these barriers were not identified in the literature, it is more likely that they are product specific and mainly apply to companies similar to Tier1Asset.

Non-technical Barriers	Description	Documented in
Poor customer perception or trust	If the remanufactured product has a poor image, the customers will not buy it, making remanufacturing unfeasible.	Literature and case
Low trust from the seller of the equipment	If the first user does not trust the reconditioner to ensure data erasure, they are more likely to send the product to destructive recycling.	Case
Low demand	If there are no customers, then remanufacturing is not viable.	Literature and case
High selling price	People will only buy remanufactured products if they cannot obtain or afford a new product. Remanufactures therefore reject products that are beyond economic repairs (around 65-70% of new costs).	Literature and case
Products are not designed for	The products are not designed for	Case

reconditioning	reconditioning and the original equipment manufacturer has no incentive to change the design.	
A certain quantity is needed	When the reconditioner cannot obtain a large quantity of similar products to be able to standardise their equipment and have a viable business.	Case
A certain quality is need	If the reconditioner cannot get a high enough quality, it is not viable to recondition the product.	Case
First user	If the first user of the product neglects the product, it is not viable to recondition the product.	Case
Handling and transport	If the product is not handled corrected when taken down and transported, it may not be viable to recondition the product.	Case

Table 13-3: Barriers relevant when reconditioning computers.

13.6.1 ECODESIGN RECOMMENDATIONS

The case study of Tier1Asset revealed some possible design recommendations to improve the reconditioning potential of laptops and desktops. In chapter 2, general ecodesign recommendations relevant for closing the loops in the circular economy were identified. In relation to reconditioning, the assessment was made that the following strategies were relevant: design for disassembly, design for durability, design for maintenance, design for repair, design for remanufacturing and design for the reuse of product parts. The specific ecodesign recommendations identified within each of these strategies were compared to the design recommendations found in the case study of Tier1Asset. The result is provided in table 13-4. The table 13-4 shows that a number of the design recommendations found in the case study were also included in the existing design guidelines (teen out of nineteen). Many of the design recommendations could be found in the two ecodesign guidelines, namely the Ecodesign Pilot and the ECMA Standard. The ecodesign guidelines also included additional requirements which could be relevant in connection with the reconditioning of computers. An example is the more detailed recommendation on easy disassembly. This indicates that ecodesign is also relevant when designing for a circular economy. However, particularly the requirements regarding cleaning were found in the design for remanufacturing guidelines, indicating that this is not as thoroughly dealt with in the Ecodesign guidelines.

One of the design recommendations found in the case study was not found in any of the guidelines. These concerned the requirements on limiting the use of BIOS passwords. It was also one of the more product specific design recommendations identified, which might explain why it was not included in the more general ecodesign guidelines and design for remanufacturing guidelines. Some of the recommendations were also only partly covered by the ecodesign guidelines and the design for remanufacturing guidelines (eight out of nineteen). Partly covered implies that the design recommendations found in the case study were more specific or detailed than the recommendations found in the existing guidelines or that a similar recommendation with some variation could be found in the existing guidelines. The case study provided a more detailed recommendation regarding: the provision of user information, the avoidance of the use of safety tags and which components were important to remove or replace to ensure upgrading, customisation and repair. Furthermore, dust removal seems to be important when cleaning both laptops and desktops, and therefore several specific recommendations were made regarding how to improve this process. Based on the case study, it can be concluded that the ecodesign guidelines are relevant when designing for a closed loop system. However, specific design for remanufacturing guidelines can provide additional design recommendations, such as more elaborate requirements for cleaning. Furthermore, more product specific requirements were identified in the case studies which were not included in the guidelines. Therefore, it might be relevant to make more product specific guidelines for closing the loops.

Recommendations from the case study		**Existing ecodesign guidelines with a similar recommendation**
Design products of high quality with a long lifespan.	Yes	Design products for long service life (Ecodesign Pilot). Ensure high functional quality (Ecodesign Pilot).
Provide the user with information on best use and maintenance recommendations of the equipment.	Partly	Indicate service intervals for product (Ecodesign Pilot). Information on options for the upgrading, expanding and repair of product (ECMA).
Limit the use of BIOS passwords. Make BIOS passwords available to the reconditioner. Producers could provide a software that can reset the BIOS password.	No PS	
Make it easier to disassemble the product.	Yes	Design structures for easy disassembly (Ecodesign Pilot).
Make it easy to remove and replace components such as keyboards, RAM modules, processors, graphics cards, batteries, palm rests, screens and covers to ensure that it is possible	Partly PS	Ensure easy access to components for repair and replacement (Ecodesign Pilot). Design for possible upgrading (Ecodesign pilot). Batteries should be easy to identify and remove unless the lifespan exceeds that of the

Recommendations from the case study		**Existing ecodesign guidelines with a similar recommendation**
to upgrade, customise and repair the products.		product and the equipment is reliant on continuous power supply (ECMA).
Make disassembly intuitive; ensure self-explanatory structures or provide instruction for the repair, customisation and updating of the product.	Yes	Design product structures for easy disassembly. Reduce the number and variety of steps necessary for disassembly (ECMA). Arrange components for ease of disassembly. Ensure self-explanatory structures or provide instructions for repair of the product (Ecodesign Pilot). Ensure visible access to connection for disassembly (Ecodesign Pilot).
Reduce or avoid screws and use the same types of screw.	Yes	Reduce the number and variety of connections (e.g. fasteners and screws) (ECMA). Reduce the complexity of disassembly, for example by standardising fasteners (Ijomah et al., 2007). Minimise the number of joints (Ijomah et al., 2007).
Where possible, use robust click systems that can be separated and reassembled several times.	Partly	A sturdy product design (Ecodesign Pilot). Ensure functioning of connections over whole service life (Ecodesign Pilot). For components destined for reuse, ensure that their materials are sufficiently durable to survive disassembly (Ijomah et al., 2007).
Use modular design.	Yes	Use a modular structure so that obsolescence occurs with a component rather than with the entire product (Ijomah et al., 2007).
Where possible, avoid safety and security tags and other labels. Use safety and security tags and other labels that can be removed without leaving a permanent mark; in particular, avoid tags that are corroded or burned into the product. Place the marks in a less visible place, e.g. on the back of product.	Partly PS	Avoid the use of adhesive backed stickers or foams on plastic parts (ECMA).
Make the surfaces easy to clean.	Yes	Design the product for easy cleaning and/or minimize susceptibility to soiling (Ecodesign Pilot).

