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Designing out Waste

MUDP report

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1. Foreword

Designing out Waste was a research and development project financed by MUDP program (Miljøteknologisk Udviklings- og DemonstrationsProgram). This is the final report of the project that ran from January 2013 till January 2015, while the dissemination activities have continued in 2015 until 2017. Part of the Designing out Waste project has also been the basis for the PhD thesis *"Ecodesign for a Circular Economy. Regulating and Designing Electrical and Electronic Equipment"* by Anja Marie Bundgaard (Bundgaard, 2016). In the PhD thesis, further details on some of the case studies can be found.

We would like to thank all the four companies that participated in the projects Bang & Olufsen, Tier1Asset, Lightyears and Siemens Gamesa Renewable Energy. Thanks for their participation in interviews, workshops and feedback on the final reporting of the workshop.

The report begins with an introduction to the theme and a description of the objectives of the project. Hereafter, the report is divided into two main parts. Part one is a literature review examining: the ecodesign concept, the current treatment of waste electrical and electronic equipment, the current European regulation of electrical and electronic equipment and how it supports resource efficiency, the existing standards supporting ecodesign and finally best praxis examples from abroad.

Part two is the description of the four case companies Bang & Olufsen, Tier1Asset, Lightyears and Siemens Gamesa Renewable Energy, and the main results of the different workshops conducted at the case companies. Søren Kerndrup and Henrik Riisgaard from Aalborg University took active part in the workshop at Lightyears. The case description of Siemens Gamesa Renewable Energy is primarily made by Jonas Pagh Jensen, who also has been an industrial Ph.D. at the company.

2. Konklusion og sammenfatning

Et mere ressourceeffektivt samfund eller en cirkulær økonomi kræver et gennemgribende skifte fra den nuværende vækstmodel, der er afhængig af let, billig og ubegrænset adgang til råmaterialer, og hvor det biologiske system fungerer som affaldsdepot. Dette er også gældende for elektrisk og elektronisk udstyr, som er præget af øget forbrug, relativt korte levetider på grund af både teknologisk og psykologisk forældelse samt utilstrækkelig affaldsbehandling.

I denne rapport er ressourceeffektivitet mere præcist defineret som *"at bruge jordens begrænsede ressourcer på en bæredygtig måde, samtidig med at miljøpåvirkningerne minimeres. Det giver mulighed for at skabe mere med mindre og at levere større værdi med mindre input."* (Commission, 2017). I denne rapport er der gennemgået fem overordnede strategier til at forbedre ressourceeffektiviteten: (1) reduktion og optimering af miljøperformance, (2) vedligeholdelse og reparation, (3) genbrug, (4) istandsætte og genfremstillen og (5) genanvendelse.

Elektronisk og elektrisk udstyr er typisk ikke designet til at være ressourceeffektivt eller til at kunne vedligeholdes, repareres, genbruges, istandsættes, genfremstilles eller genanvendes. Derfor har projektet undersøgt, hvordan ressourceeffektiviteten kan forbedres gennem ecodesign af elektronisk og elektrisk udstyr.

Formålet med projektet var at formidle allerede eksisterende viden om, hvordan produkter kan designes mere ressourceeffektivt gennem ecodesign samt gennem praksisbaseret forskning at videreudvikle og formidle forskellige metoder til at opnå et ressourceeffektivt design.

Mere specifikt har projektet haft til formål at øge ressourceeffektiviteten og omdanne affald til en ressource ved at:

1. Teste forskellige *metoder til ecodesign* på forskellige og specifikke produktgrupper
2. Få *praktisk erfaring* med forbedring af ressourceeffektivitet samt lukning af materialestrømme gennem samarbejde med virksomheder
3. Videreudvikle *kommunikations- og samarbejdsformer* mellem producenterne og affaldsbehandlerne.

Dette blev undersøgt gennem fire casestudier af henholdsvis Bang & Olufsen (B&O), Tier1Asset, Lightyears og Siemens Gamesa Renewable Energy. Nærmere detaljer om formålet med casestudierne og de berørte ressourceeffektivitetsstrategier, ecodesign metoder og produktgruppen findes i Tabel 1 nedenfor.

Desuden blev der gennemført et litteraturstudie af ecodesign, affaldsbehandling af elektrisk og elektronisk udstyr, europæisk regulering af elektrisk og elektronisk udstyr, eksisterende standarder der understøtter ecodesign samt internationale studier, som har behandlet lignende problemstillinger.

Men allerførst trækkes hovedkonklusionerne op. De tre første konklusioner svarer direkte på ovenstående tre formål med projekter; men de tre efterfølgende tilstræber at pege fremad i relation til hvad der så kan gøres.

Hovedkonklusioner fra Designing-out-waste

På baggrund af de gennemførte interviews og samarbejdet med virksomhederne, så kan følgende seks konklusioner fremhæves som de centrale. Konklusionerne er trukket lidt skarpt op som one-liners, og bliver så nuanceret og forklaret efterfølgende i teksten.

1) Ecodesign guidelines er stadig relevante og dækkende

Nogle af ecodesign værktøjerne er udviklet for 20-25 år siden, men er stadig uhyre relevante i relation til levetidsforlængelse, istandsættelse og genanvendelse samt med fornyet aktualitet i relation til cirkulær økonomi. Hvis blot disse guidelines gennem årene var blevet anvendt i design- og produktudvikling, så havde principperne i den cirkulære økonomi nærmest været implementeret i praksis. Brugen heraf kan givetvis øges ved at gøre værktøjerne mere produktspecifikke og detaljerede, samt via efteruddannelse og kurser for designere og produktudviklere. Producenterne kan også gentænke forretningsmulighederne ved at tilbyde service- og vedligeholdelseskontrakter. Endelig kan der lægges mere vægt på istandsættelse (refurbishment), hvor produkterne får forlænget levetiden via reparation og opgradering.

2) Affaldsbehandlerne er interesseret i et bedre design men er ikke udfarende

Affaldsbehandlerne er så absolut interesseret i, at produktdesignet forbedres med henblik på at gøre affaldsbehandlingen nemmere, og forbedre ressourceudvindingen og rentabiliteten i genanvendelsen. MEN affaldsbehandlerne er ikke proaktive og udfarende i forhold til produktdesignet, og kun få enkeltpersoner hos affaldsbehandlerne interesserer sig herfor, når det kommer til stykket. Affald som ressource bliver ved skåltalerne. Retfærdigvis kan fremhæves at med producentansvaret, så burde producenterne være de udfarende i forhold til ecodesign af produkterne, men dette sker kun relativt begrænset på eget initiativ.

3) Samarbejdet produktudviklere og affaldsbehandlere er ikke eksisterende

Samarbejdet om produktdesign mellem designere / produktudviklere og affaldsbehandlere er reelt ikke eksisterende, som fremhævet. Ideen med at afholde workshops var netop at etablere denne dialog på tværs af det formodede skel; men dette har været betydeligt vanskeligere end forudset. Behovet er der, men er ikke erkendt – endsige prioriteret – af nogen af parterne. Med de nuværende institutionelle rammer med kollektivordningerne, så er der ingen incitamenter, som virker fremmende for dialog og samarbejde mellem producenter og affaldsbehandlere om produktdesign.

4) Cirkulær økonomi tilbyder forretningsmæssige potentialer i samarbejdet

Cirkulær økonomi er en mulighed for at løfte denne dagsorden til en strategisk indsats hos ledelsen i virksomhederne med en højere grad af prioritet til ressourceeffektivitet i form af både en reducering og en lukning af stofstrømmene. Forretningsmulighederne i form af koble høj produkt kvalitet, holdbarhed og reparationsvenlighed med eksempelvis forretningsmodeller så som leasing og produkt service systemer er endvidere trådt tydeligere frem via debatten om cirkulær økonomi.

5) Virksomheder indenfor istandsættelse som brobyggere

Virksomheder i relation til istandsættelse er desuden specielt interessante i en cirkulær økonomi, da hele deres forretningside hviler på en forsinkelse af stofstrømmene ved at forlænge produktets levetid og give produktet et nyt liv. Denne type virksomheder er potentielle murbrækkere i relation til ”designing-out-waste”, da de dagligt har med problemstillingerne at gøre og hvor de tilstræber at bevare værdien i produkterne bedst muligt. De har således i højere grad incitament til at fungere som dialogpartner og brobygger til producenterne end affaldsbehandlerne. Tilsvarende kan Maker Spaces, Reparationsværksteder og lignende også fungere som brobyggere og fortælle om avancerede brugeres forventninger til teknologien.

6) **Skab de institutionelle rammer for designing-out-waste**

Producenterne har varierende behov, ambitionsniveau og er på forskellige stadier, men procentansvaret har ingen effekt i forhold til ecodesign på grund af bidragets størrelse og den manglende differentiering af produkterne indenfor kollektivordningen. Med EU's fokus på standarder og ecodesign i cirkulær økonomi pakken, så bliver der på sigt skabt forudsætningerne for at "designe-out-waste" via krav til produkternes holdbarhed, reparationsvenlighed, genbrug af komponenter, etc. Synergien mellem WEEE, RoHS samt Ecodesign Direktiverne kan endvidere styrkes yderligere, således Ecodesign Direktivet understøtter de krav til design forbedringer af produkterne, der bliver sat i RoHS og WEEE Direktivet.

Producenterne kan vente på, at EU opstiller egentlige lovgivningsmæssige krav til produkterne i ecodesign direktivet. Eller de kan tage udfordringen op på forkant og bruge ecodesign værktøjerne i produktudviklingen og ved i øvrigt at gå i dialog med refurbish virksomheder, affaldsbehandlere, myndigheder og vidensinstitutioner om at forbedre produktdesignet i relation til:

- øget ressourceeffektivitet og –optimering af produkterne (reduce/narrowing)
- forlænget produktlevetid via designændringer og nye forretningsmodeller (prolong)
- istandsættelse og fornyelse af "udtjente" produkter (slowing)
- forbedret kvalitet i genanvendelsen med øget genindvinding (closing)

Første del: Litteraturgennemgangen

I projektet blev ecodesign defineret som implementering af miljøaspekter i designprocessen, og hvor hele produktets livscyklus indtænkes. Gennemgangen af litteratur om ecodesign viste, at implementeringen af ecodesign i virksomheder forsat er en udfordring. Dette understreger relevansen af projektet, hvor der netop blev arbejdet med implementering af forskellige ecodesign i praksis. Derudover blev en række ecodesign værktøjer identificeret herunder to værktøjer, som gav specifikke ecodesign anbefalinger til hvordan man kan forbedre produkternes ressourceeffektivitet, og som derfor var relevant i det videre arbejde. De to ecodesign værktøjer var Ecodesign Piloten og den europæiske sammenslutning for standardisering af informations- og kommunikationssystemers (ECMA) 341 standarden for ecodesign af informations- og kommunikationsteknologi og forbrugerelektronik. Desuden blev design anbefalinger dækkende istandsættelse og genfremstilling suppleret ved brug af Ijomah et al. (2007).

I Europa er genanvendelse af elektronisk og elektrisk udstyr i vid udstrækning baseret på mekaniske, destruktive og automatiske teknologier, og manuel demontering anvendes kun i ringe omfang. Derfor vil ecodesign anbefalinger med det formål at lette demonteringen af produktet eller produktets dele ikke nødvendigvis forbedre produkternes genanvendelse. Litteraturgennemgangen viste dog, at det er en fordel at designe produkterne, således at komponenter let kan demonteres, især de der indeholder farlige stoffer eller særligt værdifulde materialer (såsom ædle metaller), eller kræver særlig affaldsbehandling, da det forbedrer genanvendelsen- og genindvindingspotentialet.

Samtidig er det værd at huske, at de produkter som designes nu først ender som affald og dermed i affaldsbehandlingssystemet om 5-10 år, og produkterne skal derfor designes til det fremtidige affaldsbehandlingssystem og ikke det nuværende. Affaldsbehandlingen af elektronisk og elektrisk udstyr er under konstant forandring, og det er derfor usikkert, hvordan systemet vil se ud om 5-10 år. I øvrigt kan modul opbygning og nem demontering også forfine andre strategier til forbedring af ressourceeffektivitet såsom vedligeholdelse, reparation, istandsættelse og genfremstilling.

Kritiske materialer og ædle metaller anvendes i vid udstrækning i elektrisk og elektrisk udstyr. Syv materialer eller materialegrupper er særligt kritiske for elektrisk og elektronisk udstyr på grund af deres teknologiske anvendelse og lave genindvindingsprocenter, herunder antimon, kobolt, gallium, germanium, indium, sjældne jordmetaller og tantal. Genindvindingen af mange af disse materialer fra affald kan forbedres, hvis komponenter indeholdende disse kritiske materialer adskilles og sendes til særlig affaldsbehandling, og hvis de relevante genanvendelsesteknologier videreudvikles og skaleres op.

I Europa er ressourceeffektiviteten af elektrisk og elektronisk udstyr reguleret gennem seks direktiver og forordninger, herunder Direktivet om fastlæggelse af krav til miljøvenligt design af energirelaterede produkter (Ecodesign direktivet), Direktivet om affald af elektrisk og elektronisk udstyr (WEEE direktivet), Direktivet om begrænsning af anvendelsen af visse farlige stoffer i elektrisk og elektronisk udstyr (RoHS direktivet), forordningen om energimærkning, den europæiske miljømærkningsforordning og direktivet om visse aspekter af forbrugerkøb og garantier i forbindelse hermed.

Direktiverne og forordningerne dækker forskellige aspekter af ressourceeffektivitet. WEEE og RoHS direktivet har primært fokus på forbedret genanvendelsen af elektrisk og elektronisk affald. Ecodesign direktivet og den europæiske miljømærkeordning kan indenfor deres rammer sætte krav til alle fem identificerede strategier til forbedring af ressourceeffektiviteten og de gør det faktisk allerede. Ecodesign direktivet har dog hidtil (juli 2017) kun fastsat specifikke krav til ressourceeffektivitet i fem gennemførelsesforanstaltninger og 2 frivillige aftaler. Mens den europæiske miljømærkeordning dækker kun få elektriske og elektroniske produktgrupper, og elektronikindustriens brug af miljømærkeordningen er fortsat lav. Den europæiske energimærkeordning har hovedsagelig forbedret energieffektiviteten. Direktivet om visse aspekter af forbrugerkøb og garantier i forbindelse hermed har forbedret mulighederne for vedligeholdelse og reparation ved at fastsætte en toårig garantiperiode og sætte krav til reparation.

De seks direktiver og forordninger har forskellige midler til at forbedre ressourceeffektiviteten. Nogle er obligatoriske instrumenter, der fastsætter minimumskrav (Ecodesign direktivet, WEEE direktivet, RoHS direktivet og direktivet om visse aspekter af forbrugerkøb og garantier i forbindelse hermed). Den europæiske energimærkeordning driver det eksisterende marked mod øget effektivitet (primært energi) gennem obligatoriske krav til forbrugeroplysninger. Den europæiske miljømærkning derimod stræber efter at forbedre ressourceeffektiviteten af de miljømæssigset bedste produkter på markedet. Ideen med de forskellige instrumenter er, at de skal understøtte hinanden ved at anvende forskellige midler til at forbedre ressourceeffektiviteten af elektrisk og elektronisk udstyr. Denne synergi er dog ikke blevet udnyttet til fulde endnu.

Der findes allerede standarder for ecodesign og integrationen af miljømæssige aspekter i designfasen. I dette projekt blev to relevante standarder og en teknisk rapport identificeret, det drejer sig om:

- Standard: ISO 14006:2011: Miljøledelsessystemer - Vejledning i indarbejdelse af ecodesign
- Teknisk rapport: ISO/ TR 14062:2002 Miljøledelse - Integrering af miljøforhold i produktdesign og –udvikling
- Standard: ECMA-341 standard for ecodesign af informations- og kommunikationsteknologi og forbrugerelektronik

ISO 14006:2011 og ISO/TR 14062:2002 er generiske ledelsesstandarder/ tekniske rapporter med fokus på, hvordan man implementerer ecodesign i eksisterende miljøledelsessystemer, produktdesign og udviklingsprocesser. ECMA-341-standarden derimod er specifik for informations- og kommunikationsteknologi og forbrugerelektronik, og den giver specifikke ecodesign anbefalinger til forbedring af produktets miljømæssige ydeevne. Endelig er der nye standarder under udvikling i forbindelse med standardiseringsmandatet M/543 om krav til miljøvenligt design med fokus på materialeeffektivitetsaspekter for energirelaterede produkter.

To centrale internationale initiativer med henblik på at forbedre ressourceeffektiviteten af elektrisk og elektronisk udstyr, blev undersøgt, nemlig Solving the E-waste Problem (StEP) og Waste Resource Action Programme (WRAP). StEP initiativet fokuserer udelukkende på at løse det stigende problem med elektrisk og elektronisk affald gennem fem nedsatte arbejdsgrupper: om henholdsvis regulering, om gendesign af produkter, om genbrug, om genanvendelse samt arbejdsgruppen med fokus på kapacitetsopbygning. WRAP initiativets mission er at accelerere overgangen til en mere bæredygtig og ressourceeffektiv økonomi. Initiativet har fokus på tre sektorer mad og drikkevarer, el og elektronik og tøj og tekstiler. To centrale bidrag har haft fokus på at skabe ressourceeffektivt design af elektriske og elektroniske produkters, nemlig WRAPs vejledninger om bedre apparater og deres gennemgange af designet af elektriske produkter.

Del 2: Casestudierne

I alt blev der gennemført fire casestudier, der undersøgte forskellige ecodesign tilgange og forskellige strategier til at forbedre ressourceeffektivitet. Hovedresultaterne fra de fire casestudier gennemgås her i oversigtsform og efterfølgende mere uddybende.

TABEL 1. Oversigt over casestudierne med angivelse af formålet, de berørte ressourceeffektivitetsstrategier, ecodesign metoder og produktgrupper.