Recommendations from the case study		**Existing ecodesign guidelines with a similar recommendation**
Avoid a design where dust and dirt can gather and be difficult to remove.	Partly	Design the product for easy cleaning and/or minimize susceptibility to soiling (Ecodesign Pilot).
Make it easy to remove dust e.g. by easy access to central parts in the desktop and laptop.	Partly PS	Use assembly methods that allow disassembly at least to the point that internal components can be accessed for cleaning (Ijomah et al., 2007). Arrange components so that all can be accessed for effective cleaning (Ijomah et al., 2007).
Easy disassembly of the desktop's sides.	Partly PS	Use assembly methods that allow disassembly at least to the point that internal components can be accessed for cleaning (Ijomah et al., 2007). Arrange components so that all can be accessed for effective cleaning (Ijomah et al., 2007). Ensure ease of cleaning for the reuse of components (Ecodesign Pilot).
Avoid the use of screws.	Yes	Reduce the number and variety of connections (e.g. fasteners and screws) (ECMA).
Use materials for the casing that are resistant to scratches and bumps.	Yes	Ensure product surfaces are smooth and wear resistant (Ijomah et al., 2007). A sturdy product design (Ecodesign Pilot). Ensure corrosion resistance (Ecodesign Pilot).
Have spare parts available for an extended period.	Yes	Ensure availability of spare parts (Ecodesign Pilot).
Use standardised components	Yes	Standardised parts (Ijomah et al., 2007). Use of common mechanical packages (covers and chassis) or common parts or components that are used for multiple models in the product family or multiple generations of the same product, allowing for the reuse of common parts (ECMA). Use of industry standard parts that may be more easily replaced and repaired (ECMA).
Standardise power plugs	Partly PS	Standardised part (Ijomah et al., 2007).

Table 13-4: Comparison of the recommendations found in the case study of Tier1Asset and the design recommendations identified in the existing guidelines. PS stands for product specific. The existing design recommendations are direct quotes

CHAPTER 14 CONCLUSIONS PART TWO

In this conclusion the main research question for part two will be answered by examining the three sub-questions in the case studies of B&O and Tier1Asset. The main research question of part two was *How to design electrical and electronic equipment for closed material loops in the circular economy using ecodesign and what are the drivers and barriers*.

In the two case studies of B&O and Tier1Asset, two strategies to close the material loops in the circular economy were examined, namely reconditioning and recyclability. The case study of B&O and the case study of Tier1Asset provided design recommendations on how to design products to improve recyclability and reconditioning potential. The two case studies of B&O and Tier1Asset also revealed that the two examined ecodesign guidelines, the Ecodesign Pilot and the ECMA 341 standard, can improve the recyclability and reconditioning potential of the examined product categories. Many of the design recommendations identified during the workshop at B&O and the interviews at Tier1Asset were already included in the two existing guidelines. However, design recommendations targeting reconditioning could be further developed, and therefore design for remanufacturing was added to the review of design recommendations.

The workshop at B&O and the interviews at Tier1Asset also gave design recommendations which could improve recycling and reconditioning respectively and which are not included or only partly included in the two ecodesign guidelines and the existing design recommendations targeting remanufacturing. The new design recommendations are more detailed and more product specific and even company specific compared to the existing design recommendations. The ecodesign guidelines can therefore be a good starting point to design for closed material loops. However, these should be supplemented with design for remanufacturing recommendations and it is important to develop those that are both product and company specific. The case study of B&O also revealed that it is possible to create a knowledge exchange between the recyclers and the producers through a workshop disassembling the producers' products, thereby developing detailed product and company specific design recommendations to improve the recyclability of products.

Chapter 10 examined *whether luxury products can support a circular economy*. A literature review of luxury products' core characteristics revealed that links to the circular economy could be established. The characteristics of luxury products which could be linked to the circular economy were the rarity of luxury products, high quality, durability, service schemes, extended warranties and large aftermarkets. The case study of B&O supported these linkages between the circular economy and luxury products. The case study of B&O only examined their core products. The fact that B&O produces luxury design products with a high quality has driven their circular activities and product attributes within the inner circles in the circular economy. This includes the activities and product attributes such as timeless design, extended warranty, a long lifespan, repair and service schemes, the availability of spare parts and aftermarkets for their products. The other circular activities, such as reuse and remanufacturing, were driven by stock and cost optimisations and the outer cycle of recycling, such as dismantling tests, the marking of plastic parts and a negative list, were driven by their own environmental agenda and by environmental regulation. Hence, luxury products can help support certain aspects of the circular economy, but this is also highly dependent on both the company and contextual factors.

The B&O case study also examined *how a company can work with design for recycling by creating knowledge exchanges between producers and recyclers through workshops*. The workshop at B&O examined a television, a remote control and a loudspeaker. The products were from their core series and from the BeoPlay series. The disassembly during the workshop did not indicate that their core products were better than their BeoPlay products in terms of recyclability. The workshop resulted in fifteen design recommendations to improve the recyclability of B&O's products. The design recommendations included aspects such as: the marking and easy disassembly of components and parts containing rare earth elements, precious metals and hazardous substances, information requirements, easy disassembly, use of hazardous substances, marking systems for easy disassembly and the contamination of material factions.

The ECMA 341 standard and the Ecodesign Pilot already cover six of the fifteen design recommendations identified during the workshop. Seven of the fifteen design recommendations are partly covered by the two ecodesign guidelines but the recommendations from the workshop were in greater detail and/or product specific compared to those in the guidelines. Two design recommendations were identified which were not covered by the ecodesign guidelines and concerned the recommendations to avoid embedding iron or stainless steel threads in aluminium elements and the recommendation to avoid soundproofing materials that disintegrate during destructive and automatic disassembly, contaminating the other fractions, or make them very easy to remove beforehand. Hence, the two ecodesign guidelines can be a good starting point to design for improved recyclability, but can be supplemented with more detailed product and company specific design recommendations.

The workshop at B&O revealed that it is possible to overcome both semantic and pragmatic knowledge boundaries and to facilitate a knowledge translation between the recyclers and B&O. Nevertheless, the proposed design of the workshop was not fully tested. The fact that the design engineers were not included in the workshop implied that their knowledge did not come into play. The design engineers were also those who should have used the knowledge in product development. Because they did not participate, the environmental consultant had to ensure that this was introduced into product development. Therefore, the environmental consultant was faced with a new knowledge boundary when she tried to implement the results of the workshop.

Drivers and barriers were identified in relation to the integration of initiatives related to circular economy in B&O. The drivers and barriers are also related to the integration of environment and sustainability more generally as it is examining how to create closed loop material flows through ecodesign. Quality, design and luxury seemed to be the main drivers of B&O's circular activities for their core products within the inner circle of the circular economy, such as timeless design, long lifespan, expended warranties, repair and service schemes, spare part availability for eight years, and aftermarkets. Stock and cost optimisation was the driver of B&O's reuse and remanufacturing of components and parts of B&O's current service system. The activities in the outer circle, such as B&O's negative list, dismantling test and marking of plastics, were driven by their environmental agenda and by environmental regulation. Hence, B&O's circular activities and product attributes were not only driven by an environmental agenda, but also by the fact that their core products are luxury products with a focus on design and quality and by stock and cost optimisations.

The circular aspects, which were a result of B&O's focus on quality and design, receive management support because these are the core values of B&O and the product attributes used to differentiate themselves from their competitors. These aspects are likely to persist when B&O is faced with a financial recession and has to prioritise its core values. The activities driven by an environmental agenda are more exposed because they are not part of B&O's core values or product attributes that they can use to differentiate themselves from their competitors. An indication of this can also be seen as almost all of B&O environmental requirements have been included in the environmental regulation and B&O has not developed further proactive environmental requirements.

Specific ecodesign guidelines can be central to the integration of ecodesign into a company. The purpose of the workshop at B&O was to develop company specific design guidelines to improve the recyclability of their products. It is therefore an opportunity for B&O to improve the outer circle in the circular economy. However, the case study of B&O also revealed that a specific guideline is not enough; it also needs to be embedded within company procedures and processes. B&O has sustainability and environmental goals for product environment. However, B&O has not identified any actions to achieve this goal. This might prove a barrier for the integration of ecodesign in B&O and for improving B&O's circular activities driven by an environmental agenda. Finally, B&O does not experience any demand from the market for sustainable luxury products, which again can present a barrier to B&O's circular activities and product attributes driven by an environmental agenda.

The case study of Tier1Asset examined *which non-technical and design barriers Tier1Asset experience when reconditioning computers*. Based on the design barriers, design recommendations were developed on how to improve the reconditioning potential. The identified design barriers and design recommendations focus on computers, but some are also of a more generic character. The case study of Tier1Asset revealed design recommendations which could improve the reconditioning potential of computers. Nineteen design recommendations were identified, targeting aspects such as: long lifespan, high quality, user information, limitations to the use of BIOS passwords, easy disassembly, the removal of key components, modular design, the avoidance or reduction of the use of safety and security tags, easy cleaning and dust removal, material resistant to wear, spare part availability, standardised components and standardised power plugs. A detailed overview of the requirements is provided in table 13-4. Teen of the nineteen design recommendations were included in either the two ecodesign guidelines or in the design recommendations for remanufacturing. Eight of the nineteen design recommendations were only partly covered by the ecodesign guidelines or the design for remanufacturing guidelines. The recommendations partly covered were more detailed and/or product specific compared to those in the ecodesign guidelines and the design recommendations for remanufacturing. One of the design recommendations from the case study was not found in the existing recommendations, namely the requirements on limiting the use of BIOS passwords.

Non-technical barriers were also identified in the Tier1Asset case when they reconditioned computers, smartphones and tablets. A potential barrier for reconditioning can be poor customer perception and trust in the reconditioned product and in the company reconditioning the product. To ensure good consumer perception and trust, Tier1Asset has a grading system and is quite strict in their grading of the products. Another potential barrier is low trust from the seller of the equipment. Tier1Asset reconditions products which may contain sensitive information. Therefore, they have to ensure data deletion and that the seller of the used equipment has trust in Tier1Asset.

Low demand is also a potential barrier for the reconditioning of products. Tier1Asset sells primarily to Germany and England because the Danish market is not yet as developed. Therefore, low demand is a barrier which Tier1Asset is partially experiencing. A too high selling price is also a potential barrier for reconditioning, as Tier1Asset has to reject products which are beyond economic repairs. Tier1Asset needs a certain quantity of similar products to be able to standardise the reconditioning process and ensure a viable business. Therefore, they mainly buy products from larger organisations and companies. This is a barrier for Tier1Asset to further develop the reconditioning of products from private consumers, as the diversity of consumer products is far greater. Furthermore, for a product to be feasible for reconditioning, it also needs to have a certain quality, since it is not cost efficient to recondition products of a low quality. Therefore, low quality of products is a barrier for reconditioning. The behaviour of the first user also has implications for a product's reconditioning potential, as does the manner in which the product is handled and transported to the reconditioner. Therefore, the first user, transport and handling can be barriers to reconditioning.

CHAPTER 15 CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the final conclusions and answers the main research question and the two main sub-questions from part one and part two. The detailed conclusions for part one and part two can be found in chapter 8 and chapter 14. Based on the conclusions of the different studies, recommendations are provided.

15.1 THE CONCEPTUAL FRAMEWORK

The first step in the research was to develop the conceptual framework and a definition of the circular economy. The circular economy is a concept dating back to the 1960s and has roots in, among other things, ecological economics, environmental economics and industrial ecology. The ecological economist Nicholas Georgescu-Roegen was one of the first to put forward the idea that the economy is a closed system by linking the second law of thermodynamics and economy. His ideas inspired others, including the ecological economists Kenneth E. Boulding and Herman Daly and the environmental economists David W. Pearce and R. Kerry Turner. However, they had different suggestions for how the economy could take into consideration the fact that it needs to function within the limits of a closed system where resources are finite. Daly believed that the solution was to create a steady state economy, whereas Pearce and Turner believed that part of the solution was to include externalities in the price, after which market forces would take care of the rest.

The idea of a closed system is also prevalent in industrial ecology, where the idea is that an industrial system should work as natural ecosystem, whereby waste is not waste but rather an input for new processes. Industrial ecology has a more explicit focus on material streams and closing the material loops through reuse, repair, reconditioning and recycling. Furthermore, eco-efficiency is also a key strategy for closing the material loops. More recently, concepts such as cradle-to-cradle and the Ellen MacArthur Foundation have emerged, which also strive to create closed material loops. However, they differ from other industrial ecologists because they do not include eco-efficiency in their models.