Virksomheden	Formålet	Ressourceeffektivitetsstrategi	Den testede ecodesign strategi	Produktgruppen
B&O	At undersøge, hvordan man kan forbedre genanvendelsen af B&O's produkter gennem ecodesign og hvordan man kan forbedre vidensdelingen og samarbejdet mellem producenterne og affaldsbehandlerne	Hovedfokus var på genanvendelse men alle fem strategier blev berørt.	Specifikke ecodesign anbefalinger	Fjernsyn, fjernbetjeninger og højtaler
Tier1Asset	At undersøge de nødvendige betingelser for istandsættelse og hvordan designet af bærebare og stationære computer kan forbedres således at potentialet for istandsættelses øges	Istandsættelse	Specifikke ecodesign anbefalinger	Bærbare og stationære computer
Lightyears	At undersøge hvordan man gennem en workshop kan understøtte udvikling af en miljøstrategi i en virksomhed med fokus på at forbedre ressourceeffektiviteten	Alle fem strategier	Ecodesign på et strategisk niveau faciliteter gennem arbejdet med kausal-kortlægning	Belysning
Siemens Gamesa Renewable Energy	At eksperimentere med forskellige metoder til at genanvende sjældne jordarter i magneter	Genanvendelse af sjældne jordarter	Ecodesign i forhold til en strategisk vigtig ressource	Vindmøller

Formålet med B&O casestudiet var at undersøge, hvordan genanvendelsen af deres produkter kan forbedres gennem ecodesign, og hvordan man kan forbedre vidensdelingen og samarbejdet mellem producenter og affaldsbehandlere. Dette blev undersøgt gennem en workshop med deltagere fra B&O, affaldssektoren samt universitet. Workshoppen begyndte med at en repræsentant fra affaldssektoren gav et oplæg om, hvordan man affaldsbehandler elektrisk og elektronisk udstyr. Dette oplæg sikrede, at alle deltager havde samme forståelse for de affaldsbehandlingsprocesser, som udstyret gennemgår. Derefter blev der arbejdet med at adskille tre nye B&O produkter, samtidig med at der løbende blev diskuteret, hvilken problemer produkterne kunne give i affaldsbehandlingen, og hvordan disse problemer kunne løses designmæssigt.

Workshoppen resulterede i femten ecodesign anbefalinger til at forbedre produkternes genanvendelse inden for fire kategorier: mærkning af komponenter, tilgængelig information, nem demontering og forurening af materialefraktioner og farlige stoffer. En sammenligning af disse anbefalinger med de eksisterende ecodesign anbefalinger i Ecodesign Piloten og ECMA-341-standarden viste, at seks ud af de femten ecodesign anbefalinger allerede var omfattet af de eksisterende manualer. Syv ecodesign anbefalinger blev delvist dækket men var mere detaljerede og/eller produktspecifikke. To ecodesign anbefalingerne blev derimod ikke dækket af de eksisterende ecodesign manualer men var helt nye. Ecodesign anbefalingerne i Ecodesign Piloten og ECMA-341 standarden er således fortsat relevante i forhold til at forbedre genanvendelsen, men de kan gøres mere detaljerede og produktspecifikke. Workshopformatet fungerede godt og skabte den nødvendige videns udveksling mellem affaldssektoren og producenterne. Hvad der kunne forbedres var deltagersammensætningen, således at der medtages flere repræsentanter fra de forskellige afdelinger i B&O involveret i produktudviklingen.

Tier1Asset istandsætter bærbare og stationære computere, servere, printere, smartphones og tablets. Formålet med casestudiet af Tier1Asset var at undersøge de nødvendige betingelser for istandsættelse af disse produktgrupper, samt hvordan designet af bærbare og stationære computere kunne forbedres således at potentialet for istandsættelse øges. Tier1Assets processer omfatter hjemtagning af produkterne, rengøring heraf, datasletning, tilpasning af produkterne efter kundens ønsker, test af produktet og endelig klassificering af produktet. De foretager kun reparation af produkterne i et begrænset omfang, da de primært køber fungerende brugte produkter. Blandt de nødvendige betingelser for en levedygtig forretning hos Tier1Asset er, at de har mulighed for at opkøbe produkter af høj kvalitet og i et større antal. Derfor køber de primært brugte produkter fra større virksomheder og organisationer. En anden nødvendig betingelse er tillid fra både sælgeren af de brugte produkter og køberen af de istandsatte produkter. Sælgeren af det brugte udstyr skal have tillid til, at Tier1Asset kan sikre en fuldstændig datasletning, og køberne af de istandsatte produkter skal have tillid til kvaliteten af produktet. Casestudiet af Tier1Asset resulterede også i sytten ecodesign anbefalinger til, hvordan man kan forbedre istandsættelsespotentialet af bærbare og stationære computer.

En sammenligning af disse ecodesign anbefalinger med anbefalinger fra Ecodesign Piloten, ECMA-341-standarden og de designanbefaling for genfremstilling, som findes i Ijomah et al. (2007), viste at otte af anbefalingerne blev dækket af de eksisterende ecodesign anbefalinger. Otte andre anbefalinger blev delvist dækket af ecodesign anbefalingerne i de eksisterende værktøjer, men de var mere detaljerede og/eller produktspecifikke. En ecodesign anbefaling var ikke dækket af nogle af de eksisterende anbefalinger og var derfor helt ny, nemlig om designanbefalinger omkring brugen af BIOS kodeord. Derfor kan det konkluderes, at anbefalingerne i de eksisterende ecodesign værktøjer er relevante for istandsættelse af produkter, men de kan gøres mere detaljerede og produktspecifikke.

Lightyears er en virksomhed, som producerer designer lamper til kvalitets- og luksusmarkedet. De har ikke tidligere arbejdet systematisk med miljøaspekter og ressourceeffektivitet. Derfor var formålet med workshoppen hos Lightyears, at undersøge hvordan en workshop kan understøtte udvikling af en miljøstrategi i en virksomhed med fokus på at forbedre ressourceeffektiviteten. Workshoppen blev designet med udgangspunkt i en kausal kortlægning af virksomheden gennem kvalitative forskningsinterviews med nøglemedarbejdere. Det lykkes gennem workshopformatet at skabe en fælles forståelse af Lightyears og deres nuværende situation, hvilket understøttede dialogen om hvordan Lightyears kunne begynde at udvikle en miljøstrategi rettet mod ressourceeffektivitet. Workshoppen førte til identifikationen af seks aspekter Lightyears kunne arbejde videre med i deres miljøstrategi herunder leverandørstyring, designstrategi, adfærdskodeks for deres leverandører, designmanualer, materialefortegnelser, materialekendskab, CE-mærkning, herunder Ecodesign direktivet, RoHS-direktivet og WEEE-direktivet. Endeligt blev der stillet konkrete forslag til, hvordan Lightyears kunne fortsætte arbejdet med at udvikle en miljøstrategi med fokus på at forbedre ressourceeffektiviteten.

Fokus på at genanvende ressourcerne er højt oppe på dagsordenen i EU, og samtidig spiller sjældne jordarter en helt særlig rolle i udviklingen af vindmøller med en såkaldt direct-drive generator. Sammen med Siemens Gamesa Renewable Energy blev den aktuelle status på genanvendelse af NdFeB magneter undersøgt I den videnskabelige litteratur, og disse generatorer i vindmøllerne har et ganske betydeligt forbrug af sjældne jordarter. Dette blev suppleret med et langstrakt studie af, hvordan Siemens Gamesa Renewable Energy kan eksperimentere med at reducere, forsinke og lukke kredsløbet for sjældne jordarter. Workshops blev gennemført over flere omgange i en længere periode med forskellige test og forsøg for helt konkret at eksperimentere med forskellige metoder til at øge genanvendelsen, specielt med henblik på at lukke kredsløbet af de sjældne jordarter i magneterne. Konklusionerne blev, at genanvendelsesteknologier er stadig på udviklingsstadiet og at ingen kommercielle virksomheder kan tilbyde at sikre genanvendelsen. Vindmøllerne er designet således at de permanente magneter blive adskilt med kun begrænsede tab, og på grund af den store koncentration af sjældne jordarter i magneterne, så er genanvendelsen af disse økonomisk attraktivt. De næste skridt i at øge cirkulariteten af de permanente magneter i Vindmølleindustrien bliver beskrevet i kapitlet baseret på mulighederne for at reducere mængden af sjældne jordarter i magneterne (reducering) og for at udvide produkt levetiden (forsinkelse).

3. Conclusions and Summary

The transition to a more resource efficient and circular economy requires a radical shift from the current growth model, which is based on cheap, easy and unlimited access to raw materials, and where nature is used as a sink for waste. This is especially true for electrical and electronic equipment, which is characterised by increasing consumption, relatively short life spans due to both technological and psychological obsolescence and inappropriate waste treatment.

Resource efficiency was defined by EU 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.”* (Commission, 2017). Five strategies were considered: (1) reduce and optimise environmental performance, (2) maintain and repair, (3) reuse, (4) refurbish, recondition and remanufacture and (5) recycle.

Electronic and electrical equipment is typically not designed to be eco-efficient, maintained, repaired, reused, refurbished, reconditioned, remanufactured or recycled. The project has therefore examined how ecodesign can improve resource efficiency.

The objective of the project was to disseminate already existing knowledge on how to design products more resource efficient through ecodesign; and to engage in a practice-based research to further develop and disseminate methods for resource efficient design.

More specifically, the project aimed to increase resource efficiency and to convert waste into a resource by:

1. Testing different *ecodesign methods* and tools with specific product groups
2. Gaining *practical experiences* in improvement of resource efficiency and working together with companies to close the materials loops
3. Further developing the *communication and cooperation* between producers and the waste treatment sector

Four case studies were examined: Bang & Olufsen (B&O), Tier1Asset, Lightyears and Siemens Gamesa Renewable Energy. More specific details on the purpose of the case studies and the applied resource efficiency strategies, ecodesign methods and product groups can be found in Table 2.

A literature review was performed on the subjects of ecodesign, the treatment of waste electrical and electronic equipment, European regulation of electrical and electronic equipment, existing standards on ecodesign and the best practice examples from abroad.

The main conclusions are highlighted below. The three first conclusions directly reflect the three objectives above; while the three following conclusions aim at future recommendations related to what can and should be done.

Main conclusions from Designing-out-waste

Based on the interviews conducted and the workshops in collaboration with the enterprises involved, then the following six conclusions can be highlighted as the most important. The conclusions are written briefly and bold as one-liners and then expanded and explained.

1) Ecodesign guidelines are still relevant and comprehensive

Some of the ecodesign tools were developed 20-25 years ago, but are still relevant in relation to durability, reusability and recyclability and have renewed relevance in connection with circular economy. If these guidelines had been applied over the years in design and product development, then the principles behind circular economy would have been implemented in practise. Uptake of the tools can probably be improved by making the tools more product specific and detailed, and by creating courses and life-long learning for designers and product developers. Manufacturers should also rethink the business potentials of offering improved maintenance and service contracts. Finally, refurbishment should play a more important role by prolonging product life through repair and up-grading.

2) Waste managers are interested in improved design but are not proactive

The waste management companies are definitely interested in improved product design in order to ease waste handling and to improve the recovery of resources and the profitability of recycling. BUT waste management companies are not that proactive, do not take initiatives related to the product design, and only few individual waste handlers are specifically interested. Waste as a resource is more talk than walk in this sector. According to producer responsibility, manufacturers ought to be proactive in relation to the ecodesign of products, but this is also rather rare.

3) Collaboration between product designers and waste handlers is non-existent

Collaboration in product design between product designers and developers on one side and the waste management companies on the other is in reality non-existent. The idea of the workshops was exactly to establish dialogue across this expected gap. The need is there, but not fully realised or prioritised – by any of the partners. Under the current framework conditions, no incentives exist for this dialogue and for collaboration on product design between the producers and the waste handlers.

4) The circular economy offer new business potential in collaboration

Circular economy has the potential for making this agenda one of the strategic priorities of top management in the companies, and resource efficiency is including both narrowing (reducing and optimising the use of materials) and closing the flow of materials. The business potentials related to high product quality, durability and reparability can be combined with business models such as leasing and product service systems that has become more present in the debate on circular economy.

5) Refurbishment companies as bridge-builders

Refurbishment and remanufacturing enterprises are especially interesting in a circular economy, since their whole business idea is based on slowing material flows by prolonging the life time of the products. This type of enterprise can act as instrumental entrepreneurs in designing-out-waste, since they are dealing with these challenges on a daily basis, and have an interest in retaining the products at their highest value. Refurbishers can therefore be brokers and bridge builders to the producers to a greater degree than waste management companies. In the same way, Makers spaces, Repair shops, etc. can also be bridge builders and explain about advanced users' expectations to the technologies.

6) Creating the institutional framework for designing-out-waste

Producers have various needs and ambitions on different levels, but extended producer responsibility has no effect in relation with ecodesign due to the levels of the contributions and the lack of differentiation of products within a common producer responsibility scheme. EU has decided to develop standards and eco-design as part of the circular economy package, and in the long-term this can create frame-work conditions for “designing-out-waste” by setting requirements for product durability, reparability, the reuse of components, and so on. The synergy between WEEE, RoHS and the Eco-design Directive can be improved further, and the Ecodesign directive in particular can support the RoHS and WEEE directives by setting requirements to design improvements of the products.

Producers can wait for these types of requirements in the different product groups covered by the ecodesign directive, or they can take up the challenge and be proactive by applying the eco-design tools in product development and by entering into a dialogue with refurbishers, waste handlers, authorities and knowledge institutions on improved product design related to:

- increased resource efficiency and –optimisation of products (reduce/narrowing)
- prolong product lifetime via design changes and circular business models (prolong)
- refurbishment of used equipment (slowing)
- improved quality in recycling with increased recovery of materials (closing)

Part One: The Literature Review

Ecodesign was in the project defined as the implementation of environmental issues in the design process taking the entire life cycle of the product into consideration. The ecodesign literature review showed that the implementation of ecodesign into companies is still a challenge, emphasising the importance of this project. The literature review identified ecodesign tools, specifying ecodesign guidelines and recommendations to improve the resource efficiency relevant for further testing. The two ecodesign tools examined were the Ecodesign Pilot and the European Association for Standardising Information and Communication Systems (ECMA) 341 standard for environmental design considerations for information and communication technology (ICT) and consumer electronic (E) products. Design recommendations for remanufacturing were supplemented by Ijomah et al. (2007).

In an European context, the recycling chain for waste electrical and electronic equipment (WEEE) is to a large extent based on mechanical, destructive and automatic technologies, and manual disassembly is only applied on a small scale. Design recommendations targeting easy disassembly may therefore not necessarily improve the actual recycling of WEEE. Designing products where it is easy to remove hazardous components that need special treatment and components containing precious metals makes sense, as it improves the recycling process and can increase the recovery of the precious metals. Products that are designed today will first enter the recycling system in five to ten years, so we are not designing products for the current waste treatment system but for the future system. The recycling processes of WEEE are under constant change, and it is difficult to foresee, how the recycling system will look like in five to ten years, when the products design and produced today will enter the recycling system. Finally, modular design and easy disassembly can improve other strategies to improve resource efficiency such as maintenance, repair, refurbishment, reconditioning and remanufacturing.

Critical materials and precious metals are widely used in electrical and electrical equipment. Seven materials or material groups are particularly critical for electrical and electronic equipment due to their technological application and low recycling rates including, antimony, cobalt, gallium, germanium, indium, rare earth elements and tantalum. Recycling rates could however be improved, if certain components were separated and sent for special treatment, and if the appropriate recycling technologies were further developed and scaled up.

Resource efficiency of electrical and electronic equipment In Europe is and can be regulated through six directives and regulations comprising the Ecodesign Directive, the Waste Electrical and Electronic Equipment (WEEE) Directive, the Restriction on Hazardous Substances (RoHS) Directive, the EU Energy Labelling Directive, the EU Ecolabelling Regulation and the Consumer Sales Directive. The Directives and Regulations cover different aspects of resource efficiency. The WEEE Directive and the RoHS Directive have primarily improved the recyclability of electrical equipment via phasing out some dangerous substances. The Ecodesign Directive and the EU Ecolabel include in their scope the ability to set resource efficiency requirements for all five identified strategies in order to improve resource efficiency, and they already have requirements that target this. So far, the Ecodesign Directive has only set specific resource efficiency requirements in five implementing measures and two voluntary agreements. The EU Ecolabels include few electrical and electronic product groups, and industry uptake is low. The EU Energy Labelling has mainly improved energy efficiency, whereas, the Consumer Sales Directive has improved maintenance and repair by setting a two-year guarantee period and offering obligations for repair.

The policy instruments apply different means to improve resource efficiency. Some are mandatory instruments setting minimum performance requirements (Ecodesign Directive, WEEE Directive, the RoHS Directive and the Consumer Sales Directive). The EU Energy Label drives the existing market towards increased efficiency by setting mandatory requirements for available consumer information. Finally, others are voluntary instruments that encourage the best performing products on the market to improve resource efficiency (EU Ecolabel). The intention is that the policy instruments should support each other by applying different means to improve the resource efficiency of electrical and electronic equipment; however, these synergies are not fully utilised yet.

There are already standards on ecodesign and environmental aspects in the design phase. Two relevant standards and one technical report were identified during the study:

- Standard: ISO 14006:2011: Environmental management systems: Guidelines for incorporating eco-design
- Technical report: ISO/TR 14062:2002 Environmental management: Integrating environmental aspects into product design and development
- Standard: ECMA-341 on Environmental design considerations for ICT and CE products

ISO 14006:2011 and ISO/TR 14062:2002 are both more generic management standards regarding how to implement ecodesign into existing environmental management systems and product design and development processes. The ECMA-341 standard, on the other hand, is specific to ICT and consumer electronics and provides specific design recommendations about how to improve the environmental performance of ICT products. Finally, new standards are under development under standardisation mandate M/543 for ecodesign requirements for material efficiency in energy-related products.

Two main international initiatives were identified during to improve the resource efficiency of electrical and electronic equipment: Solving the E-waste Problem (StEP) initiative and the Waste and Resource Action Programme (WRAP). The StEP initiative focuses solely on solving the e-waste problem and has five main taskforces, the policy taskforce, the redesign taskforce, the reuse taskforce, the recycling taskforce and the capacity building taskforce. The WRAP initiative’s mission is to accelerate the transition towards a sustainable and resource efficient economy and focuses on three sectors: food and drink, electricals and electronics, and clothing and textiles. Two of the key contributions from the WRAP initiative are the WRAP better appliances guidance and the electrical product design reviews.

Part Two: The Case Studies

Four case studies were conducted examining different ecodesign approaches and different strategies to improve resource efficiency. The following sections provide the main conclusions of the four case studies after a brief overview of the companies.

TABLE 2. Overview of the case companies included in the studies.