The definition of a circular economy in this study primarily uses industrial economy as its starting point and a circular economy is defined as *a consumption and production system based on closed loops that minimises resources, energy flows and environmental degradation without restricting economic, social or technical progress*. The material loops can be closed through five strategies: (1) reducing consumption of energy and resources, (2) maintenance and repair, (3) reuse, (4) reconditioning and remanufacturing, and (5) recycling. Another way to close the material loops is through resource efficiency. In this study, resource efficiency is defined as "*using the Earth's limited resources in a sustainable manner while minimising impacts on the environment. It allows us to create more with less and to deliver greater value with less input."* (European Commission 2015e). In the study, resource efficiency can be improved through the same five strategies which could close the material loops in the circular economy.

The material loops in the circular economy can be closed in many different ways using a wide range of approaches, methods and tools. In this PhD project, the premise was ecodesign and how it could help close the material loops. Here, ecodesign is defined as the implementation of environmental issues in the design process taking the entire lifecycle of the product into consideration(Tischner et al. 2000).

15.2 HOW ECODESIGN CAN CLOSE THE MATERIAL LOOPS IN THE CIRCULAR ECONOMY?

The main research question was *how ecodesign can close the material loops in the circular economy for electrical and electronic equipment*. It was examined by looking at how regulations and companies can close the material loops in the circular economy.

A study of the regulations showed that the European IPP instruments do and can improve resource efficiency. The Ecodesign Directive plays an important role in improving resource efficiency because it is the only mandatory policy instrument which can set minimum performance requirements for all five strategies to close the material loops. Still, the remaining IPP instruments also play an important role. The RoHS Directive and the WEEE Directive improve recyclability. The EU Energy Labelling and the EU Energy Star Regulation mainly improve energy efficiency in the use phase. The EU Ecolabel and the EU guidelines on GPP can set criteria for all five strategies to close the material loops in the circular economy. Thus the EU Ecolabel and the EU guidelines on GPP can help close the material loops by encouraging consumers (private or public) to purchase more environmentally friendly products.

The study examined two case companies, Bang & Olufsen and Tier1Asset, and two of the strategies to close the material loops in the circular economy, reconditioning and recycling. B&O is a producer of high-end audio and visual equipment and Tier1Asset is a reconditioner of primarily computers, tables and smartphones. These two case studies revealed that the two examined ecodesign guidelines, the Ecodesign Pilot and the ECMA 341 standard, could be used to improve the recyclability and reconditioning potential of the examined product categories. However, design recommendations for reconditioning could be further developed in the two examined guidelines. The two case studies also revealed a number of design recommendations which were not included or only partly included in the guidelines. It is therefore relevant to develop both product and company specific guidelines. In the B&O case, the circular activities were not primarily driven by an environmental agenda. B&O's negative list, dismantling test and marking of plastics were driven by their environmental agenda and by environmental regulation. However, their activities within the inner circles in the circular economy were driven by their focus on quality and design while their remanufacturing of components was driven by stock and cost optimisations. Hence, there might be drivers behind closing the material loops other than environmental improvements. As an example, modularisation may not only be driven by a wish to make the product easier to repair or update but also by a wish to have cost-effective and fast product development cycles. Tier1Asset's circular activities were not driven by an environmental agenda but because they saw a business potential.

15.2.1 CONCLUSIONS AND RECOMMENDATIONS PART ONE: REGULATING FOR RESOURCE EFFICIENCY

Part one examined *how have the EU product policies covering electrical and electronic equipment integrated resource efficiency aspects and what is the role of the Ecodesign Directive*.

In the European regulations, the integration of environmental aspects into the product design of electrical and electronic equipment is managed by a number of policy instruments such as the WEEE Directive, the RoHS Directive, the EU Energy Label, the EU Energy Star, the Ecodesign Directive, the EU Ecolabels and the EU Guidelines for GPP. Each of these tools can, in their scope and in the actual requirements or criteria, target different resource efficiency aspects.

The WEEE Directive has set up collection and recycling systems in Europe and ensures the recycling and recovery of materials through specific targets. In 2015, prepare for reuse was included in the recycling target, however because a separate target was not set, it is not possible to evaluate whether the WEEE Directive will improve prepare for reuse. The WEEE Directive also introduced producer responsibility, making the producer financially responsible for the handling of waste electrical and electronic equipment. The intention was to stimulate the producers to make design changes. However, in many Member States collective producer schemes have been implemented and therefore such incentives for the producers to change the product design have not been created. Therefore, the WEEE Directive has so far primarily improved recycling.

The RoHS Directive has also predominantly improved recyclability by restricting the use of certain hazardous substances. The EU Energy Labelling and the EU Energy Star target mainly energy efficiency but also other essential resources in the use phase. The EU Energy Labelling has succeeded in creating a market transformation towards more energy efficient products. The EU Ecolabels and the EU guidelines for GPP apply a lifecycle perspective and the review of the three product groups of PCs and servers, imaging equipment and windows revealed that the criteria documents cover many resource efficiency aspects. Hence, the tools in the IPP policy mix cover many of the five strategies to close the material loops in the circular economy. Hence, the Ecodesign Directive, the EU Ecolabel and the EU guidelines for GPP are the only instruments that set requirements or criteria for all five strategies.

The IPP instruments use different means to improve the environmental performance of products. The EU Ecolabels and the EU guidelines for GPP are voluntary instruments which provide the consumers (private or public) with the necessary information to select the environmentally best performing products on the market. Thus they encourage the development of more environmentally friendly products. The EU Energy Labelling is a mandatory instrument and provides information mainly on the energy efficiency of the product and thereby helps drive the existing market towards more environmentally friendly products. The WEEE Directive is a bit different because it does not directly target the design of the products, but rather sets requirements for recovery and a shared target for recycling and prepare for reuse. The Ecodesign Directive and the RoHS Directive are the only two mandatory policy instruments setting minimum requirements for the design of electrical and electronic equipment. This implies that the Ecodesign Directive is the only mandatory instrument which can set minimum performance requirements for all of the five strategies to close the material loops. Therefore, the Ecodesign Directive is key to improving resource efficiency through regulation within the EU.

So far, the actual uptake of resource efficiency requirements other than energy in the Ecodesign Directive is still limited. In 2013, there were 21 adopted implementing measures and two recognised voluntary agreements, and only five implementing measures and one voluntary agreement included specific requirements targeting resources other than energy and fifteen implementing measures and one voluntary agreement included information requirements targeting resources other than energy.

To understand what made it possible to include resource efficiency requirements in the Ecodesign Directive, two product categories which had succeeded in integrating resource efficiency were selected for further study. An analysis was made of the process and stakeholder interactions which formed the basis for integrating resource efficiency requirements into the implementing measure for vacuum cleaners and the voluntary agreement for imaging equipment. The two case studies revealed a number of factors which had made the uptake of the resource efficiency requirements possible. Based on these factors, recommendations were made on how to further improve the uptake of resource efficiency requirements in the Ecodesign Directive.

- A focus on the most significant impact has resulted in a focus on energy requirements. A recommendation is therefore to also consider requirements with greater potential for improvement.
- The results of the preparatory study were important for the integration of resource efficiency requirements into the Ecodesign Directive. Therefore, a recommendation is to broaden the scope of MEErP and the EcoReport tool to ensure that resource efficiency is fully considered during the preparatory study.
- Political attention was important for the integration of resource efficiency requirements. A recommendation is therefore to make use of current political attention to resource efficiency and keep the focus on resource efficiency.
- The stakeholders involved in the ecodesign process also help to facilitate the integration of the resource efficiency requirements in the Ecodesign Directive and a recommendation is to continue the open ecodesign process and strengthen stakeholder consultations during the preparatory study.
- DG Environment played a role in getting the requirements integrated and has a wider lifecycle perspective. It is therefore recommended to strengthen the role of DG Environment in the ecodesign process further.
- Standards defining test methods and verification procedures were essential for the integration of resource efficiency requirements for the two product groups, and it is therefore recommended to continue developing standards through e.g. the Standardisation Mandate on Materials Efficiency.

Based on part one, it was possible to provide a list of recommendations on how to make better use of the synergies between the policy instruments. These are to:

- Harmonise the product definitions and calculation methods used in the EU Ecolabels with those of the Ecodesign Directive and EU Energy Labelling.
- Further synchronise the process of updating or developing new ecolabelling criteria with the corresponding product groups in the Ecodesign Directive and the EU Energy Labelling.
- Examine whether durability could be included in the EU Energy Labelling.
- Use the Ecodesign Directive to obtain information on the content of hazardous substances in a specific product and use the Ecodesign Directive to restrict the use of hazardous substances for a specific product when a general restriction through the RoHS Directive is not required.
- Set requirements in the Ecodesign Directive for the easy dismantling of those substances, mixtures and components which need to be removed according to the WEEE Directive Annex VIII(European Commission 2012a) to ensure the environmentally sound reuse, recycling, recovery or disposal.Conclusions and Recommendations Part Two: Designing for a circular economy in companies

15.2.2 CONCLUSIONS AND RECOMMENDATIONS PART TWO DESIGNING FOR A CIRCULAR ECONOMY IN COMPANIES

The second part of the PhD thesis examined *how to design electrical and electronic equipment for closed material loops in the circular economy using ecodesign and which drivers and barriers are faced*.

The B&O case examined how to design products that could be more easily recycled and the Tier1Asset case examined how to design products that could be more easily reconditioned. The two case studies revealed that the recommendations from the two selected ecodesign tools, the Ecodesign Pilot and the ECMA 341 standard for environmental design considerations for information and communication technology and consumer electronic products, were relevant when designing for the closed material loops in the circular economy. However, design recommendations for reconditioning could be further developed in the two examined guidelines. Therefore, the design guidelines for remanufacturing were further examined.

The two case studies also revealed a list of design recommendations which were not included or only partly included in the existing guidelines (see table 15-1). The recommendations were more detailed and product or even company specific than the recommendations in the guidelines. A conclusion is therefore that existing design recommendations in the examined guidelines are useful, however it is relevant to develop more detailed and product and company specific design recommendations to close the material loops. Furthermore, it is recommended to examine the design recommendations for the remaining strategies to close the material loops and to study possible synergies and trade-offs between the different design recommendations to close the material loops.

	Not covered by the guidelines	Partly covered by the guidelines
Design for recycling, generic	Avoid embedding iron or stainless steel threads in aluminium elements.	Mark components that contain rare earth elements and precious metals and make it easy to disassemble these. Mark components that contain hazardous substances that require special treatment and make it easy to disassemble these. Make the product easy to disassemble to facilitate the easy removal of components that need special treatment, such as printed circuit boards, batteries and components containing hazardous substances, before the products are dismantled destructively. Use a marking system to make it easy to determine which screw to remove to disassemble the product or certain components. Avoid the use of glues that are suspected of causing environmental problems
Design for recycling, product specific	Avoid soundproofing materials that disintegrate during the destructive and automatic disassembly and contaminate the other fractions, or make is very easy to remove them beforehand (loudspeakers).	Make the plastic pieces used to diffuse the LED light in flat screens easy to disassemble and avoid using glues or other materials that could hinder easy assembly (televisions).
Design for remanufacturing, generic		Where possible, use robust click systems that can be separated and reassembled several times. Provide the user with information on best use and maintenance recommendations of the equipment Avoid a design where dust and dirt can gather and become difficult to remove..

	Not covered by the guidelines	Partly covered by the guidelines
Design for remanufacturing, product specific	Make it easy to remove and replace components such as keyboards, RAM modules, processors, graphics cards, batteries, palm rests, screens and covers to ensure that it is possible to upgrade, customise and repair the products (computers).	Limit the use of BIOS passwords. Make BIOS passwords available for the reconditioner. The producers could provide a software to reset the BIOS password (computers). Where possible, avoid safety and security tags and other labels. Use safety and security tags and other labels that can be removed without leaving a permanent mark; in particular, avoid tags that are corroded or burned into the product. Place the marks on a less visible place, e.g. on the back of the product (computers). Easy disassembly of the desktop's sides (computers). Make it easy to remove dust by e.g. easy access to central parts in the desktop and laptop. Standardise power plugs (computers).

Table 15-1: Overview of the design recommendations found in the two case studies not covered or only partly covered by the existing guidelines examined.

In the case study of B&O, both opportunities and barriers were identified in their work with closing the material loops through ecodesign. A clear opportunity for B&O is that regarding their core products they already have many activities and product attributes significant for the inner circles in the circular economy. These include activities such as timeless design, three-year warranty, long lifespan, repair and service schemes, availability of spare parts for eight years, and aftermarkets. Hence, B&O has a good starting point for the development of a circular business. Furthermore, these aspects are linked to aspects which B&O considers key to differentiating themselves from their competitors, namely quality and design. Thus these circles are also likely to have management commitment.

However, B&O also faces a number of barriers which hinder their work with ecodesign and the circular economy. B&O is in a financial recession and therefore activities which are not related to their core values and cannot provide value for the company in the short term are not prioritised. Environmental aspects are considered as something embedded within the quality dimension, but these are not something B&O can use to differentiate themselves from their competitors according to B&O. Therefore, the circular activities and circular product attributes which are not driven by quality and design, such as their negative list, the marking of plastics, dismantling tests and the remanufacturing of components, will not hold as strong a position as those driven by their core values (design and quality). Another potential barrier is the fact that B&O has not set any goals for product environment in their CSR report covering the period from June 2015 to June 2016. Furthermore, B&O is not experiencing any demand from the market for environmentally friendly or circular products.