Case Company	Purpose	Resource Efficiency Strategy	Ecodesign Methods Tested	Product Groups
B&O	To examine how the recyclability of B&O's products could be improved and how waste managers and producers could improve knowledge sharing and cooperation	Main focus on recycling in the workshop, but all five strategies covered	Specific ecodesign guidelines	Televisions, remote controls, loud speakers
Tier1Asset	To examine necessary conditions for refurbishment and how products could be designed to improve the refurbishment potential	Refurbishment	Specific ecodesign guidelines	Laptop and desktop computers
Lightyears	To examine how a workshop can support the development of an environmental strategy focused on resource efficiency	All five strategies	Ecodesign at a strategic level and working with causal mapping	Lighting
Siemens Gamesa Renewable Energy	Experimentation with different methods for recovering rare earth elements in magnets	Recovering and recycling of rare earth elements	Ecodesign related to a strategic resource	Wind turbines

The purpose of the B&O case study was to examine how the recyclability of their products could be improved and how waste managers and producers could improve knowledge sharing and cooperation. A workshop was designed, where the producers were provided with an overview of the recycling processes of electrical and electronic waste by a representative from the waste treatment sector. The overview provided shared knowledge from the outset, which was useful during the rest of the workshop. Representatives from B&O, a waste treatment facility (Averhoff) and Aalborg University then worked on separating three new B&O products and including discussion during the process about which problems the products might pose in the recycling system and about recommendations on how to improve the design of the products. The workshop resulted in fifteen design recommendations regarding how to improve the recyclability of electrical and electrical equipment within the four categories: marking components, available information, easy disassembly and contamination of the material fractions and hazardous substances.

A comparison of these ecodesign recommendations with the existing ecodesign recommendations in the Ecodesign Pilot and the ECMA-341 standard showed that six of the fifteen ecodesign recommendations were already included in the existing ecodesign guidelines, and seven of the ecodesign recommendations were partly covered although these were more detailed and product specific. Two of the ecodesign recommendations were not covered by the existing guidelines but were completely new. The existing ecodesign guidelines are still relevant, when designing for improved recyclability, but could be made more detailed and product specific. The workshop format worked well, creating the necessary knowledge exchange between the representative from the waste treatment sector and the producers, but the composition of the workshop participants could have been improved. An advantage would have been to have had more representatives from different departments at B&O that are also involved in product development.

Tier1Asset is a refurbisher of desktops, laptops, servers, smartphones, tablets and printers. The Tier1Asset case study examined the necessary conditions for refurbishment, and how laptop and desktop computers could be designed to improve their refurbishment potential. Tier1Asset's key processes are: receiving the equipment, cleaning it, date deletion, customisation, performance testing and the grading of the equipment. They only do limited repairs on the products, as they primarily buy used and operating equipment. The necessary conditions for the Tier1Assets refurbishment processes were that they have access to products of high quality and in larger numbers. They therefore mainly buy used equipment from larger companies and organisations. Another necessary condition is trust from both the seller and the buyer. The seller of the used equipment needs to trust that Tier1Asset can ensure complete data deletion, and the buyer of the refurbished equipment needs to have trust in the quality of the refurbished equipment.

The Tier1Asset case study also provided seventeen ecodesign recommendations regarding how to improve the refurbishment potential of laptop and desktop computers. A comparison of these ecodesign recommendations with the ecodesign recommendations provided in the Ecodesign Pilot, the ECMA-341 standard and in the design for remanufacturing guidelines (provided in Ijomah et al., 2007) showed that; eight of the ecodesign recommendations were already covered by the existing ecodesign guidelines. Eight of the ecodesign recommendation were partly covered by the ecodesign recommendations, but were more detailed and product specific. One design recommendation was not covered in any of the existing ecodesign recommendations but was completely new, explicitly the ecodesign recommendation on the use of BIOS passwords. The conclusion is that the ecodesign guidelines are still relevant when designing products for refurbishment, but could be more detailed and product specific.

Lightyears is a producer of lamps for the premium to high-end market, and the company has not previously worked systematically with environmental issues and resource efficiency. The purpose of the workshop at Lightyears was to examine how a workshop can support the development of an environmental strategy focused on resource efficiency. The workshop was inspired by casual mapping and based on qualitative research interviews with key employees at Lightyears. The workshop format succeeded in creating a shared understanding of Lightyears and facilitated a dialogue about how Lightyears could develop an environmental strategy that also targeted resource efficiency. The workshop suggested to six areas, in which Lightyears could further their environmental strategy including: management of suppliers, design strategy, code of conduct, design brief and bill of materials, knowledge of materials, CE marking including the Ecodesign Directive, the RoHS Directive and the WEEE Directive. Finally, an action plan was made on how to proceeded with the work on developing a strategy.

Recovering resources is high on the agenda of the EU, and rare earth elements play a crucial role in the development of direct drive wind turbines, as these utilise NdFeB permanent magnets. The current status of end-of-life handling of NdFeB magnets was explored through the scientific literature, since the use of magnets in the direct drive generator of the wind turbines implies a significant consumption of rare earth elements. This was supplemented by a longitudinal case study of how a wind turbine manufacturer, Siemens Gamesa Renewable Energy, has been experimenting with narrowing, slowing and closing the use of NdFeB magnets for the direct drive technology. Workshops were used to especially investigate different methods for closing the material loops. The conclusions were

- recycling technologies are still in the testing phase with no commercial recycling plants available,
- the wind turbines are designed so the permanent magnets can be dismantled with only minor losses and
- due to the large concentration of REE in magnets, the recovery of these magnets is economically viable.

The next steps for advancing the circularity of NdFeB magnets in the wind industry are outlined in the chapter based on the potential for reducing the amount of rare earth elements in the magnets (narrowing) and extending the product life (slowing).

4. Introduction and objectives

Sustainable growth means a radical change from the current growth model of production and consumption, based on easy, cheap and unlimited access to raw materials, and where nature is seen as a sink for different types of waste. This applies also to the production and consumption of electrical and electronic equipment. When it comes to electrical and electronic equipment, then this radical change seems far away. Over the past three decades, the amounts of WEEE have increased continuously, and in 2014 the global generation of WEEE was estimated to 41.8 MT (Baldé et al., 2015). The increasing generations of WEEE is a result of more products being produced for an increasing consumer group (Amankwah-Amoah, 2016), and further accentuated by the relatively short life span of electrical and electronic equipment (Prakash et al., 2016).

Technological obsolescence caused by changes in technology and short innovation cycles of especially hardware has played a large role in the relatively short life expectancies of electrical and electronic equipment (Robinson, 2009). A study by Prakash et al. (2016) has showed that a large part of the electrical and electronic equipment that are replaced is still working. 30.5% of larger household appliances were still functioning when replaced and for flat screen televisions 60% were still functioning when replaced (Prakash et al., 2016). This also indicates that psychological obsolescence is a contributing factor in the relative short life spans of electrical and electronic equipment. Finally, proper recycling of electrical and electronic equipment is of key importance to limit the impacts on both humans and the environment. WEEE contains both hazardous and precious metals (Chancerel et al., 2009). Only 15% of all WEEE is treated formally (Zhang et al., 2017), so there is a large improvement potential in increasing the resource efficiency of electrical and electronic equipment.

4.1 Resource Efficiency and Strategies for Improvements

To establish how to improve resource efficiency of electrical and electronic equipment, it is necessary to define recourse efficiency. In this study, the definition of resource efficiency developed by the European Union was applied, and it defines resource efficiency 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.”* (Commission, 2017).

Various strategies can be applied to improve resource efficiency. In this study five different strategies to improve resource efficiency were considered: including (1) reduce, (2) maintenance and repair, (3) reuse, (4) refurbish, recondition and remanufacture and (5) recycling. Reduce was introduced as the first strategy to represent eco-efficiency and optimisation of material use. The remaining four strategies are based on Ellen MacArthur Foundation’s (2012) model of the circular economy and Stahel’s (1982) four replenishing loops in his self-replenishing system. An overview of the model is presented in Figure 1. The idea is that a product should go through several of the cycles, and that the inner circles should be given priority before the outer circles. Furthermore, the product and the production processes should be as efficient as possible.

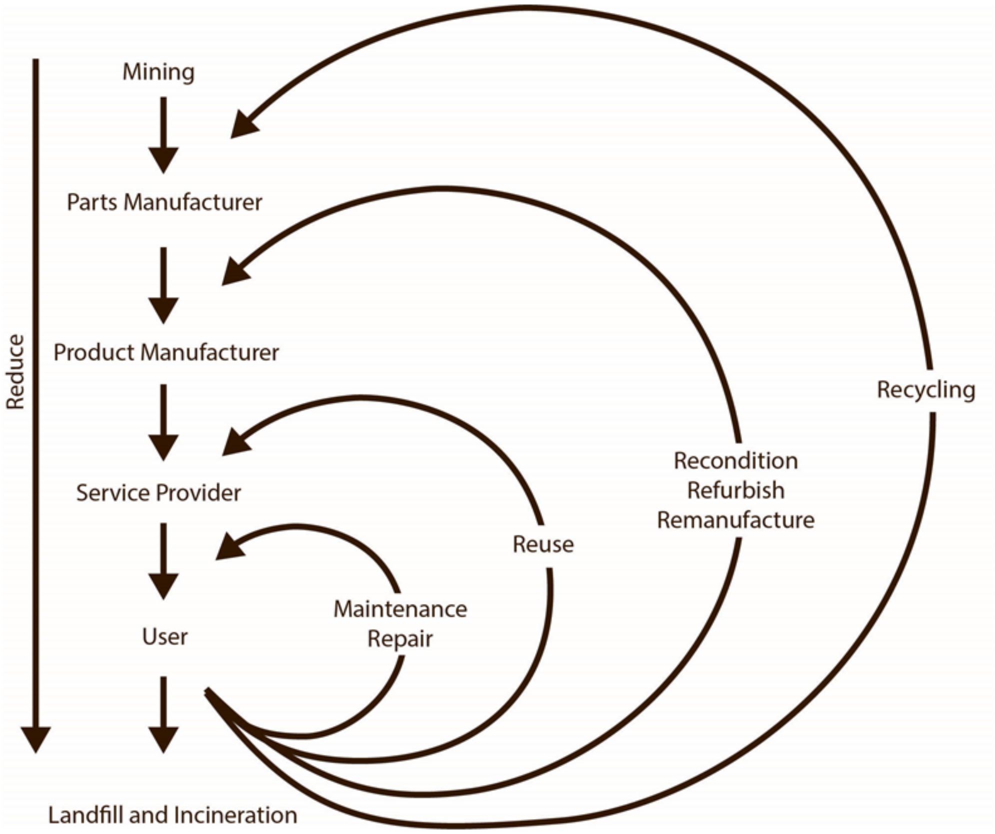


FIGURE 1. A model of the five strategies to improve resource efficiency adapted from Ellen MacArthur Foundation (2012) and Stahel (1982).

In this study, reduce as the first strategy to increase resource efficiency is defined as the decrease of energy, resource and environmental impacts considering the entire life cycle of the product (Lifset and Graedel, 2002). The purpose of the second strategy *maintenance and repair* is to extend the life span of the product or component, and then the environmental impact will be reduced relatively, because fewer products are needed to provide the same service. Here, maintenance includes activities such as updating and servicing as well as preventive maintenance, while repair refers to the correction of faults in a component or product (King et al., 2006). More specifically, a repaired product or component will typically have a lower quality than a remanufactured, reconditioned or refurbished product. The warranty of a repaired product will be less than for a new product and may only cover the repair (Ijomah, Childe and McMahon, 2004; King et al., 2006).

The third strategy is reuse defined as direct reuse of the entire product as it is for its original purpose (Ilgin and Gupta, 2010). Consequently, there are no repair or upgrading activities involved in the reuse activity. Again, the purpose of this strategy is to extend the life span of the product by allowing the product to go through several use cycles.

Recondition, refurbish and remanufacture are group together as the fourth strategy to improve resource efficiency. Recondition, refurbish and remanufacture are considered as one strategy, as it is assumed that the three processes are similar, although they vary in extend and degree. The activities covered by remanufacturing, refurbishment and reconditioning typically include: sorting, inspection, disassembly, cleaning, reassembly and reprocessing, replacement of components, and final testing (Hatcher, Ijomah and Windmill, 2011). In the study, it is assumed that refurbishment and reconditioning are similar processes. More specifically, reconditioning and refurbishment is defined as the process of returning a used product to an acceptable working conditioning inferior to its original specifications (Ijomah, Childe and McMahon, 2004; King et al., 2006). Typically, the warranty of the product will also be less than for a new product (Ijomah, Childe and McMahon, 2004; King et al., 2006). Remanufacturing on the other hand is defined as the process of returning a secondhand product to at least original working conditioning and providing the product with a warranty that is at least equal to a new product (King et al., 2006).

The fifth and final strategy to increase resource efficiency is recycling and it is defined as *“any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes”* (European Commission, 2008: 10).

4.2 The Objectives of the Designing out Waste Projects

The challenge is that electrical and electronic equipment is rarely designed for resource efficiency. The equipment is not designed to be maintained, repaired, reused, reconditioning, refurbished, remanufactured or recycled. The objectives of the project were therefore to disseminate already existing knowledge on how to design products more resource efficient through ecodesign as well as engage in a practice-based research to develop and disseminate methods for resource-efficient design further. This project’s aim was to put resource efficiency on the corporate agenda and thus help companies to adapt to a circular economy and opportunities therein.

The project aimed to increase resource efficiency and to convert waste into a resource by:

1. Testing different methods for ecodesign on specific product groups
2. Gaining practical experience with improvement of resource efficiency as well as of closing the materials loop
3. Further develop communication and cooperation between producers and waste treatment sector

The objective of this study was examined through four case studies of Bang and Olufsen (B&O), Lightyears, Tier1Asset and Siemens Gamesa Renewable Energy. The four case studies have examined different ecodesign methods and focused on different strategies to improve resource efficiency. The different ecodesign methods has also been a result of the different ecodesign maturity levels of the case companies. Table 3 provides and overview of the purpose of the workshop at the case company, the resource efficiency strategy in focus and the ecodesign approach tested.

- The B&O case examined how the recyclability of their products could be enhanced testing existing design guidelines and how producers and waste manager could improve knowledge sharing and cooperation.
- The Tier1Asset case examined necessary conditions for refurbishment and tested and developed design for refurbishment recommendations of mainly laptops and desktops.
- The Lightyears case examined how a workshop, designed based on causal mapping could support the development of an environmental strategy focused on resource efficiency.

TABLE 3. Overview of the case companies, the purpose of the workshops, the resource efficiency strategy in focus and the ecodesign methods tested.

Case Company	Purpose	Resource Efficiency Strategy	Ecodesign methods tested	Product groups
B&O	To examine how the recyclability of B&O's products could be improved and how waste managers and producers could improve knowledge sharing and cooperation	Main focus on recycling in the workshop, but all five strategies covered	Specific ecodesign guidelines	Televisions, remote controls, loud speakers
Tier1Asset	To examine necessary conditions for refurbishment and how products could be designed to improve the refurbishment potential	Refurbishment	Specific ecodesign guidelines	Laptop and desktop computers
Lightyears	Examination of how a workshop can support the development of an environmental strategy focused on resource efficiency	All five strategies	Ecodesign at a strategic level and working with causal mapping	Lighting
Siemens Gamesa Renewable Energy	Workshops as a tool for practical experiments and tests of how to recycle magnets	Recycling of rare earth elements in magnets in direct drive generators	Ecodesign of magnets with rare earth elements to improve recovering	Wind Turbines

A literature review has been conducted of ecodesign, the treatment of WEEE, European regulation of electrical and electronic equipment, existing standards supporting ecodesign and best praxis examples from abroad.

Part 1: Literature Review

5. Ecodesign

This first chapter in the literature review will provide an introduction to the main concept tested in this project namely ecodesign. The chapter begins with an introduction to how the concept has developed, the implementation of ecodesign in companies and finally ecodesign tools and how they can improve resource efficiency. The chapter is also included in Bundgaard (2016) with some variations.

5.1 The Development of the Ecodesign Concept

Victor Papanek introduced environmental and social factors in the design process in the 1970s as one of the first (Papanek, 1971). The designers were assigned a central position as “a bridge between human needs, culture and ecology” (Keitsch, 2012: 183). Since then, the concept has developed, and additional concepts have emerged with the aim to implement environmental criteria into the design process.

In the 1980s, green design was introduced (Burall, 1991; Mackenzie, 1997; Madge, 1997; Sherwin, 2000). Green design was seen as the introduction of environmental factors into everyday design practice, thereby demonstrating that green design was not against the industry (Sherwin, 2000). The concept, furthermore, tended to focus on the redesign of products and to a less extend represented a complete change of the product system. In the 1990s, ecodesign emerged as a new design concept integrating environmental considerations into the product development (Tischner et al., 2000; Karlsson and Luttropp, 2006). Moreover, ecodesign considers environmental impacts from the entire product life cycle. 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 and Luttropp, 2006).

The development of ecodesign is also connected to design for the environment (Keitsch, 2012). Both design for the environment and the ecodesign concepts are widely comprised of quantitative and empirical methods and are linked to the development of life cycle assessment methodology. Life cycle assessments document the environmental impacts of a product or a service for the entire life cycle, while eco-design has more focus on improvements (Sherwin, 2000). The final concept to be introduced here is sustainable design or design for sustainability. The concept applies a more holistic approach including environmental, social and economic issue (Spangenberg, Fuad-Luke and Blincoe, 2010). There is a tendency that design for sustainability moves away from the product focus towards a system perspective (Dewberry, 1996; Spangenberg, Fuad-Luke and Blincoe, 2010). In this project, ecodesign has been defined as the implementation of environmental issues in the design process taking the entire life cycle of the product into consideration.

5.2 Implementation of Ecodesign in Companies

Even though, ecodesign or similar concepts has been known for 30 years, implementing ecodesign into companies is still a challenge (Bovea and Pérez-Belis, 2012; Pigosso, Rozenfeld and McAloone, 2013). As expressed "implementation is scarce and the case studies are, in many cases theoretical examples, without the backing of a product company" (Bovea and Pérez-Belis, 2012). Existing literature have also identified some core gaps in terms of implementing and managing ecodesign in companies (Pigosso, Rozenfeld and McAloone, 2013). Firstly, the existing ecodesign practices are not sufficiently systematised and there is a focus on developing new tools for product design (Pigosso, Rozenfeld and McAloone, 2013). Secondly, ecodesign is often not integrated into the broader context of the company such as corporate strategy, product development, sales and marketing, etc. (Pigosso, Rozenfeld and McAloone, 2013). Thirdly, the companies lack a roadmap to support them in continuously improving the implementation in their company thereby implementing ecodesign on higher levels (Pigosso, Rozenfeld and McAloone, 2013). Finally, the companies have difficulties in prioritising and defining which ecodesign practices to use and in proceeding from pilot projects towards implementing ecodesign into the core business (Pigosso, Rozenfeld and McAloone, 2013). A challenge is still to move from the development of different ecodesign tools and strategies towards the actual implementation in companies.

The purpose of this project was to support the implementation of ecodesign with a focus on resource efficiency into companies instead of developing new tools. Therefore, the project took outset in already existing methods when targeting ecodesign in a company perspective. The specific methods were selected in collaboration with the company, but a common feature is the implementation of ecodesign into the companies' strategy to ensure that it is embedded in the company.