What was also documented in the case study of B&O was that the circular activities and circular attributes of their core products were not primarily driven by an environmental agenda. They did have some circular activities, such as their negative list, the dismantling tests and the marking of plastics, which were driven by an environmental agenda and environmental regulation. However, the remaining circular activities and product attributes of their core products, such as the availability of spare parts for eight years, repair and service schemes, long lifespan, three-year warranties, timeless design, aftermarkets and the reuse and remanufacturing of components for their repair and service system, were driven by B&O's focus on quality, design and luxury as well as by cost and stock optimisations. In 2016, the majority of the circular activities and product attributes driven by an environmental agenda were included in the environmental regulation and new, more proactive requirements have not been set. Therefore, ecodesign might not be the easiest way to implement circular activities or product attributes in a company, especially in a company where environmental aspects are not part of the core values or represent a feature that can be used to differentiate themselves from their competitors or when the company is facing a financial recession. In such a case, it might be easier to implement circular activities and circular product attributes through resource optimisation, design for manufacturing, standardisation, cost and stock optimisations or, as it was the case with B&O, aspects such as design, quality and luxury which can be used to differentiate themselves from their competitors.

The case study of Tier1Asset identified non-technical barriers which can hinder reconditioning. A potential barrier is that the purchaser of the reconditioned products doubts that the product has a satisfying quality. Thus the purchaser needs to have trust in the reconditioner having done a good job. Another potential barrier is that the seller of the used equipment has no trust in the reconditioner. Computers, tables and smartphones can contain sensitive information and therefore the seller needs to be sure that this data and information is deleted from the equipment in a responsible way. The reconditioner needs to make a profit on the reconditioning of the product, therefore a barrier can be that the repairs of the used products are not economical. For Tier1Asset to have a viable business, they also need a certain quantity of products in order to have standardised and efficient processes. A certain product quality is also needed to ensure that the price and quality of the reconditioned product is high enough. Therefore, small quantities and low quality are potential barriers to reconditioning. Another barrier is the fact that the products are not designed for repair, reconditioning and remanufacturing and that the producers have little or no incentive to change the design. The first user of the equipment can be a barrier for reconditioning, if the equipment is not maintained properly. Finally, incorrect handling when the product is taken down and transported can also hinder reconditioning. In summary, the following recommendations can be made to improve the reconditioning of products:

- The reconditioner should have a good image and ensure consumer trust.
- The reconditioner should ensure the trust of the seller of the used equipment.
- Ensure it is not too expensive to recondition a product in comparison to the resale price.
- Design products for reconditioning.
- Produce products with a high quality.
- Provide guidance to the first user on correct use, maintenance and updating.
- Ensure that the products are handled correctly when being taken down and transported.

15.3 THE IMPLICATION OF REGULATION ON THE CIRCULAR LOOPS IN THE COMPANIES

Regulation can help close the material loops in the circular economy by setting requirements to reduce resource and energy consumption and improve the possibilities for maintenance, repair, reuse, reconditioning, remanufacturing and recycling. The different tools in the IPP policy mix have already improved these aspects, however there is, as documented in part one, still a potential for improvement. However, regulation can also hinder some of the strategies to close the material loops or even make them impossible to achieve. An example of this is the RoHS Directive, which has implications for remanufacturing. The RoHS Directive has, according to the waste handlers, improved the recyclability and the recovery of materials from WEEE(Ellegaard 2013). However, the RoHS Directive can also complicate other strategies to close the material loops in the circular economy, as when a certain substance is restricted in the RoHS Directive, it can hinder the remanufacturing of a component or product containing that restricted substance.

B&O experienced this in their remanufacturing loop for components in their repair and service scheme(Manager Technical Product Service 2013). When the RoHS Directive was implemented in the Danish legislation, the manager of Technical Product Service at B&O had a dialogue with the Danish EPA to establish whether B&O's remanufactured components produced before the RoHS Directive came into effect could be used to repair new products complying with the RoHS Directive(Manager Technical Product Service 2013). It turned out that the components could not be used in the new products(Manager Technical Product Service 2013). The manager of Technical Product Service therefore had two options: either to have two repair loops, one for products before the RoHS Directive came into effect and one for products after it came into effect, or to discard all old components from the repair loop(Manager Technical Product Service 2013).

The RoHS Directive improves the recyclability of materials but makes the remanufacturing of components and products difficult. Therefore, it is important when developing minimum requirements to also consider the implications for reuse, repair, remanufacturing and reconditioning. The new regulations should not hinder the resale, reuse, reconditioning and remanufacturing of old products unless the environmental or health benefits from banning the products exceed those from prolonging the lifetime of the products. Furthermore, regulations should provide clear guidelines on how the requirements concern resale, reuse, reconditioning and remanufacturing.

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Appendix A. Design requirements and recommendations

The specific recommendations identified in the Ecodesign Pilot, ECMA 341 standard and the result of the examination of specific design recommendations targeting remanufacturing are provided in table 15-2.

	Design for Material Efficiency	**Source**
	Design product for minimum consumption of process materials	Ecodesign Pilot
	Prefer the use of recycled materials (secondary materials)	Ecodesign Pilot ECMA
	Preferably use single material components and/ or reduced number of different types of materials	Ecodesign Pilot ECMA
	Reduce materials input by design aiming at optimum strength	Ecodesign Pilot
	Reduce materials input by integration of functions	Ecodesign Pilot
	Use materials with a low environmental impact	Ecodesign Pilot ECMA
	Avoid and/ or minimise waste at use stage	Ecodesign Pilot
	Reduce the amount of materials used and the weight of the product	ECMA
	Consider functions to reduce or save the use of consumables	ECMA
	Consider ease of replacement and maintenance of consumables	ECMA
	Design for Energy Efficiency	**Source**
	The designer shall identify specific power modes, which apply to the product under development	ECMA
	The designer shall consider energy efficiency measures for the identified power modes	ECMA
	The designer should identify where power is consumed with the product and which units or components can be improved to reduce overall power consumption	ECMA
	The designer should consider using low power components and design options as well as efficient power supply components such as voltage regulators and DC-DC converters to reduce the power consumption in the on modes.	ECMA
	The designer should consider identified modes when specifying the power supply. The AC-DC conversion efficiency should be high in the most used modes.	ECMA
	The designer should consider the true specification needs for the product	ECMA