5.3 Ecodesign Tools and Strategies

Several review articles and books have been made on ecodesign and the tools and strategies developed to design more environmental conscious products (Tischner et al., 2000; Birch, Hon and Short, 2012; Bovea and Pérez-Belis, 2012; Vallet et al., 2013). These reviews strive to provide an overview and classification of the different tools and approaches, which can help guide for instance producers on how to approach ecodesign and which tools to apply.

As the focus of the designing out waste project was to help companies implementing ecodesign into their design and development process to improve resource efficiency, our focus was on tools that help the designer find the right ecodesign strategy or idea. It covers tools such as spider diagrams, rules of thumb, ecodesign checklists and expert rules. On the basis of the three reviews of ecodesign tools made by Tischner et al. (2000), Bovea and Pérez-Pelis (Bovea and Pérez-Belis, 2012) and Byggeth and Hochschorner (2006), a number of ecodesign tools were identified that could support the implementation of ecodesign in the design processes and product development. An overview of the tools is provided in Table 4.

TABLE 4. Overview of the tools with a focus on integrating environmental aspects into product development (Byggeth and Hochschorner, 2006; Bovea and Pérez-Belis, 2012)

Tools	Purpose	Sources
AT&T Checklist	A list of questions that can support the designer during the design process in addressing environmental aspects.	(Keoleian, Kock and Menerey, 1995)
Kodak Checklist		(Betz and Vogl, 1996)
Fast Five Philips Checklist		(Meinders, 1997)
Ten Golden Rules	Ten rules that can help integrate environmental demands in product development process. The rules are generic and need to be customised to the product and company to be directly useful.	(Luttropp and Lagerstedt, 2006)
Eco-Design Checklist Method	A combination of checklists and semi-qualitative information. The tool identifies weak points in the design based on a semi-qualitative assessment and provides suggestion to how to improve the environmental performance of the product.	(Wimmer, 1999)
Product Investigation Leaning and Optimisation Tool (Eco-design Pilot)	A further development of the Ecodesign Checklist Method, including additional guidelines on how to improve the environmental performance and detailed examples and explanations on each guideline.	(Wimmer and Züst, 2003)
EcoDesign Checklist	A set of questions, based on which a qualitative assessment of the product in a lifecycle perspective can be made. Based on the assessment suggestions for improvement strategies are provided.	(Tischner et al., 2000)
LiDS-Wheel	Gives the designer an overview of the environmental improvement potential by means of eight environmental improvement strategies.	(Brezet and van Hemel, 1997)
Strategy List	Ecodesign criteria and strategies to be used as a basis for making company-specific criteria and strategies.	(Tischner et al., 2000)

Based on the review of ecodesign tools, the Ecodesign pilot was chosen, because it provides specific design recommendations on how to improve the environmental performance of the products and it is freely available. Furthermore, the European association for standardising information and communication systems (ECMA) 341 standard for environmental design considerations for information and communication technology (ICT) and consumer electronic (E) products was selected as a product specific design guideline, and because it included a comprehensive list of design recommendation and it is an industry-based standard at the same time. The ECMA standard is described in more details in chapter 5.

5.3.1 Design Recommendation to improve resource efficiency

A review was conducted of the ECMA 341 standard and the Ecodesign Pilot identifying ecodesign recommendations that could help improve resource efficiency. The categories were grouped according to the following categories: material efficiency, energy efficiency, maintenance, repair, reuse of product parts, durability, recyclability and disassembly. Remanufacturing was also included based on design recommendations from Ijomah et al. (2007). A full outline of these design recommendations can be found in Appendix 1. Table 5 provides and overview of how the different categories of design recommendations are relevant in relation to the five different strategies to improve resource efficiency.

TABLE 5. Overview of different categories of design recommendations relevant when improving resource efficiency according to the five strategies introduced in chapter 1 from Bundgaard (2016: 59).

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

5.4 Sub-conclusion

Ecodesign is in this project defined as the implementation of environmental issues in the design process taking the entire life cycle of the product into consideration. Previous studies have showed that the actual implementation of ecodesign into companies is still challenging. This emphasis the important of projects, such as this, focused on the implementation of ecodesign into companies. The review of existing ecodesign tools identified two tools relevant for further testing in the project. The two ecodesign tools were the Ecodesign Pilot and the European association for standardising information and communication systems (ECMA) 341 standard for environmental design considerations for information and communication technology (ICT) and consumer electronic (E) products. Additionally, design recommendation for remanufacturing were supplemented from Ijomah et al. (2007).

6. Waste Electrical and Electronic Equipment

When designing products for improved recyclability, it is essential to know the challenges related to different compositions of materials and the type of recycling systems for WEEE. Therefore, the following chapter will provide an overview of the European waste treatment of WEEE, along with a section on critical raw materials and precious metals in electrical and electronic equipment.

6.1 The Material Composition of Waste Electrical and Electronic Equipment

The composition of WEEE can vary significantly depending on the type and age of the equipment (Gramatyka, 2007). Up to 1.000 different substances and metals are used, when producing certain types of electrical and electronic equipment (Gmünder, 2007). Typically, WEEE is composed of 40% metals, 30% plastic, and 30% refractory oxides (Gramatyka, 2007). The metals from WEEE typically consist of 20% copper, 8% iron, 4% tin, 2% nickel, 2% lead, 1% zinc, 0.1% gold, 0.2% silver and 0.005% palladium. The plastic components from WEEE typically consist of polyethylene, polypropylene, polyesters and polycarbonates (Gramatyka, 2007).

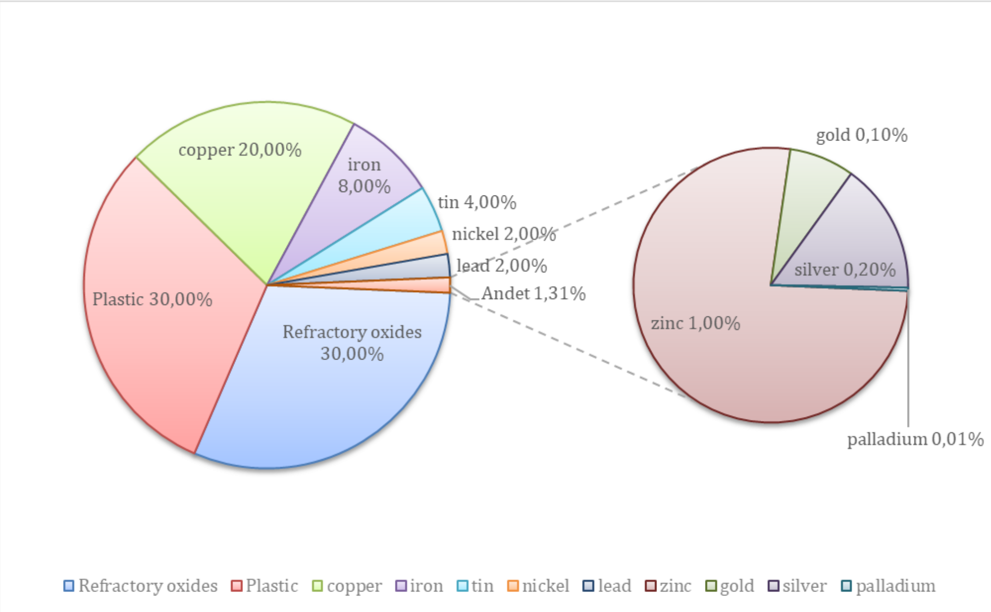


FIGURE 2. Composition of WEEE (Gramatyka, 2007).

A tendency is that the concentration of precious metals and non-ferrous metals in e-waste has decreased over the years (Cui and Zhang, 2008). According to the executive secretary of the European Electronic Recyclers Association (EERA), it implies that waste treatment of WEEE is getting less feasible for the recyclers (Zonneveld, 2014).

6.2 The Recycling Chains

Globally, only 15 % of all WEEE is formally treated, and even in the EU only 25-40 % of WEEE is treated in the official system, despite the implementation of the European WEEE Directive in 2003 (Zhang et al., 2017). Therefore, the main source of material loses from WEEE is still insufficient collection and improper treatment (Zhang et al., 2017).

The treatment of WEEE depends on the geographical context and composition of the WEEE. It is therefore not possible to assess with certainty, how the recycling of a certain product will be. In Europe, mechanical and a more technological solution is typically chosen to treat WEEE (Gmünder, 2007). Where, the WEEE is pre-processed mechanically using destructive methods combined with different sorting techniques, and the resulting fractions are processed in refineries (Gmünder, 2007). The following section will describe some of the most commonly used techniques. Typically, the main steps in the recycling of WEEE is (1) collection, (2) sorting, dismantling and pre-processing (including processes such as mechanical treatment, sorting and dismantling) and (3) end-processing (see Figure 3) (Tanskanen and Takala, 2006; Schluep et al., 2009). The technology requirements and investment cost associated with the two first steps, collection and pre-processing, are considerable less than the investment cost of the end-processing. Therefore, collection and pre-processing is typically carried out in a regional context; whereas the end-processing happens in a global context (Schluep et al., 2009). In this review, WEEE collection will not be covered in details, but further information on the Danish collection system can be found in Parajuly et al. (2017) and Grunow and Gobbi (2009).

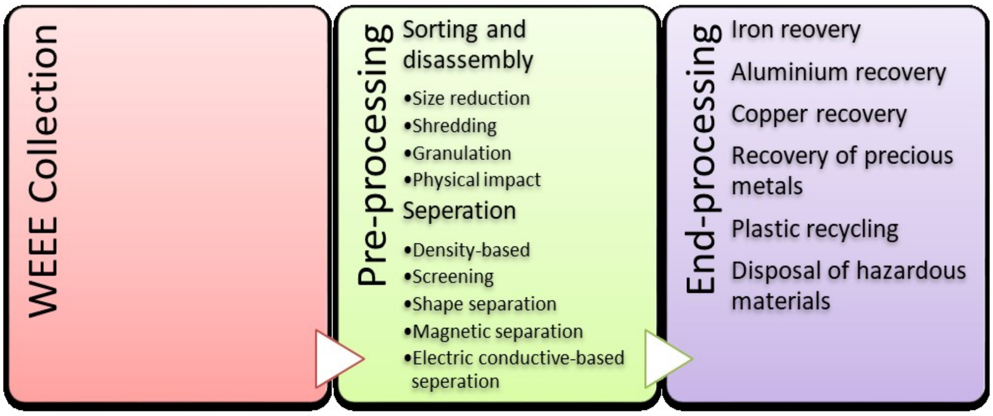


FIGURE 3. Overview of a typical steps and technologies applied in the recycling chain based on (Cui and Forssberg, 2003; Dalrymple et al., 2007; Chancerel et al., 2009).

6.2.1 Pre-processing

In the pre-processing stage, the products typically go through mechanical separation including manual sorting and separation, size reduction and separation of the different factions (Gramatyka, 2007). The pre-processing of WEEE can be designed in many different ways including various technologies. In this section, the most commonly applied steps and technologies are described, but the actual facilities can vary significantly. The main steps and technologies are illustrated in Figure 3. Many recycling facilities use some sort of manual sorting and disassembly (Dalrymple et al., 2007). Typically, it includes removing hazardous components such as batteries (according to e.g. the WEEE Directive), valuable components and materials (Dalrymple et al., 2007) and contaminants (such as mercury switches, PCP containing capacitors) (Gramatyka, 2007). The degree of manual sorting will depend on various aspects such as labour costs, legal requirements, hazardous components and valuable components. The next step in the recycling chain is typically size reduction often by applying automatic and destructive techniques such as physical impact, shredding and granulation (Dalrymple et al., 2007). The purpose of size reduction is to break down the product into reusable or recyclable parts, components and materials (Dalrymple et al., 2007). The applied technologies are causing a down-cycling of the materials and losses of value.

After the size reduction, the materials are sorted or separated into different fractions. Different technologies can be applied depending on which fractions should be separated. Often a combination of different sorting technologies is applied to separate the various fractions and materials the WEEE residue consists of. A description of some of the technologies is provided below:

- Screening and shape separation uses particle size and shape properties to separate the fractions (Cui and Forssberg, 2003).
- Magnetic separation uses a magnetic field to separate iron, steel, ferrosilicon or other ferromagnetic materials from non-magnetic bulk materials (Dalrymple et al., 2007).
- Electric conductivity-based separation uses the materials different electric conductivity or resistivity to separate the materials into different fractions. There are three electric conductivity-based separation techniques: eddy current separation used for sorting non-ferrous/ non-metal separation (aluminium), corona electrostatic separation mainly used for separation of copper or aluminium separation and triboelectric separation used for separation of plastic (Cui and Forssberg, 2003).
- Density-based separation uses the materials' different density to separate heavier materials from lighter materials. Different processes can be applied: sink-float separation, sorting by jigging, sorting in chutes and on tables and up-stream separation (Cui and Forssberg, 2003). The technology is typically, used to separate plastics, copper and precious metals (Tanskanen, 2013).

The use of automatic and destructive disassembly may impact the relevance of the design guidelines and rules focused on improving the recyclability of WEEE described earlier in chapter 2. Especially, those guidelines and rules targeting easy disassembly.

6.2.2 End-processing

The pre-processing and the technologies applied during this stage influence the mechanical properties of the output materials. The pre-processing will therefore also affect the end-processing stages and the technologies applied. Even though WEEE is complex and contains many different materials and components, the fractions from the pre-processing typically end in iron recovery, aluminium recovery, copper recovery, recovery of precious metals or plastic recycling. If it is not possible to recover or recycle the materials, because of their content of hazardous substances, the materials will be disposed or deposited (Chancerel, Bolland and Rotter, 2011). Typically, it is not possible to recover all the different materials in the waste, and it is necessary to prioritise, what should be recovered.

The recovery of *ferrous metals* (such as iron and steel) are done by re-smelting the iron and steel scrap from the pre-treatment (Schluep et al., 2009). The steel can be recovered in electric arc furnaces, where electricity is used to melt the scrap. The scrap from WEEE can also be used with scrap from other sectors or during the production of iron and steel from primary ores. In this case, the iron and steel fraction have to be pure; especially from metallic copper, lead and tin, as they are undesirable in the steel re-smelting process.

Aluminium fractions from the pre-treatment can be recovered through re-smelting the fractions (Schluep et al., 2009). Electrical and electronic equipment primarily is made from cast alloys, which contains a maximum of 20% alloying elements, therefore the aluminium fractions from e-waste is treated in refiners (Schluep et al., 2009). The four main steps in the refining process are compilation of furnace charge, charging of furnace and melting, refining, alloying and casting and salt slag treatment (Schluep et al., 2009). One of the advantages of recovering aluminium is that the energy required is only 5-10% of the energy needed for primary production of aluminium (Schluep et al., 2009). Therefore, there is a large energy saving potential in recovering aluminium, and the recovery can be done without loss of the material value (Schluep et al., 2009).

Precious metals including *copper* can be recovered in copper smelters or integrated smelter-refineries (Schluep et al., 2009). In developed countries, printed wired boards, integrated circuits, processors, connectors and small electronic devices or fractions hereof are typically treated in integrated smelter refineries (Schluep et al., 2009). An integrated operation typically starts with a pyrometallurgy step, where the WEEE or WEEE fractions are smelted together with other materials in a furnace or smelter to separate the valuable metals (Schluep et al., 2009). In this process, the organic compounds, such as plastic, are used as energy source. After this step, different pyrometallurgy, hydrometallurgy and electrometallurgy operations are combined and used to get the optimal recovery of the materials (Schluep et al., 2009). The use of extensive off-gas cleaning systems during the process is important to avoid the formation of VOCs, dioxins, acid gases and dust (Schluep et al., 2009). The integrated smelters and refineries can recover 17 different metals that can be reused (Au, Ag, Pd, Pt, Rh, Ir, Ru, Cu, Pb, Ni, Sn, Bi, In, Se, Te, Sb, As) (Schluep et al., 2009). Because the applied technologies are so complex there are only integrated smelting and refining facilities in Belgium, Canada, Germany, Japan and Sweden (Schluep et al., 2009). Copper can also be recovered in copper smelters, but these are predominantly used in transition countries or developing countries (Schluep et al., 2009). Studies have shown that the pre-processing steps can have an impact on the recovery of precious metal such as cobber, silver and gold (Chancerel et al., 2009; Chancerel, Bolland and Rotter, 2011). For instance, shredded printed circuit boards contain 7% less precious metals than the un-shredded printed circuit boards. It indicates that shedding can reduce the recovery potential of precious metals (Chancerel et al., 2009).

Mechanical recycling, feedstock recovery or energy recovery can recycle or recover plastic from WEEE. Mechanical recycling is the reprocessing of plastic from WEEE to form a new plastic product with a similar or lower quality (Buekens and Yang, 2014). After the plastic is free from the non-plastic fractions, during the pre-treatment, the plastic is sorted into the different resins and then further processed (Buekens and Yang, 2014). Mechanical recycling of plastic from WEEE can be a challenge, because of the many different resins used. Therefore, to improve the feasibility of recycling plastic from WEEE, it may be necessary to reduce the number of resins used. Also, the different additives and brominated flame-retardants used can pose a problem, because they as the resins can be mutually incompatible. Furthermore, brominated flame-retardants and other hazardous substances also reduce the recycling potential, because they can pose a threat to human health. Another possibility for recovering plastic from WEEE is feedstock recycling, where the plastic from WEEE is converted into fuels, monomers or other chemicals by thermal decomposition (pyrolysis) or into synthesis or fuel gas by gasification (Buekens and Yang, 2014). Finally, the plastic from WEEE can be used for energy recovery. Here, the brominated flame-retardants and heavy metals can also pose a problem and hinder the recovery of energy from the plastic (Buekens and Yang, 2014).

6.3 Non-renewable Critical Raw Materials and Precious Metals in Electrical and Electronic Equipment

The electronic industry is strongly reliant on on critical raw materials and precious metals. Especially, information technology (IT), telecommunication and consumer equipment contain most of the critical raw materials used by the electronic industry (Chancerel et al., 2013), and precious metals are universal in many electrical devices (Zhang et al., 2017). Therefore, if a secure supply of critical metals is not ensured, it could potentially hinder the development and deployment of new technologies (Zhang et al., 2017).

6.3.1 Critical Raw Materials

There are various definitions of what a critical raw material is, and different lists of critical raw materials exist. Typically, the criticality of the materials is a combination of the demand for the critical metals, geological reserve, geopolitical constraints and supply risks (Chancerel et al., 2013; Zhang et al., 2017). Here, the definition applied by the European Commission is used: *'raw materials with a high supply-risk and a high economic importance'* (European Commission, 2014: 2). This definition also implies that criticality is not only dependent on the geological scarcity but also on supply-risks and economic importance.

TABLE 6. Overview of critical raw materials identified by the European Commission and their application in electrical and electronic equipment based on Chancerel et al. (2015) and the European Commission (Commission, 2014).

Critical raw material	Application in electrical and electronic equipment	End of life recycling input rate
Antimony (Stibium)	Flame retardants.	11 %
Beryllium	Electric/ electronic connectors.	19 %
Borates	Glass of LDCs and to a small extent in flame retardants.	0 %
Chromium	Stainless steel.	13 %
Cobalt (Cobaltum)	Li-ion and NiMH batteries.	16 %
Coking coal	No application in electrical and electronic equipment	0 %
Fluorspar (Fluorite)	Not considered in Chancerel et al. (2015).	0 %
Gallium	LEDs and integrated circuits.	0 %
Germanium	LEDs and electronic components	0 %
Indium	LCD panels, to a minor extent in LEDs, solders and semi-conductors	0 %
Magnesite	Not considered in Chancerel et al. (2015).	0 %
Magnesium	Casings	14 %
Natural graphite	Li-Ion batteries.	0 %
Niobium	Some magnets.	11 %
Phosphate rock	Not considered in Chancerel et al. (2015).	0 %
Platinum group metals	Palladium in electronic components and PCB, platinum and ruthenium in hard disk drives, iririum in LEDs	35 %
Heavy rare earth elements	Magnets in motors, drivers and loudspeakers, NiMH batteries, phosphors of CCFL and LED backlighting systems.	0 %
Light rare earth elements		0 %
Silicon metal (Silicium)	Silicon semiconductors in chips.	0 %
Tungsten (Wolframium)	Not considered in Chancerel et al. (2015).	37 %

In 2010, the European Commission published their first list of critical raw materials, and in 2014, a revision was made. The critical raw material list from 2014 and the end of life recycling input rate can be seen in Table 6 above. The end of life recycling input rate is defined as the proportion of metal and metal products that are produced from end of life scrap and other metal bearing low grade residues in end of life scrape worldwide (Commission, 2014: 7).

Chancerel et al. (2013, 2015) have examined the application of the critical raw materials in electrical and electronic equipment, and an overview is also provided in Table 6. As the study shows, many of the critical raw materials prioritised by the EU are applied in electrical and electronic equipment. According to Chancerel et al. (2013), antimony, cobalt, gallium, germanium, indium, REE and tantalum are the most relevant critical raw materials for the electrical and electronic equipment industry due to their criticality, their technological application in electrical and electronic equipment and their low recycling rates. Therefore, a more detailed description of these metals and metal groups along with the platinum group are described in the following section.

Antimony in the form of antimony oxide is mainly used as a flame retardant in plastic casings, cables, PCBs, cable coatings, electrical connectors and other plastic parts used in electrical and electronic equipment (Chancerel et al., 2013). The use of antimony in electrical and electronic equipment has decreased since 2000 (Chancerel et al., 2013). *Cobalt* is mainly used in lithium-ion and nickel-cadmium batteries, but the cobalt content in batteries is decreasing (Chancerel et al., 2013). In 2013, rechargeable batteries consumed around 41 % of the total global cobalt demand (Zhang et al., 2017). *Gallium* is used in integrated circuits and optoelectronic devices such as laser diodes, LEDs, solar cells and photodetectors (Chancerel et al., 2013). *Germanium* or more specifically silicon germanium is used in integrated circuits of wireless local area network hardware, navigations systems and mobile phones (Chancerel et al., 2013). Germanium combined with magnesium is also used in lamps (Chancerel et al., 2013).

Indium is one of the critical materials, where the electrical and electronic equipment industry accounts for a large share of the total consumption (Zhang et al., 2017). Indium is especially used in LCD panels (Zhang et al., 2017). More specifically, in indium tin oxides (ITOs), which are used as a transparent conductive film in LCDs (Zhang et al., 2017). The ITOs production consumes more than 80 % of the total indium consumption (Zhang et al., 2017). LCD panels are the leading technology in flat panel display production and is integrated in a wide selection of products including cell phones, smart phones, tablets, computers and televisions (Zhang et al., 2017). Therefore, the demand for indium has increased rapidly from 149 tons to 819 tons in the last twenty years (1995-2015), and especially since 2004, when LCDs began to replace CRTs (Zhang et al., 2017). Furthermore, indium is subjected to both constraints in the geological reserves and geopolitical constraints (Zhang et al., 2017). The global reserve of indium is about 16-19 thousand tons and some Asian countries account for 70-80 % of the global production (Zhang et al., 2017). The supply of indium for the electrical and electronic equipment industry can be a challenge.

Rare earth element (REE) is a group of 17 elements including 15 lanthanides (cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodymium, praseodymium, promethium, samarium, terbium, thulium, ytterbium), scandium and yttrium. REE are applied in almost all technological products including but not limited to flat screen TVs, electric motors, smartphones, high performing metal alloys, nickel-metal hybrid batteries, and automotive catalysts (Zhang et al., 2017). The demand for REEs is increasing rapidly from 64,5 ktons in 1994 to 133 ktons in 2014 (Zhang et al., 2017). The application and amount of REE in electrical and electronic equipment varies significantly. Neodymium is one of the REE with a high demand. Neodymium magnets uses around 20% of the total demand for REE, and 35 % of the neodymium magnets are used in computer hard desks (Zhang et al., 2017). Geographically, REEs are widely distributed, but they are mainly mined, concentrated and separated in China (providing more than 90% of the worlds REEs) (Zhang et al., 2017). China has since 2010 restricted the supply of REEs (with some softening of the of the export control) (Zhang et al., 2017). Consequently, REEs are at a high supply risk (Zhang et al., 2017).

Tantalum is primarily used in electrical and electronic equipment for miniaturised capacitors, but also in other electronic components such as tantalum film resistors, optoelectronic semiconductors and surface acoustic wave filters (Chancerel et al., 2015).

6.3.2 Precious Metals

Usually, precious metals include the platinum group metals (PGMs), silver and gold. Precious metals are typically used by the electronic industry to increase storage capacity in computer hard disk drives and are universal in electronic devices, hybridised integrated circuits and multilayer ceramic capacitors (Zhang et al., 2017). A general tendency is that the use of precious metals in electrical and electronic equipment is decreasing because of new substitutions without or with less precious metals (Zhang et al., 2017).

The platinum group metals (PGMs) are both critical raw materials and precious metals. The platinum group metals (PGMs) are a group of six metals clustered together in the periodical table and include ruthenium, rhodium, palladium, osmium, iridium and platinum (Zhang et al., 2017). They have many of the same chemical and physical properties, and they can often be found in the same mineral deposits (Zhang et al., 2017). These properties include but are not limited to a good electrical conductivity, corrosion resistant and a high melting point.

Gold is predominately used in jewelry and arts (75-89% from 2000-2012) and to a less extend in electrical and electronic equipment (4-6% from 2000-2012) (Zhang et al., 2017). Gold is primarily used in electrical and electronic equipment due to its conductivity. In recent years, the use of gold in electrical and electronic equipment was decreased due to the development of new technologies, which can reduce of replace the gold in electrical and electronic equipment (Zhang et al., 2017).

6.4 Recycling of Critical Raw Materials

The recycling of critical raw materials and precious metals from WEEE follows the same steps as WEEE recycling in general namely: collection, pre-processing and end-processing. To recover the critical materials and precious metals in the crushed materials from the pre-processing step, different methods need to be applied depending on which metal or metal group that should be recovered. As Table 4 indicates the end of life recycling input is low for most of the critical raw materials, and there is therefore a large potential to increase the recycling of critical raw materials from WEEE.

Some main obstacles for the recirculation of critical raw materials from WEEE are: the inefficient collection of WEEE, and the low concentrates of some critical raw materials in WEEE, which has implications for the economic feasibility of recovering the materials (Zhang et al., 2017). Another obstacle for the recovery is that many state-of-the-art pre-processing facilities are optimised for mass recovery at the expense of the recovery of critical and precious metals (Reck and Graedel, 2012). Finally, the recovery of a list of metals might happen on the expense of the recovery of other metals. This is further illustrated in the simplified version of the metal wheel in Figure 4.

The metal wheel is based on primary metallurgy but is also valid for the recycling of metals (Reuter et al., 2013). The wheel shows the destination of the elements in base-metal minerals as a function of connected metallurgical process technology (Reuter et al., 2013). The metal wheel is separated into slices, and each of the slices represent a basic metal used by society or a carrier metal and its main processing route using best available technologies (primary and recycling metallurgy) (Reuter et al., 2013). The light-blue, white and green rings illustrate the main possibly valuable elements related with the carrier metal (Reuter et al., 2013). The light-blue covers mostly metallic elements that dissolve in the carrier metal, when using primarily pyrometallurgy (Reuter et al., 2013). The white ring includes component elements mainly treated by hydrometallurgy (Reuter et al., 2013). Finally, the green ring shows the elements that are lost in the waste (Reuter et al., 2013). The green colored dots in Figure 4 are elements compatible with the carrier metal or which can be recovered in subsequent processing. The yellow colored dots are elements in alloys or compounds in oxidic products that most likely are lost. The red colored dots in Figure 4 are elements that are not compatible with the carrier metal or product and therefore are lost. As an example, when processing cobber and nickel, then thorium, rare earths, phosphor, calcium, natrum and various oxides are lost.

Waste LCDs screens are a potential source of *indium*, with concentrations of available indium varying from 102 g/t in televisions screens to 1102 g/t for LCD screens in mobile phones (Zhang et al., 2017). If a polymer film (which is attached to the LCD screen) is removed, then the amount of available indium from television LCD screens could increase up-to 1400 g/t (Zhang et al., 2017). The recycling rate of indium is extremely low. One of the main reasons being that the number of recycled LCD screen is still low. There are different methods to recover indium from the LCD screens such as hydrometallurgical processes, pyrometallurgy and chloride or carbon-induced vaporisation, but these methods are mainly applied on a laboratory scale. Furthermore, due to the difficult separation of the LCD panels from electronics (especially for small equipment), the processing of LCD screens in integrated smelters provides higher recovery rates than mechanical processing and hydrometallurgy.

The recycling technologies needed to recover REEs from WEEE will be different depending on which type of REE should recovered (Zhang et al., 2017), and different technologies are needed to recover REEs. Due to the widespread use of REEs in low concentrates in electrical and electronic equipment, the recycling of REE from WEEE is more difficult and less cost efficient (Zhang et al., 2017). As a result, the recycling of REEs is less than 1 % (Zhang et al., 2017).

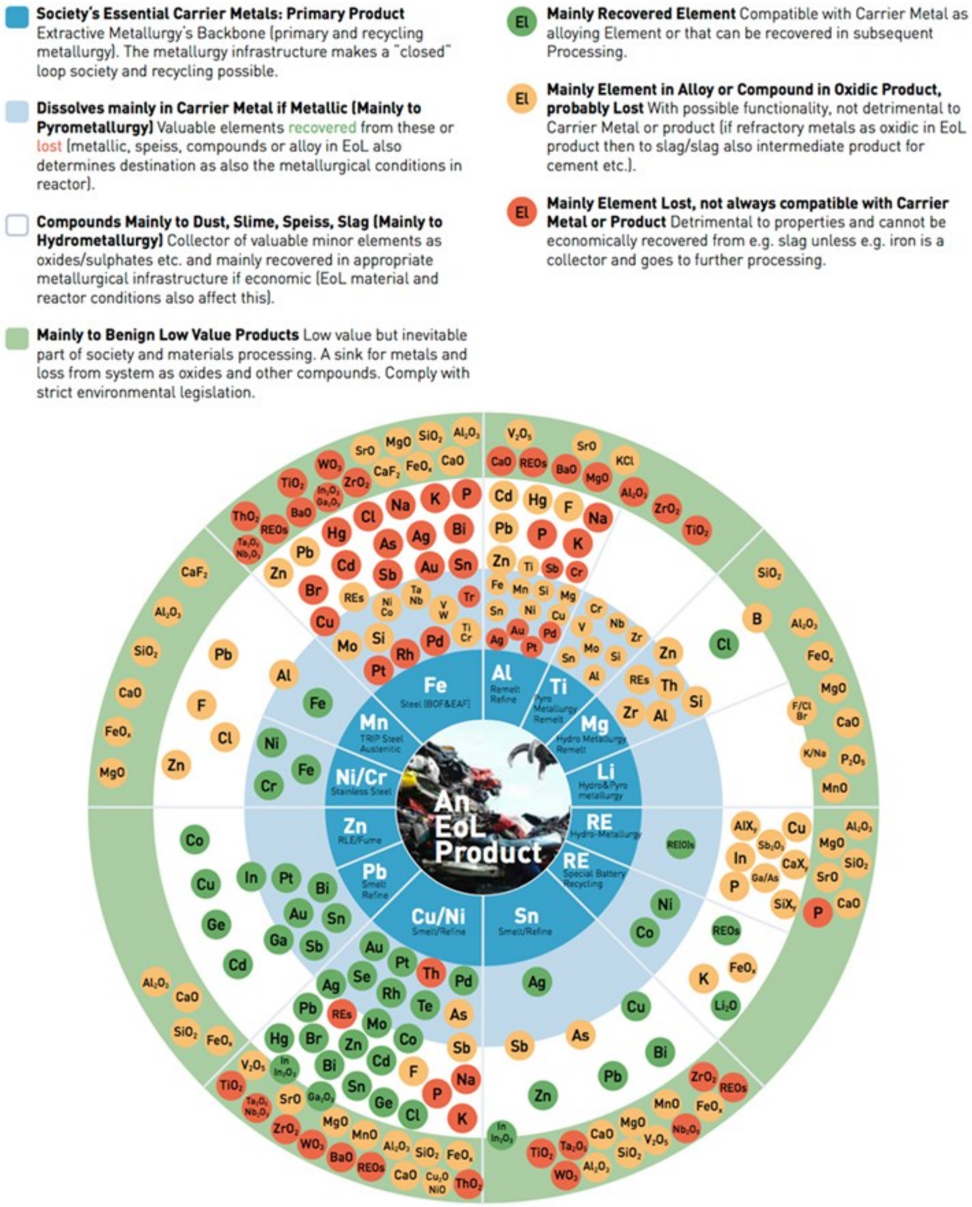


FIGURE 4. A simplified version of the metal wheel (Reuter et al., 2013).

6.4.1 Recommendations for improved recycling and recovery of critical and precious metals

To improve the recovery of certain critical and precious metals and materials, Chancerel et al. (2015) have made recommendations for recycling routes for ICT and consumer electronics (Figure 5). The recommendations are based on what is currently (2015) economically viable and physically possible. For *smart phones* Chancerel et al. (2015) recommend recovering gold, palladium, silver and tin through current metallurgical recovery processes, as it is both technically possible and economically feasible. Furthermore, they recommend removing the battery for cobalt recovery, and if future research makes it possible REE recovery. Future research is needed, to ensure the recovery of gallium from integrated circuits, as the routes to recover gallium is still at research stage. For *mobile phones and other small high-grade equipment,* the recommendation is to use metallurgical recovery processes to recover gold, palladium, silver and tin after the battery is removed for cobalt recovery and potentially in the future REE recovery (Chancerel et al., 2015).

For *desktop personal computers*, the recommendation is to remove the PCBs and to recover gold, palladium, silver and tin. The recommendation is to send REE containing magnets for REE recovery, when in the future REE recovery is fully developed and scaled up. For *laptops*, the recommendation is to remove PCBs and batteries for gold, palladium, silver and tin recovery and cobalt recovery (potentially also REE recovery) respectively. Finally, for *LCD televisions with CCFL and LED backlighting* the recommendation is to remove PCB again for gold, palladium, silver and tin recovery. Finally, it is recommended to recover REE containing magnets and indium containing display panels for REE recovery and indium recovery, when the future research on the recovery processes are fully developed.

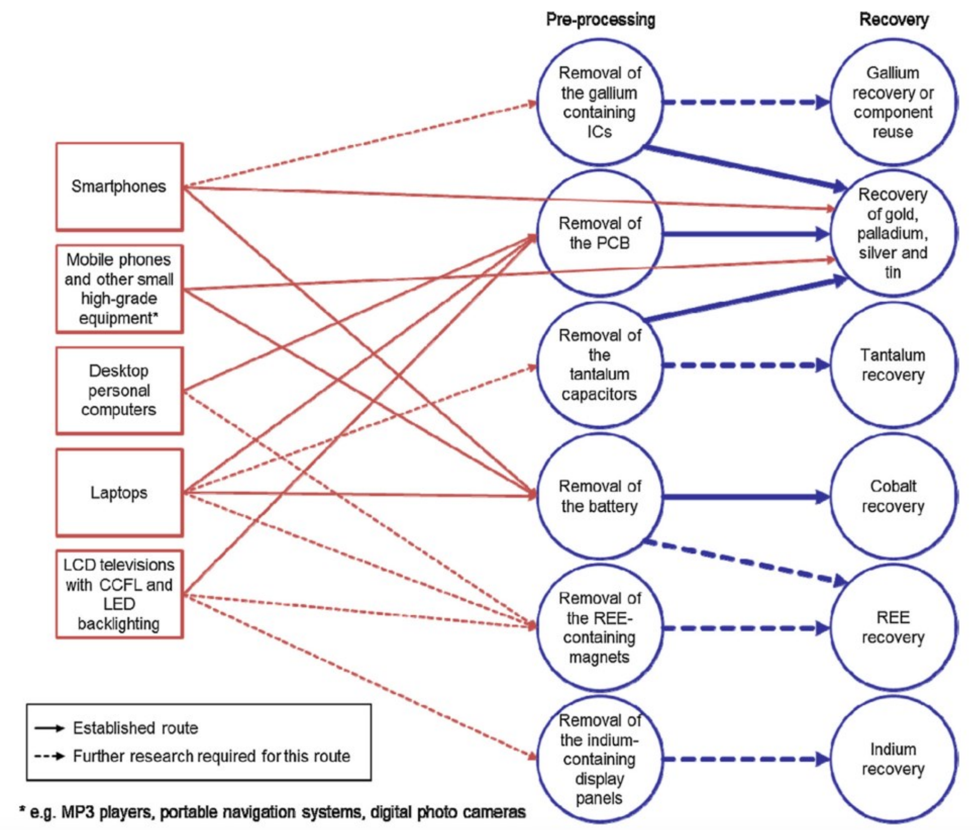


FIGURE 5. Recommended recycling routs for the ICT and CE (Chancerel et al., 2015).