	The designer should consider the effect of the operating environmental specification provided to users and installers.	ECMA
	The designer should consider practical design options to automatically switch from on mode to save modes. The save mode settings should be adjustable by the user.	ECMA
	The designer should consider the effect of the time to resume on the user acceptance to use the save modes extensively.	ECMA
	The designer should consider design options to reduce the power consumption in the energy save modes.	ECMA
	Inform the user of the higher power consumption if the save mode is disabled	ECMA
	Consider design options to automatically switch from save mode to off mode	ECMA
	Reduce the power consumption in the soft off modes to the lowest values	ECMA
	Place the main power switch on the product so the use can easily reach and use it	ECMA
	Inform the user if zero Watt in the state a user would consider hard off is not achievable	ECMA
	Consider design options that reduce power consumption of no load mode to the lowest value	ECMA
	Minimise energy consumption at use stage by increasing product efficiency	Ecodesign Pilot
	Minimize energy demand at use stage by choosing an adequate principle of function	Ecodesign Pilot
	Design for maintenance	**Source**
	Design product for easy cleaning and/ or minimize susceptibility to soiling	Ecodesign Pilot
	Concentrate wear on replaceable components of products	Ecodesign Pilot
	Make signs of wear easily visible	Ecodesign Pilot
	Indicate service intervals for product	Ecodesign Pilot
	Ensure maintenance with standard tools	Ecodesign Pilot
	Ensure high reliability of product	Ecodesign Pilot
	Ensure high functional quality and minimise influence of possible disturbance	Ecodesign Pilot
	Design product for adjustment and adaptation at use stage	Ecodesign Pilot
	Design for possible upgrading	Ecodesign Pilot
	Realise simple principle of function	Ecodesign Pilot
	Design for repair	**Source**
	Ensure self-explanatory structure or provide instructions for repair on product	Ecodesign Pilot
	Ensure easy access to components for repair and replacement	Ecodesign Pilot

	Ensure availability of spare parts	Ecodesign Pilot
	Standardised components and/ or use identical structural components for different variants of products	Ecodesign Pilot
	Ensure re-workability of worn components	Ecodesign Pilot
	Use refurbished components as spare parts	Ecodesign Pilot
	Design for reuse of product parts	**Source**
	Ensure simple assembly through hierarchical structure of product	Ecodesign Pilot
	Ensure simple assembly by reduction of parts used	Ecodesign Pilot
	Provide for testing and measuring devices for the refurbishing of components	Ecodesign Pilot
	Provide for over measure of material with a view to the reuse of components	Ecodesign Pilot
	Label components to indicate remaining service life	Ecodesign Pilot
	Ensure ease of cleaning for reuse of components	Ecodesign Pilot
	Use standardised elements, parts, and components for easy reuse	Ecodesign Pilot
	Reuse of components in other products	Ecodesign Pilot
	Reuse of components, parts and systems whenever applicable	Ecodesign Pilot ECMA
	Design for durability	**Source**
	Timeless product design	Ecodesign Pilot
	Ensure high appreciation of the product	Ecodesign Pilot
	Design product for long service life	Ecodesign Pilot
	A sturdy product design	Ecodesign Pilot
	User friendly surfaces	Ecodesign Pilot
	Ensure corrosion resistance	Ecodesign Pilot
	Harmonize service life of individual components	Ecodesign Pilot
	Use of common mechanical packages (covers and chassis) or common parts or components that are used for multiple models in the product family or multiple generations of the same product, allowing for the reuse of common parts.	Ecma
	Use of industry standard parts that may be more easily replaced or repaired	Ecma
	Use of modular components	Ecma
	Information on options for upgrading, expanding and repair of the product	Ecma
	Batteries should be easy to identify and remove unless the lifespan exceeds that of the product and the equipment is reliant on continuous power supply	Ecma
	Information on the batteries in the product shall be made available	Ecma
	Battery management features that prolong the durability of	Ecma

	batteries shall be considered	
	Design for recyclability	**Source**
	Avoid or reduce the use of toxic materials and components	Ecodesign Pilot
	Prefer materials from renewable raw materials	Ecodesign Pilot
	Avoid inseparable composite materials	Ecodesign Pilot
	Avoid raw materials, components of problematic origin	Ecodesign Pilot
	Prefer the use of recycled materials (secondary materials)	Ecodesign Pilot
	Preferably use single material components and/or reduce number of different types of material (Mono-materials)	Ecodesign Pilot
	Ensure labelling of materials conforming to standards	Ecodesign Pilot
	Make possible separation of materials for recycling	Ecodesign Pilot
	Ensure simple extraction of harmful and valuable substances	Ecodesign Pilot
	Ensure that materials are suitable for recycling	Ecodesign Pilot
	Ensure that surface coating and base material are suitable for recycling	Ecodesign Pilot, ecma
	Make possible extraction of process materials and unavoidable harmful substances	Ecodesign Pilot
	Take into account end-user's opportunities for disposal and provide for instructions for disposal	Ecodesign Pilot
	Easy and safe separation of parts containing hazardous substances and preparation shall be possible	ecma
	Limitations to chemical content	ecma
	Incompatible materials (including electronic modules) connected to case/ housing parts or chassis shall be easily separable	ecma
	Disassembly down to the module level (e.g. power supply, disk drive, circuit board) shall be possible using commonly available tools and all such parts shall be accessible.	ecma
	Type of polymer, co polymer, polymer blends or alloys of plastic parts including additives with a weight greater than 25 g shall be indicated through a marking in conformance with ISO 11469	ecma
	Avoid the use of coatings and surface finishes on plastic parts that are difficult to recycle without downgrading	ecma
	Avoid the use of adhesive backed stickers or foams on plastic parts	ecma
	Avoid the use of metal inserts in plastic parts (unless easily removable with common tools)	ecma
	Use the same polymer throughout the design of a product or limited the number of plastic types used in the product	ecma
	Use labels and other identification marks made from the same material as the body of the product or a compatible	ecma