Based on these recycling recommendations, it is possible to translate them into design for recycling guidelines. Due to the time lack from the design and production of a product to its end of life management, it is assessed that the proper technologies for tantalum, REE and indium recovery are in place. The design for recycling guidelines are presented in Table 7.

TABLE 7. Design for recycling guideline

Product group	Design for recycling guideline
Smartphone	Easy removal of gallium containing integrated circuits. Easy removal of batteries
Mobile phones and other small high-grade equipment	Easy removal of batteries
Desktop personal computers	Easy removal of PCB Easy removal of REE-containing magnets
Laptops	Easy removal of PCB Easy removal of batteries Easy removal of REE-containing magnets
LCD televisions with CCFL and LED backlighting	Easy removal of PCB Easy removal of REE-containing magnets Easy removal of indium-containing display planes

6.5 Sub-conclusion

When designing products for improved recycling it is necessary to know, which recycling systems the products will enter into, as it will have an impact on the type of design guidelines and rules that can improve the recycling of WEEE. Plastic recycling seems to be difficult under the current conditions. The use of many different plastic resins makes the recycling process challenging along with the different hazardous substances used such as brominated flame-retardants. Hence, there is an improvement potential. A possibility could be to reduce the number of plastic resins and additives used in electrical and electronic equipment and make identification of the different resins easier. Additional restrictions, in addition to those in the RoHS Directive, could be made on the use of hazardous substances in electrical and electronic equipment. Finally, a modular structure and easier disassembly of the different parts is a necessary road ahead.

The review of the European recycling chain has shown that today mechanical and automatic technologies are widely applied in the pre-processing stage and highly technological advance refining processes in the end-processing. Manual disassembly is only applied to a small degree and mainly selective manual disassembly to remove hazardous components, which need special treatment, and valuable components such as printed circuit boards. Therefore, design requirements targeting easy disassembly of the product may not improve the recyclability of the WEEE, because mechanical and destructive processes are used to “disassemble” the used product. In any case, it will make sense to design the products in a way, where it is easy to remove hazardous components for special treatment and components containing precious metals, because pre-treatment using shredders decreases the recovery of precious metals. The question is also, how the recycling system will look in 5 or 10 years, when the products designed now will end up in the recycling system. With the current focus on circular economy and resource efficiency, it is likely that the recycling system will change, but it can be difficult to foresee exactly how it will look in the future. Easy disassembly and modular designs will advance other aspects that can improve resource efficiency such as repair, remanufacturing and refurbishment for electrical and electronic equipment. International regulation at least on European level is needed to make sure this will happen (see chapter 4).

Precious metals and critical materials are widely applied in electrical and electronic equipment, and especially antimony, cobalt, gallium, germanium, indium, REE and tantalum are critical due to their technological application in electrical and electronic equipment and their low recycling rates. The recycling rates are low for many of the critical and precious metals. Separation of components such as integrated circuits containing gallium, PCBs tantalum capacitors, batteries, REE containing magnets and indium containing display panels could potentially improve recovery of gallium, gold, palladium, silver, tin, tantalum, cobalt REE and indium, if the appropriate recycling technologies were developed and up-scaled.

7. European Regulation: Supporting the Circular Economy for Electrical and Electronic Equipment

This chapter will introduce the regulatory framework, which can support resource efficiency and the circular economy for electrical and electronic equipment. The chapter is an updated version of a chapter in the PhD thesis of Bundgaard (2016).

Resource efficiency and circular economy are on the European political agenda. Some of the first initiatives goes back to 2011, where the European Commission launched two key publications: *Flagship to a resource-efficient Europe* (European Commission, 2011e) and *Roadmap to resource efficiency* (European Commission, 2011a). The Flagship to a resource-efficient Europe sets up a policy framework that should support a resource efficient and low carbon economy, and the Roadmap to resource efficiency sets specific target on how to reach a more resource efficient Europe.

In 2014, the first EU Action Plan for Circular Economy was published but withdraw shortly after. In 2015, a new EU Action Plan for Circular Economy was published (European Commision, 2015). The plan presents concrete measures on how to reach a circular economy in Europe. Several projects have been carried out on how more specifically to improve resource efficiency and circularity. A key project, called Integration of resource efficiency and waste management criteria in European product policies, has addressed the Ecodesign Directive and its possibility to integrate resource efficiency requirements (Ardente et al., 2011a, 2011b, 2011c, Ardente and Mathieux, 2012a, 2012b; Ardente, Mathieux and Forner, 2012). The project was conducted by the Joint Research Centre and analysed the feasibility and opportunity to develop resource efficiency requirements within the Ecodesign Directive. The project encompasses a review and analysis of existing end of life and resource efficiency requirements and their verification and measurement approaches.

7.1 The Policy Instruments

Electrical and electronic equipment and specifically resource efficiency aspects are regulated through six European Directives and Regulations, including the Ecodesign Directive, the Waste Electrical and Electronic Equipment (WEEE) Directive, the Restriction on Hazardous Substances (RoHS) Directive, the EU Energy Labelling Directive and the EU Ecolabelling Regulation and the Consumer Sales Directive. Especially, the Ecodesign Directive is highlighted in the Roadmap to resource efficiency and the Action Plan on Circular Economy version 2 as an important policy instrument to increase resource efficiency and create a circular economy. The following section will provide an introduction to the six policy instruments.

7.1.1 Ecodesign Framework Directive

The Ecodesign Framework Directive was first adopted in 2005, and it was revised in 2009 (European Commission, 2009). The Ecodesign Framework Directive aims to continuously improve the environmental performance of energy-related products in a life cycle perspective. The Ecodesign Directive is a framework Directive, and therefore product specific requirements are specified in implementing measures and self-regulation measures such as voluntary agreements (European Commission, 2009). For a product group to be within the scope of the Ecodesign Directive it should (1) have a volume of sales and trade of more than 200,000 units/year, (2) have a significant environmental impact, and (3) have a significant potential for environmental improvements without requiring excessive costs (European Commission, 2009). The ecodesign requirements set down in the implementing measures and voluntary agreements should consider the entire product life cycle and should target the environmental aspects with a significant environmental impact (European Commission, 2009). The implementing measures set minimum performance requirements. Therefore, the ecodesign regulation removes the environmentally worst performing products from the European market through a regulatory push.

The Ecodesign Framework Directive is one of many directives and regulations, which producers or importers need to comply with in order to obtain the CE-marking and thereby gain access to the European Market. When an implementing measure is adopted for a specific product category, then the product can only be put on the European Market, if it complies with the ecodesign requirements. The CE making is based on manufacturers' self-declaration and documentations that the products comply with the requirements in the relevant directive. The Ecodesign Framework Directive is in Denmark enforced by the Danish Energy Agency. Since 2010, the Danish Energy Agency have assigned the responsibility of administrating and coordinating the surveillance of product compliance to the Secretariat for Ecodesign and Energy Labelling of products. The results of the check samples are available from the homepage of the Danish Energy Agency going back three years.

Resource Efficiency Requirements in the Implementing Measures and Voluntary Agreements

In July 2017, 27 implementing measures and three voluntary agreements were in place for specific product categories see Table 8. An implementing measure is in place setting requirements to the use of tolerances in verification procedures. All implementing measures and voluntary agreements have targeted and improved the energy efficiency of the products (Bundgaard, Remmen and Zacho, 2015). The implementing measures and voluntary agreement can target a wide selection of environmental aspects. To examine if the adopted implementing measures and acknowledged voluntary agreements target resource efficiency aspects beyond energy efficiency; the 27 implementing measures and three voluntary agreements were analysed and specific requirements and information requirements were identified targeting resource efficiency aspects other than energy efficiency (see Table 8).

The review showed that 20 implementing measures and two voluntary agreements had information requirements targeting resource efficiency aspects beyond energy efficiency. The information requirements primarily targeted recyclers and end-consumers and contained information on recycling or disposal of the end of life product, disassembly and easy disassembly, hazardous substances, durability and the most resource efficient use of the product.

Specific requirements targeting improved resource efficiency beyond energy efficiency were only included in five (5) implementing measures and two voluntary agreements. The specific requirements included requirements on water consumption in the use phase, product durability, resource efficient use of consumables, design for improved recyclability and reparability of the products, requirements to services that refurbish or repair the out of warranty product, non-destructive disassembly, marking of plastic and spare part availability. For further details on the types of resource efficiency requirements included in the implementing measures and voluntary agreements see Bundgaard et al. (2015).

TABLE 8. Overview of resource efficiency requirements in the 27 adopted implementing measures and three recognised voluntary agreements in July 2017 (green indicates that resource efficiency requirements and grey indicates no resource efficiency requirements).

Implementing Measure/ Voluntary Agreement	Specific requirements	Information requirements	Year for adoption/ year for revision	Regulation
Air conditioners and comfort fans			2012	(EU) 206/2012
Air heating and cooling products			2016	(EU) 2016/2281
Circulators Glandless standalone circulators and glandless circulators integrated in products			2009/2012	(EU) 641/2009 (EU) 622/2012
Computers and computer servers			2013	(EU) 617/2013
Domestic cooking appliances Domestic ovens, hobs and range hoods			2014	(EU) 66/2014
Electric motors			2009/2014	(EC) 640/2009 (EU) 4/2014
No-load condition electric power consumption and average active efficiency of external power suppliers			2009	(EC) 278/2009
Household dishwashers			2010	(EU) 1016/2010
Household tumble driers			2012	(EU) 932/2012
Household washing machines			2010	(EU) 1016/2010
Industrial fans			2011	(EU) 327/2011
Fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires			2009/ 2010	(EU) 245/2009 (EU) 347/2010
Directional lamps, light emitting diode lamps and related equipment			2012	(EU) 1194/2012
Non-directional household lamps			2009/2015	(EU) 245/2009 (EU) 859/2009 (EU) 2015/1428
Local Space heaters			2015	(EU) 2015/ 1188
Space and combination heaters			2013	(EU) 813/2013
Water heaters and hot water storage tanks			2013	(EU) 814/2013
Small, medium and large power transformers			2014	(EU) 548/2014
Professional refrigerated storage cabinets, blast cabinets, condensing units and process chillers			2015	(EU) 2015/1095
Household refrigerating appliances			2009	(EC) 643/2009
Simple set-top boxes			2009	(EC) 107/ 2009
Solid fuel boilers			2015	(EU) 2015/1189

Standby and off mode electric power consumption of electrical and electronic household and office equipment			2008	(EC) 1275/2008
Televisions			2009	(EC) 642/2009
Vacuum cleaners			2013	(EU) 666/2013
Ventilation units			2014	(EU) 1253/2014
Water pumps			2012	(EU) 547/2012
Imaging equipment (Voluntary Agreement)			2013	Version 5.2 April 2015
Complex set top boxes (Voluntary Agreement)			2010	Version 3.1 19. June 2013
Game consoles (Voluntary agreement)			2015	Version 1.0 – 22. April 2015

7.1.2 WEEE Directive

The first European WEEE Directive entered into force in February in 2003 and in August 2012 a revised WEEE Directive was adopted and effective from February 2014 (European Commission, 2012). The objective of the WEEE Directive is to improve the prevention, reuse, recycling and recovery of WEEE. The directive should reduce waste and ensure a more efficient use of resources and recovery of valuable secondary raw materials. The WEEE Directive obliges the Member States to ensure a free-of-charge collection system for consumers and retailers. The directive sets-up minimum collection and recovery rates and recycling and prepare-for-reuse targets, which the Member States should comply with. The revised WEEE Directive from 2012 includes a regrouping of the product categories effective from 2018 and a prepare-for-reuse is included in the recycling target. The recovery, recycling and prepare-for-reuse and recycling targets for each product category for the new and the old product categories are presented in Table 9. Furthermore, there should be a minimum collection rate of 45 % based on the average weight of the electrical and electronic equipment placed on the market the last three years. Finally, the WEEE Directive identifies substances, mixtures and components that should to be removed for selective treatment.

TABLE 9. Product categories and recovery and recycling rates and prepare-for-reuse and recycling targets in the revised WEEE Directive (European Commission, 2012).

	August 2012- August 2015		August 2015 -August 2018			From 15. August 2018	
Categories	**Recovery**	**Recycling**	**Recovery**	**Prepare-for-reuse and recycling**	**Categories**	**Recovery**	**Prepare-for-reuse and recycling**
1. 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 telecommunication 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 %			

When the WEEE Directive was adopted in 2003, it introduced the producer responsibility principle into European product regulation. Thereby, the WEEE Directive makes the producer financially responsible for the collection, treatment, recovery and disposal of WEEE. The idea behind introducing the producer responsibility principle was that by making the producer financially responsible for the end of life handling of WEEE, it would encourage the producer to design products that more easily could be reused, recycled and recovered. The WEEE Directive and especially the producer responsibility has been implemented differently in the Member States (van Rossem, Dalhammer and Toulouse, 2009). In many Member States including Denmark, collective schemes have been set-up, where the producers often pay a fixed fee per weight of electrical and electronic equipment, they put on the market (van Rossem, Dalhammer and Toulouse, 2009). Thereby, the producers do not have the same incentive to improve the design of their products. The WEEE Directive has therefore not lead to design changes of the products that could have improved reuse, recycling or recovery of electrical and electronic equipment.

The WEEE Directive is implemented into Danish legislation through the Danish Environmental Protection Act and through the executive order on bringing electrical and electronic equipment in circulation and the treatment of WEEE (BEK nr. 130 from 06/02/2014). The WEEE Directive is managed by the Danish Environmental Protection Agency, but the rules on producer responsibility for electrical and electronic equipment are administrated by the Danish Producer Responsibility System (DPA-system). The DPA-system has different tasks in relation to the WEEE Directive: they handle and run the mandatory product registration, register and process the data from the producers and importers of electrical and electronic equipment, register the municipal collection sites, calculate and assign the recovery of WEEE and batteries, develops statistics monitoring environmental targets and informs all relevant actors (DPA, 2016). The DPA system also assigns the different municipal collection sites to the collective schemes. In Denmark in 2017, there were five collective schemes handling waste electrical and electronic equipment (elretur, ERP Denmark asp, LWF, Recipo Aps and RENE) and one handling batteries (Returbat) (DPA, 2017). The collective schemes then hand over the responsibility of collection and treatment of WEEE to waste treatment companies.

7.1.3 RoHS Directive

The RoHS directive is from February 2003 (European Commission, 2003) and in 2011, a recast of the RoHS Directive was adopted effective from January 2013 (European Commission, 2011b). The purpose of the RoHS Directive is to restrict the use of certain hazardous substances in electrical and electronic equipment to protect human health and to support an environmentally sound recovery and disposal of waste electrical and electronic equipment. The RoHS Directive restricts the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) with some exemptions.

The recast of the RoHS Directive made it easier to include additional restriction on hazardous substances through delegated acts. In 2015, the first delegated act was adopted restricting the use of bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP). The recast of the RoHS Directive also expanded the product scope. In the recast all electrical and electronic equipment is included unless otherwise specified. Finally, with the recast of the RoHS Directive, the directive was included in the CE marking scheme. The RoHS Directive is managed by the Danish Environmental Protection Agency and is implemented into Danish legislation through the executive order on the restriction of import, sale and production for export within EU of electrical and electronic equipment containing certain hazardous substances (BEK. no. 1331 of 17/11/2016).

7.1.4 EU Energy Labelling Directive

The EU Energy Labelling Directive was first adopted in 1992 and a recast of the directive was adopted in 2010 (European Commission, 2010a). The purpose of the directive is to create a harmonised framework for end-user information through standardised product information and labelling. The EU Energy Label contains information on energy consumption during use, the consumption of other relevant resources during use and additional relevant information making it possible for the users to select the most efficient product. The first directive from 1992 targeted household appliances, but the recast extended the scope to energy-related products. The scope extension aligns the EU Energy Labelling with the Ecodesign Directive, making it possible to better exploit the synergies between the two directives. The product specific requirements are set in delegated regulation, and they are thereby directly legally binding when adopted by the European Commission. In Table 10, an overview of the adopted energy labelling legislation by July 2017 is provided.

TABLE 10. Energy Labelling legislation adopted by July 2017.

Air conditioners
Domestic ovens and range hoods
Electrical lamps and luminaries
Heaters and water heaters
Household dishwashers
Household refrigerating appliances
Household tumble driers
Household washing machines
Local space heaters
Professional refrigerated storage cabinets
Residential ventilation units
Solid fuel boilers
Televisions
Vacuum cleaners
Household combined washer-driers
Tyre Labelling regulation
Labelling of energy-related products on the internet (omnibus regulation)
Use of tolerances in verification procedures (omnibus regulation)

When the Energy Labelling Directive was first introduced, the A to G scale was used ranking the energy efficiency of products. A represented the best performing products and G represented the worst performing products on the European Market. The product energy efficiency has improved, and therefore a different energy labelling scale were introduced ranking for instance products from A+++ to D. The energy labelling scale became different depending on the product and it became rather complex information to the consumers. The European Commission proposed in 2015 a return to one single A to G scale in order to make the scale simpler and well understood by consumers. As the Ecodesign Directive, the Energy Labelling Directive is enforced by the Danish Energy Agency, and the responsibility of administrating and coordinating the surveillance of product compliance is handled by the Secretariat for Ecodesign and Energy Labelling of products.

7.1.5 EU Ecolabelling Regulation

The first EU Ecolabel Regulation was introduced in 1992, and the regulation was revised in 2000 and 2010 (European Commission, 2010b). The EU Ecolabel is a voluntary ecolabel award scheme with the purpose of promoting products with a reduced environmental impact and to offer consumers information on the environmental performance of the product. The ecolabelled products should be the environmentally best performing products on the market. The Ecolabelling criteria should take into account the entire life cycle of the product and focus on the most significant environmental impact. The ecolabelling criteria are adopted through a Commission decision. In 2016, criteria were revised or developed for the following electrical and electronic products: imaging equipment, personal computers, notebook computers, televisions, heat pumps and water-based heaters. The EU Ecolabelling is managed by the European Union Ecolabelling Board (EUEB).

7.1.6 The Consumer Sales Directive

The Consumer Sales Directive differs from the directives and regulations described above, as its main purpose is not to target environmental aspects, but instead to protect consumer interests. Still the directives can play a role to ensure a longer lifetime of products, which can help improve resource efficiency. The Consumer Sales Directive was first introduced in 1999 (European Commission, 1999). The purpose of the directive is to harmonise consumer sales contract laws, when it comes to legal guarantees (warranties) and to some extent also commercial guarantees. The Consumer Rights Directive introduced the two-year guarantee period as a standard and offers obligations for repair (Tonner and Malcolm, 2017).

7.2 Policy Instruments for Supporting Resource Efficiency

The six directives and regulations cover different resource efficiency aspects and have to a certain degree successfully improved resource efficiency of electrical and electronic equipment. An overview of how the different directives and regulations target resource efficiency aspects in their scope and in their actual implementation is presented in Table 11. The resource efficiency aspects have been categorised according to the five strategies to close the material loops described in section 1.1. The strategies include reduction, maintenance and repair, reuse, reconditioning, refurbishment and remanufacturing and recycling.

The RoHS Directive and the WEEE Directive have target recyclability by setting up take-back systems, recovery, recycling and prepare-for-reuse targets and restricting hazardous substances in electronic and electrical equipment. The WEEE Directive was also intended to stipulate design changes for improved prevention, reuse and recycling of electrical and electronic equipment by introducing the producer responsibility. The prevalence of collective producer schemes in many Member States implied that the introduction of the producer responsibility did not have the intended effect on ecodesign.

The EU Ecolabel is a voluntary instrument that applies a lifecycle perspective, and therefore can and do set criteria targeting a broad variety of resource efficiency aspects (Bundgaard, 2016). The EU Ecolabel can and does target all five strategies to improve resource efficiency. So far, the EU Ecolabelling criteria cover few electrical and electronic product groups and industry up-take is low within electronics. Therefore, the EU Ecolabel has not yet fully utilised its potential to improve the resource efficiency of electrical and electronic equipment.

The EU Energy Label has improved energy efficiency of electrical and electronic equipment on the European Market for the product categories it covers. The EU Energy label primarily targets the use phase and mainly energy efficiency and a narrowing and reducing strategy. The Consumer Sales Directive improves maintenance and repair by setting a two-year guarantee period as a standard and offers obligations for repair. The Ecodesign Directive is the only mandatory policy that applies a life cycle perspective, and sets minimum requirements for all the five strategies to improve resource efficiency (Bundgaard, 2016). As documented earlier only five implementing measures and two voluntary agreements included specific requirements targeting resource efficiency beyond energy efficiency.

TABLE 11. Overview of how the six different directives and regulations target the five strategies to improve resource efficiency: reduction, maintenance and repair, reuse, reconditioning, refurbishment and remanufacturing and recycling. The green colour implies that the directive or regulation include resource efficiency aspects in their scope and also set specific requirements or criteria for resource efficiency. The blue colour implies that the regulation or directive include resource efficiency requirements in their scope but that actual requirements or criteria are not set. The grey colour implies that the regulation or directive neither set specific resource efficiency requirements or targets resource efficiency in their scope.

	EU Ecolabel	Ecodesign	Consumer sales Directive	EU Energy Label	RoHS	WEEE
Reduce	Included in the scope and specific requirements targeting resource efficiency.	Included in the scope and specific requirements targeting resource efficiency.		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 criteria targeting maintenance and repair.	Included in the scope and specific requirements targeting resource efficiency.	Two-year guarantee period as a standard and offers obligations for repair.			
Reuse	Included in the scope and criteria targeting reuse.	Included in the scope and requirements targeting reuse.				Should contribute to reuse of WEEE, but no separate targets for reuse.
Reconditioning, refurbishment and remanufacturing	Included in the scope and specific criteria improving reconditioning, refurbishment and remanufacturing.	Included in the scope and requirements targeting reuse.				
Recyclability and recovery	Included in the scope and sets specific criteria to improve recyclability.	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.

7.2.1 How to further support the synergies between the policy instruments?

The six directive and regulations use different mechanisms to improve resource efficiency (see Figure 6). The Ecodesign, the RoHS and the Consumer Sales Directive push the market towards resource efficiency by setting mandatory minimum requirements. The WEEE directive sets requirements for take-back systems, the recovery, recycling and prepare-for-reuse targets and introduced the producer responsibility principle for electrical and electronic equipment. The EU Energy Label strives to pull the market towards increased energy efficiency by providing consumers with information that makes it possible for the consumer to purchase the most efficient product. The EU Ecolabel also strives to pull the market towards more resource efficient and environmentally friendly products by providing the consumer with information on the environmentally best performing products on the market. The intention is that the policy instruments should support each other and that the different synergies between the policy instruments should be used.

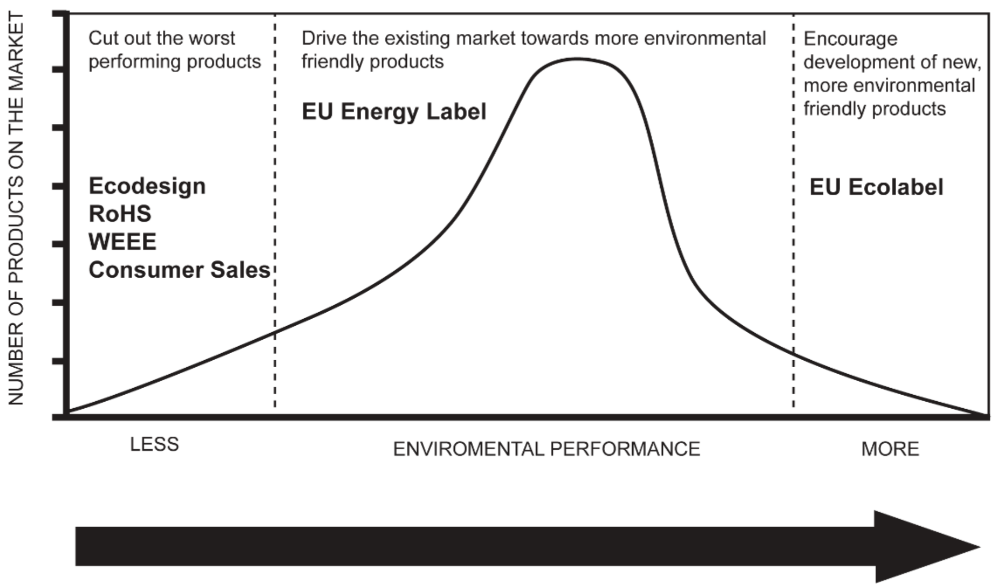


FIGURE 6. Intended synergies between policy instruments adapted from (Huulgaard, 2015).

At European level, actions have been taken to improve the synergies between the policy instruments. Especially, the Ecodesign Directive and EU Energy Label have been rectified. The EU Ecolabel criteria target a broad variety of resource efficiency aspects and a large share of these criteria could be transferred to the Ecodesign Directive. When setting requirements in the Ecodesign Directive, existing criteria in voluntary instruments such as the EU Ecolabel is already considered during the preparatory study, but there is a greater potential for further systemisation and utilisation of these synergies.

The WEEE, the RoHS and the Ecodesign Directive are intended to support each other, and it is even explicitly mentioned in the three directives. These synergies could be further explored. The Ecodesign Directive could compensate for the limited effect of the producer responsibility on product design by setting requirements to improve the prevention, reuse, recycling and recovery of WEEE. At least, the Ecodesign Directive could ensure that substances, mixtures and components that have to be removed according to the WEEE Directive can in fact be easily removed. The Ecodesign Directive could also supplement the RoHS Directive by setting product specific restrictions to hazardous substances adding to the more generic restrictions in the RoHS Directive. The Ecodesign Directive could, for relevant product categories, set more specific requirements to the lifetime expectancy going beyond the minimum 2 years guarantee period set in the Consumer Sales Directive.

7.3 Sub-conclusion

Six European directives and regulations can regulate resource efficiency of electrical and electronic equipment, including the Ecodesign Directive, the WEEE Directive, the RoHS Directive, the EU Energy Labelling Directive and the EU Ecolabelling Regulation and the Consumer Sales Directive. The WEEE Directive and the RoHS Directive primarily improve the recyclability of electrical and electronic equipment. The Ecodesign Directive and the EU Ecolabel can and do set requirements to all five identified strategies to improve resource efficiency. Until now (July 2017), the Ecodesign Directive has only set resource efficiency requirements (beyond energy requirements) in five implementing measures and 2 voluntary agreements. Additionally, the EU Ecolabel so far only covers a few electrical and electronic product groups and the actual application by industry is low. The EU Energy Labelling mainly covers energy efficiency. The Consumer Sales Directive covers maintenance and repair by setting a two-year guarantee period and offer obligations for repair. It is the intention that the policy instruments should support each other by using different means to improve the environmental performance and resource efficiency of electrical and electronic equipment. The synergies between the different instruments could be improved.

8. Standards

This chapter provides an introduction to standards focused on ecodesign and the introduction of environmental aspects in the design phase. There exist standards addressing ecodesign and environmental aspects in relation to electrical and electronic equipment. ISO has developed a generic standard: ISO 14006:2011 - Environmental management systems: Guidelines for incorporating eco-design and a technical report: ISO/TR 14062:2002 Environmental management: Integrating environmental aspects into product design and development. Moreover, the European Computer Manufactures Association (ECMA) has developed a specific standard ECMA-341 on Environmental design considerations for ICT and CE products. Finally, Danish Standard has a technical committee working on environmental standardisation of electrical and electronic products (S-611). The following section will provide an introduction to the standard and technical report developed by ISO, the standard developed by ECMA and the work conducted by the S-611 technical committee.

8.1 Introduction to Standards

Standards are important when designing products to be more resource efficient or circular through ecodesign. There are several reasons for this. Firstly, standards help provide a communication form through technical specification, which is needed in order to change the design of electrical and electronic equipment. Secondly, standards are also decisive when technical specifications are communicated between suppliers and producers, and it is especially relevant for a product category such as electrical and electronic requirements, where the value chain is highly globalised. Thirdly, regulation of electrical and electronic equipment is, as mentioned in the previous section, an important driver in the transition towards more resource efficient and circular products, and standards are a significant tool to support setting up regulatory requirements. Finally, standards can also support innovation and different types of standards can support the different steps of innovations.

There are several different standardisation bodies working on different levels (international, European and national). An overview of the main standardisations bodies is provided in Table 12. The work of these different standardisations bodies is highly harmonised.

TABLE 12. Overview of the main international, European and national standardisation bodies based on Bøgh (2015).

International	International Electrotechnical Commission IEC	International Organization for Standardisation ISO	Develops standards for the telecommunication field ITU
European	European Committee for Electrotechnical Standardisation CENELEC	European Committee for Standardisation CEN	European Telecommunications Standards Institute ETSI
National	National Standardisation Organisations		

8.2 ISO 14006:2011 and ISO/TR 14062:2002

The intention of the ISO 14006 standard is to be used in connection with an environmental management system such as ISO 14001, and it therefore provides guidelines on how an organisation can integrate ecodesign within its existing environmental management system. The ISO/TR 14062 on the other hand assists in the integration of environmental aspects into the design and development process. Figure 7 provides an overview of how the standards are intended to support each other. As illustrated, the ISO/ TR 14062 should link the environmental aspects and the design process and the ISO 14006 should link both the design process, the environment and the management system.

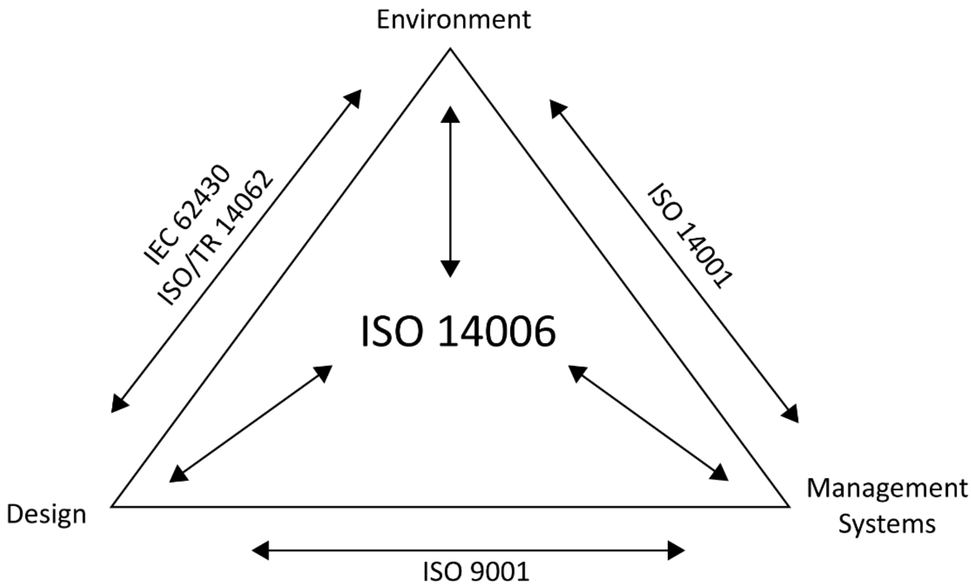


FIGURE 7. The relationship between the ISO 14006, ISO 14001, ISO 9001, IEC 62430 and ISO/TR 14062 (ISO, 2011: vi).

8.2.1 ISO 14006:2011 Environmental Management Systems – Guidelines for Incorporating Eco-design

As mentioned, the ISO 14006 provides guidelines on how organisations can establish a systematic and structured approach to integrate and implement ecodesign within an existing environmental management system such as ISO 14001. More specifically, the scope of the ISO 14006 is *"to assist organisations in establishing, documenting, implementing, maintaining and continually improving their management of eco-design as part of an environmental management system"* (ISO, 2011). ISO 14006 is seen as an integrated part of an organisations environmental management system. Here, ecodesign is defined as the *"integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle"* (ISO, 2011).

The ISO 14006 specifies that the role of top management is to set the organisation's strategic direction in relation to ecodesign and to manage the implementation. The standard specifies specific tasks for top management, which should ensure that ecodesign is embedded properly within the organisation. ISO 14006 also provides guidelines for how to incorporate ecodesign into the environmental management systems in relation to the specific phases of the ISO 14001, such as the development of the environmental policy, the planning phase, the implementation and operation phase, the checking phase and the management review phase. Finally, the ISO14006 provides a generic description of ecodesign activities in product design and development. The description includes aspects such as life cycle thinking, ecodesign processes, environmental assessment, analysis of interested parties' environmental requirements, ecodesign review and value chain involvement.

8.2.2 ISO 14062:2002 Environmental Management - Integrating Environmental Aspects into Product Design and Development

ISO 14062:2002 is a technical report, and it explains current practices and concepts in relation to the integration of environmental aspects into product design and development (ISO, 2002). Here, the term product covers both goods and services (ISO, 2002). The technical report is intended to be used to develop sector specific documents and is not usable as specification for certification and registration purposes (ISO, 2002).

The technical report specifies that, *"the goal of integrating environmental aspects into product design and development is the reduction of adverse environmental impacts of products throughout their entire life cycle"* (ISO, 2002). More specifically, it describes how environmental aspects can be integrated into product design and development specifying the strategic, management and product considerations that need to be considered. Finally, the technical report provides a more detailed description of how environmental aspects can be integrated into the different stages of the product and development process. Figure 8 provides a generic model of how environmental aspects can be integrated into the different stages of the product design and development process. The technical report also emphasises that the integration of ecodesign needs to be related to the specific organisation and their product design and development process. Finally, the technical report provides suggestions for specific actions and tools to use in the integrations of environmental aspects in the different processes.

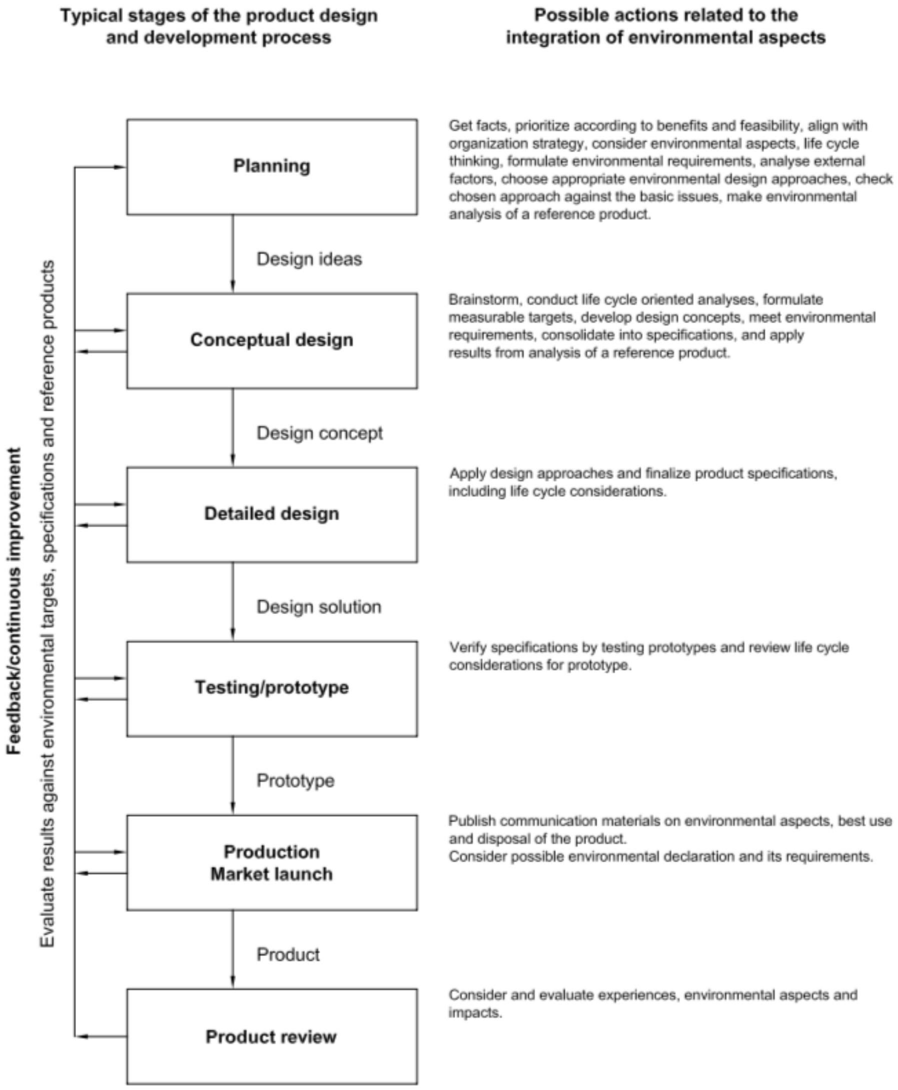


FIGURE 8. Example of a generic model of integrating environmental aspects into the product design and development process from ISO (2002).

8.3 ECMA-341:2004 Standard - Environmental Design Considerations for ICT & CE Products

The European Computer Manufactures Association (ECMA) was established in 1960 with the purpose of standardising aspects in relation to the growing field of computers. Today, the main purpose of ECMA is the development and publication of standards and technical reports for information and communication technology and consumer electronics. Its members include companies such as Google, Hewlett Packard, Hitachi, IBM, Intel, Konica Minolta, Microsoft, Paypal and Yahoo.