	material	
	Batteries should be easy to identify and remove.	ecma
	Information on batteries should be made available	ecma
	Alternative batteries with reduced environmental impact should be considered	ecma
	Batteries should not contain more than 5 ppm of mercury by weight.	ecma
	Design for disassembly	**Source**
	Ensure easy access to connecting parts	Ecodesign Pilot
	Ensure reversibility of assembly procedure	Ecodesign Pilot
	Design product structure for easy disassembly (uniform directionality for assembly and disassembly work)	Ecodesign Pilot
	Minimize time and paths for disassembly	Ecodesign Pilot
	Use easily detachable connections	Ecodesign Pilot
	Ensure easily visible access to connections for disassembly	Ecodesign Pilot
	Ensure easy access to connecting parts for disassembling tools	Ecodesign Pilot
	Ensure functioning of connections over whole service life	Ecodesign Pilot
	Reduce the number and variety of welds and adhesives	ecma
	Reduce the number and variety of connections (e.g. fastener and screws)	ecma
	Reduce the number and variety of steps necessary for disassembly	ecma
	Reduce the number and variety of tools required for disassembly	ecma
	Reduce the number and variety of position changes that have to be made by the dismantler	ecma
	Design for ease of disassembly and therefore use snap fits or screws	ecma
	Making disassembly plans including information on disassembly, identification of potentially valuable and/ or reusable parts, identification of parts containing hazardous substances and special handling and disposal precautions.	ecma
	Design for Remanufacturing	**Source**
Disassemble product	For components distained for reuse ensure that their materials are sufficiently durable to survive disassembly	(Ijomah et al., 2007)
	Ensure that fasteners' materials are similar or compatible to that of base materials thus limiting opportunity of damage to parts during disassembly	(Ijomah et al., 2007)
	Use assembly methods that allow disassembly without damage to components	(Ijomah et al., 2007)
	Arrange components for ease of disassembly	(Ijomah et al., 2007)
	Reduce the total number of parts	(Ijomah et al., 2007)

	Reduce the complexity of disassembly for example by standardising fasteners	(Ijomah et al., 2007)
	Use modular components thus reducing complexity of disassembly because types of assembly techniques are reduced	(Ijomah et al., 2007)
	Arrange components so that separation joints are easily accessible and easily identifiable	(Ijomah et al., 2007)
	Minimise the number of joints	(Ijomah et al., 2007)
	Reduce/ eliminate redundant parts	(Ijomah et al., 2007)
	Simplify and standardise components fits	(Ijomah et al., 2007)
Cleaning	Use materials that would survive cleaning process e.g. ensure that materials melting point is higher than cleaning process temperature	(Ijomah et al., 2007)
	Limit the number of material types per part	(Ijomah et al., 2007)
	Identify components requiring similar cleaning procedures and cleaning agents	(Ijomah et al., 2007)
	Use assembly methods that allows disassembly at least to the point that internal components can be accessed for cleaning	(Ijomah et al., 2007)
	Ensure that all parts to be cleaned are easily accessed	(Ijomah et al., 2007)
	Reduce/ eliminate redundant parts	(Ijomah et al., 2007)
	Arrange components so that all can be accessed for effective cleaning	(Ijomah et al., 2007)
	Ensure product surfaces are smooth and wear resistant	(Ijomah et al., 2007)
Remanufacture and test components	Use materials that are at least durable enough to survive the refurbishment process	(Ijomah et al., 2007)
	Use materials that do not prevent upgrade and rebuilding of the product	(Ijomah et al., 2007)
	Identify component materials	(Ijomah et al., 2007)
	Use assembly methods that would allow disassembly at least to the point that internal components and subsystems requiring work can be accessed	(Ijomah et al., 2007)
	Use assembly methods that do not prevent upgrade of product	(Ijomah et al., 2007)
	Use joining methods that allow disassembly at least to the point that internal components and subsystems requiring it can be accessed for testing before and after refurbishment	(Ijomah et al., 2007)
	Incorporate fault tracking device	(Ijomah et al., 2007)
	Reduce/ eliminate redundant parts	(Ijomah et al., 2007)
	Structure to facilitate ease of upgrade of product	(Ijomah et al., 2007)
	Arrange components for ease of access to parts prone to damage	(Ijomah et al., 2007)
	Standardised parts	(Ijomah et al., 2007)
	Structure for ease on determining component condition	(Ijomah et al., 2007)

	Structure to testing is sequential, mirroring reassembly order	(Ijomah et al., 2007)
	Minimize the disassembly level required to effectively test components	(Ijomah et al., 2007)
	Standardise test procedures	(Ijomah et al., 2007)
	Clearly identify component load limits, tolerances and adjustments	(Ijomah et al., 2007)
Assemble product	Limit the number of different materials	(Ijomah et al., 2007)
	Identify components requiring similar tools and techniques	(Ijomah et al., 2007)
	Choose assembly methods that do not prohibit disassembly without damage to reusable components	(Ijomah et al., 2007)
	Use assembly methods that facilitate easy disassembly without damage to reusable components	(Ijomah et al., 2007)
	Apply design for assembly methods that do not prevent disassembly without damage to components	(Ijomah et al., 2007)
	Reduce complexity of reassembly e.g. standardised fasteners	(Ijomah et al., 2007)
	Reduce structural complexity	(Ijomah et al., 2007)
	Identify components assembly sequence	(Ijomah et al., 2007)
	Reduce redundant parts	(Ijomah et al., 2007)
	Standardised parts	(Ijomah et al., 2007)
	Structure for ease of access to short life and prone to break down parts	(Ijomah et al., 2007)
	Use modular structure so that obsolescence occur with component rather than with entire product	(Ijomah et al., 2007)

Table 15-2: Design recommendations from the Ecodesign Pilot, the ECMA 341 and Ijomah et al (2007) covering material efficiency, energy efficiency, maintenance, repair, reuse of product parts, durability, recyclability, disassembly and remanufacturing. The recommendations are direct quotes from the guidelines.

SUMMARY

The Earth is a closed system and with the exception of energy, the resources available to us are finite, but our consumption and productions systems are typically linear systems where resources are extracted, used and wasted. The circular economy is proposed as an alternative and is defined as a consumption and production system based on closed loops that minimise resources, energy flows and environmental degradation. In this PhD thesis, I have examined how ecodesign can close the material loops in the circular economy for electrical and electronic equipment. The study examines how to improve resource efficiency through regulation and how companies can design products for closed material loops. The study of the European product policies showed that the policies can improve resource efficiency, but the potential of the product policies and their synergies can be utilised further. The Ecodesign Directive plays an important role as it can set minimum performance requirements for several resource efficiency aspects. The studies of Bang & Olufsen and Tier1Asset revealed that existing ecodesign guidelines can be applied to improve the recyclability and the reconditioning potential, but it can be necessary to develop both product and company specific guidelines. The analysis revealed that activities or product attributes of importance to a circular economy are not solely driven by ecodesign.

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