More specifically, the ECMA-341:2004 standard identifies design practices that can reduce the environmental impact of products for Information and Communication Technology (ICT) and Consumer Electronic (CE) products (ECMA, 2004). The standard covers the following aspects (ECMA, 2004):

1. Energy efficiency
2. Material efficiency
3. Consumables and batteries

4. Chemical and noise emissions
5. Extension of product lifetime and end of life considerations
6. Substances and preparations needing special attention
7. Product packaging
8. Documentation

The standard emphasises that the design considerations need to be considered as early as possible in product development process, to ensure that there is still opportunity to improve the environmental performance of the product, while balancing additional aspects such as technical features and economic viability (ECMA, 2004). The standard highlights life cycle thinking, and that all stages of the products life cycle should be considered (ECMA, 2004). Especially, the use phase is emphasised, as it is often the main source of environmental impact for ICT and CE equipment (ECMA, 2004). The ECMA-341:2004 standard provides design requirements and recommendations for the eight aspects listed above, and then it provides a design checklist to be used by the designers. The design requirements and recommendations and the design checklist are not product specific, but covers a wide range of ICT and CE products (ECMA, 2004). Table 13 provides examples of design requirements and recommendations as they are formulated in the ECMA-341:2004 standard.

TABLE 13. Examples of design and recommendations for End of life from the ECMA-341: 2004 standard (ECMA, 2004).

Design requirements and recommendations for End of life
Easy and safe separation of parts containing hazardous substances and preparations shall be possible.
Incompatible materials (including electronic modules) connected to case/housing parts or chassis shall be easily separable.
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.

8.4 The work of the technical committee S-611: Environmental standardisation of electrical and electronic products

The technical committee develops standards and guidelines on environmental aspects in the field of electro-technics including; labelling, declaration and measurement of substances regulated by law and also the recyclability of worn-out products (Dansk Standard, 2017). The technical committee S-611 is part of the international electro-technical committee IEC TC 111: Environmental standardisation for electrical and electronic products and system and the European electro-technical committee CENELEC TC 111X: Environment (Dansk Standard, 2017).

8.4.1 Standardisation supporting legislation

The main fields of work of the technical committee S-611 is in relation to the European WEEE Directive, RoHS Directive, REACH Regulation and the Ecodesign Directive. Thus, there are no standardisation activities in connection with the REACH Regulation (Dansk Standard, 2017).

The WEEE Directive

In connection with the latest revision of the WEEE Directive from 2012, the Commission issued a standardisation mandate to CENELEC, with a description of the standards needed to support the revision of the WEEE Directive (Dansk Standard, 2017). These standards will deal with requirements to the collection and processing of WEEE and requirements to the actors within the field (Dansk Standard, 2017).

The RoHS Directive
With the latest revision of the RoHS Directive, the directive is now covered by the CE Labelling Directive. Both IEC TC 111 and CENELEC are involved with standardisation in connection with the RoHS Directive. CENCELEC has accepted a standardisation mandate (M/499) from the Commission (Dansk Standard, 2017). The purpose of this mandate is to develop a standard that can provide guidance on the technical documentation needed to assess conformity with the recast of the RoHS Directive (European Commission, 2011c).

The Ecodesign Directive
Extensive standardisation efforts have been in relation to the Ecodesign Directive under the standardisation mandate 495 (Dansk Standard, 2017). The objective of the standardisation mandate 495 is to provide European standards that can ensure the implementation of the Ecodesign Directive (European Commission, 2011d). The mandate is generic and overarching and should cover all standardisation needs in relation to the Ecodesign Directive (European Commission, 2011d). The standardisation mandate 495 is accepted by CENELEC and CEN (Dansk Standard, 2017). The work is largely driven by existing technical committees, which already worked with product standards for the product categories covered by the implementing measures and voluntary agreements adopted by the Ecodesign Directive (Dansk Standard, 2017). Standardisation mandate 495 is continually expanded as more product categories are included within the Ecodesign Directive (Dansk Standard, 2017).

In 2015, a new standardisation mandate was issued under the Ecodesign Directive M/543 on ecodesign requirements on material efficiency aspects for energy-related products (European Commission, 2015). The objective is to develop generic standards covering ecodesign requirements to material efficiency aspects such as recyclability, recoverability and reusability, durability, reversible disassembly and end of life extraction time (European Commission, 2015). The standardisation mandate M/543 has six working groups developing a standard each (Lauridsen, 2017):

- 1: Terminology
- 2: General method for the assessment of the durability of products
- 3: Upgradability, ability to repair, facilitate reuse, use or reused components
- 4: General method for assessing the ability to remanufacture
- 5: Recyclability, recoverability, RRR index, recycling, use of recycled materials
- 6: Documentation and/or marking regarding information relating to material efficiency of the product

The standards developed in the working groups will be horisontal standards and should therefore cover all product categories (Lauridsen, 2017). Going forward, vertical standards will be requested supporting the individual implementing measures (Lauridsen, 2017). These future standards will be key towards the integration of material efficiency requirements into the Ecodesign Directive's implementing measures and voluntary agreements.

8.5 Sub-conclusion
The ISO 14006:2011 and ISO/TR 14062:2002 are relevant if a company want to implement ecodesign into its existing environmental management system and/or product design and development processes. The standard and the technical report have a focus on the managerial aspects of integrating ecodesign into an organisation, but they do not provide specific design recommendations on how to improve resource efficiency or circularity of electrical and electronic products. The ECMA-341:2004 standard, on the other hand, provides specific design recommendations on how to improve the environmental performance of ICT and consumer electronic equipment including also design requirements for improving resource efficiency and circularity.

A large part of the work conducted by the technical committee S-611 is also relevant, when developing specific design requirements or recommendations to improve the resource efficiency and circularity of electrical and electronic equipment. Especially, the standardisation activities conducted in connection with the RoHS Directive and the Ecodesign Directive are relevant, but perhaps most importantly the work conducted under standardization mandate M/543, where there is a specific focus on material efficiency. This work is developed to set mandatory requirements to material efficiency for energy-related product, but might also provide valuable knowledge and measurement methods for companies' voluntary ecodesign initiatives.

9. Best practice abroad

Different projects have been carried out and organisations have been set-up to handle the increasing problems with WEEE. Two larger initiatives are Solving the E-waste Problem (StEP) initiative and the English Waste and Resource Action Programme (WRAP). The following section provides an introduction to the two initiatives.

9.1 Solving the E-waste Problem (StEP) Initiative

The StEP initiative raised from a book project in 2003 at the United Nation's University. The book was on Computers and the Environment. This initial work showed the extent of the electronic waste problem and called for further efforts. The StEP initiative is now led by the United Nations University-hosted SCYCLE (Sustainable cycle) programme (United Nations University, 2017). The initiative has more than 60 members from various sectors amongst these UN Environment, the US Environmental Protection Agency, the Japanese Ministry of Environment, the Chinese Academy of Science, Cisco, HP, Dell, Ericsson, Philips, Microsoft, Umicore and Massachusetts Institute of Technology (MIT) (United Nations University, 2017).

The purpose of the StEP initiative is to facilitate a solutions-oriented dialogue, consensus and cooperation by creating a global platform for sharing scientific knowledge (United Nations University, 2017). The initiative works internationally to develop effective policies to stimulate the prevention of electronic waste (counting aspects such as product design, refurbishment, repair, recycling capacity and improved management systems) in close collaboration with a broad range of partners (United Nations University, 2017).

The StEP initiative has five main taskforces:

- The *policy* taskforce with the purpose to report and analyse the existing approaches and legislation covering electronic waste and used electronic products (StEP, 2017b). Based on these studies recommendations are made for future developments that can help solve the problems related to electronic waste (StEP, 2017b).
- The *redesign* taskforce strives to foster redesign of electric and electronic equipment to reduce the negative impact from the equipment covering their entire life cycle (StEP, 2017d).
- The *reuse* taskforce strives to develop replicable and sustainable systems for reuse, refurbishment and spare parts development of electrical and electronic equipment with the purpose of minimising the environmental, health and safety impacts associated with WEEE (StEP, 2017e).
- The recycling taskforce aims to enhance global recycling infrastructures, systems and technologies to gain a more sustainable recycling of WEEE (StEP, 2017c).
- The *capacity building* taskforce's mission is to increase public, scientific and business awareness of the global problem with electrical and electronic waste (StEP, 2017a). One way is to offer open access to the experiences and knowledge deriving from the five taskforces described, but the taskforce also does active capacity development and training (StEP, 2017a).

In relation to this project on designing out waste, especially the initiatives within the redesign taskforce are relevant. Here, the main contribution from the StEP initiative is a green paper on the Worldwide Impacts of Substance Restrictions in ICT published in 2011 (Chancerel and Schischke, 2011). The report gives an overview of hazardous substances and materials found in electronics globally, and on the restrictions on hazardous substances established in the European Union, California, China, Japan and other countries (Chancerel and Schischke, 2011). The report provides a description of the direct and secondary impacts of the substance and material restrictions covering electronics hereunder the environmental impact, the impact on recycling, economic impacts and other effects (Chancerel and Schischke, 2011).

Another key contribution from the StEP initiative is the report: Recycling – From E-waste to Resources (Schluep et al., 2009). The report provides an analysis of the market potential in selected developing countries of relevant technologies used in the recycling of electronic waste (Schluep et al., 2009). It further examines "the Framework for UNEP Technology Transfer Activities in support of Global Climate Change Objectives" potential to transfer the technologies to the electronic waste recycling sector in developing countries (Schluep et al., 2009). Finally, innovation hubs and centres of excellence in emerging economies in relation to electronic waste recycling technologies is identified (Schluep et al., 2009). The StEP initiative also publish an annual report with an account of their activities.

9.2 The Waste and Resources Action Programme (WRAP)

The Waste and Resources Action Programme (WRAP) is a UK based programme established in 2000. Their vision is: a world where resources are used in a sustainable way, and they try to reach this vision by working with governments, communities and businesses to provide practical solutions to how resource efficiency can be improved (WRAP, 2017a). Their mission is more specifically to accelerate the transition towards a sustainable and resource-efficient economy through (WRAP, 2017a):

- Reinventing how we design, manufacture and sell products
- Rethinking the use and consumption of products
- Redefining what is achievable through reuse and recycling

They focus their activities within three business areas namely food and drinks, electricals and electronics and clothing and textiles.

9.3 Sustainable electricals and electronics

The following section will focus on WRAP's work in relation to the electrical and electronic sector. WRAP has three main activities within sustainable electricals: the electrical and electronic equipment sustainability action plan, the Resource Efficient Business Models (REBus) project and the Critical Raw Material Closed Loop Recovery (CRM Recovery) Project. The following will provide an introduction to the three initiatives.

9.3.1 Electrical and electronic equipment sustainability action plan (esap)

One of WRAP's main activities in relation to electronics is their action plan from 2014 running to 2025. The electrical and electronic equipment sustainability action plan (esap) strives to develop more sustainable electronic equipment that can benefit business, consumers and the environment. These specific benefits are set within five pillars (1) improving durability, (2) minimising returns, (3) increasing reuse and recycling, (4) resource efficient business models and (5) supply chain resilience (WRAP, 2017f).

Improving durability

Research conducted by WRAP has shown that the consumers expectations to product durability are significantly different to the actual life time of the electrical and electronic equipment (WRAP, 2017f). For instance, certain products such as fridges, freezers, vacuum cleaners, televisions and laptop computers were 35-96% more durable than what the customers expected (WRAP, 2017f). WRAP has developed detailed guidance and advice on product durability to address this issue. Two key initiatives are: the WRAP better appliances guidance and the electrical product design reviews. The WRAP better appliances guidance is a web-side that provides guidance and technical details needed to procure and build better, durable products (WRAP, 2017g). In 2017, six products were covered including: LCD TVs, vacuum cleaners, washing machines, irons, DAB radios and toasters (WRAP, 2017g). The electrical product design reviews are made based on a detailed product-breakdown, where WRAP identifies potential cost savings and design improvements that could increase durability, prolong the life span of the product and reduce return rates (WRAP, 2017d). In 2017, six products had undergone review: washing machines, microwaves, vacuum cleaners, fridge freezers, televisions and laptops.

Minimising product damage and returns
WRAP also work on minimising product damage and returns in the distribution chain, as they have identified return rates in the range of 5-10%. Product returns covers both product returns due to the product's condition or quality on arrival and a mismatch between the product and the expectations of the customers. WRAP is working on several projects within this field: including a project identifying the cost and resource impacts of electrical product return, and a project collecting the product age of electrical and electronic equipment when the products are donated or disposed.

Increasing reuse and recycling
The combination of continuously increasing sales of electronics and increasing product innovation and complexity implies that the recyclers of electronics can expect growing volumes of electronic waste and increasing product diversity and complexity (WRAP, 2017f). Furthermore, there are significant consumer barriers to the reuse of electronic products (WRAP, 2017f). Therefore, WRAP is working with a number of initiatives to increase reuse and recycling of electrical products that includes guidance on collecting and treating waste electricals, guidance on waste electricals materials and community waste collections events (WRAP, 2017f).

Resource efficient business models
WRAP has also developed a process that can support a business through the process of developing a resource efficient business model (WRAP, 2017f). The guides and tools include an explanation of the resource efficient business models and an innovative business model map (WRAP, 2017e). The business models included are service systems, hire and leasing incentivised return, reuse and long life (WRAP, 2017e). WRAP's activities within resource efficient business models are also linked to the EU project: Developing Resource Efficient Business Models (REBus), which is described more in section 6.3.2.

Supply Chain Resilience
The final pillar, WRAP is working with in terms of sustainable electronics, is supply chain resilience (WRAP, 2017f). Here, WRAP is working with businesses to mitigate some of the risk associated with the mainly linear supply chain of electrical and electronic equipment (WRAP, 2017f).

9.3.2 Developing Resource Efficient Business Models (REBus) project
The REBus project is an EU project, where different organisations across EU are collaborating including WRAP (WRAP, 2017c), with the main focus on the UK and the Netherlands. The aims of the REBus project are:

- To develop a base of evidence of existing circular economy models
- Support businesses in the innovation process
- Assess the commercial viability of resource efficient business models
- Provide pilot projects of resource efficient business models (WRAP, 2017c)

The REBus project covers sevens sectors including electrical and electronic products, textiles, construction, furniture, information and communications technology (ICT), catering and carpeting (REBus, 2017). The two main contributions of the REBus project are a guideline for circular procurements and a guide for suppliers, but these are not yet published as the project is not finalised (REBus, 2017).

9.3.3 The Critical Raw Material Closed Loop Recovery (CRM Recovery) Project

The critical raw material closed loop recovery (CRM recovery) project investigates the commercial opportunities for reclaiming critical raw materials and precious metals from waste electronic products, and is made in partnership with KTN, Wuppertal Institute, ERP UK Ltd and EARN (WRAP, 2017b).

9.4 Sub-conclusion

The StEP initiative focuses solely on the electronic sector, whereas WRAP focuses on several sectors amongst these the electronic sector. The StEP initiative has so far not that many activities within their redesign taskforce, but one of the main results is the report: Worldwide Impacts of Substance Restrictions in ICT (Chancerel and Schischke, 2011). The report provides an overview of the positive effects of substance and material restrictions in electronics.

WRAP has many initiatives within the electronic sector, two of the main initiatives, that also have a specific focus on design improvements, are the better appliance guidelines and the electrical product design reviews. The better appliance guidelines provide guidance and technical details that can support the procurement and construction of better and durable products. The electrical product design reviews provide guidance for cost savings and design improvements that could increase product durability, prolong the life span of the products and reduce product return rates.

Part 2: The Four Case Companies

Introduction to the four cases

Four case studies were conducted during the project of the four companies: Bang and Olufsen, Tier1Asset, Lightyears and Siemens Gamesa Renewable Energy. The four case studies had four different focuses in order to illustrate different angels on how resource efficiency can be improved within companies through ecodesign. The selected angel depended on the company, their needs and how fare along they were in their work with environmental aspects more generally. The four case studies represent four different approaches on how to work with resource efficiency and resource efficient design within companies. Thereby, the project strived to illustrate, the many different approaches that can be applied when working with resource efficiency and ecodesign within companies and the importance in selected the approach based on the specific context.

In addition to the four case companies, research interviews were conducted with actors from the electronic and electrical waste treatment sector. The purpose of these interviews was to get an overview of current waste treatment practices of WEEE and to learn about possibilities for design improvements. An overview of the interviews is provided in table 14. All interviews were semi-structured and an interview guide was made beforehand. Furthermore, all interviews were recorded and transcribed. All quotations were sent to the interviewees for comments and their approval to verify claims and conclusions made based on the interview.

TABLE 14. Overview of interview conducted with the waste treatment sector.

Company/ Organisation	Interviewee	Position	Purpose
	Waste Treatment Sector		
Averhoff	Tom Ellegaard	Responsible for the Technical Aspects	Recorded and transcribed
DCR Environment A/S	Simon Zittlau Halvarsson	Sales manager	Recorded and transcribed
European Electronic Recyclers Association (EERA)	Norbert Zonneveld	Executive Secretary	Recorded and transcribed
Danish Producer Responsibility	Johnny Bøwig	Manager DPA	Recorded

10. Designing for Recyclability – a Case Study of Bang & Olufsen

This chapter provides an account of the B&O case study. The chapter begins with an introduction to B&O and their existing work with environmental aspects and corporate social responsibility. Then, a mapping of B&O's existing activities supporting resource efficiency is provided. Finally, and account of the workshop focused on improving the recyclability of B&O's product is provided. The chapter is based on a chapter in Bundgaard et al. (2016).

10.1 Introduction to Bang & Olufsen

In 1925, Peter Bang and Svend Olufsen founded B&O. B&O ideal is *"to move your world with long-lasting magical experiences"* (Bang & Olufsen 2014). Their core values are passion, pride and persistence (Bang & Olufsen, 2014). Their passion is to create the magic the customers experience when using B&O products. B&O is proud of creating new experiences and setting new standards for quality and functionality. Finally, they are persistent in creating a sound and sustainable company (Bang & Olufsen 2014). B&O produces products within the following categories: integrated systems (BeoMedia), sound systems (BeoSound), loud speakers (BeoLab), televisions (BeoVision) and headphones. They have their core products, which are the high-end products, and then they have B&O Play products, which are relatively more low-cost products. Their products are sold in stores around the world and in their concept stores.

10.1.1 Environment and Corporate Social Responsibility in Bang & Olufsen

Traditionally, quality and design has been B&O's main competitive parameters. For this reason, environmental aspects have not been used in the marketing of B&O products. Even though environmental aspects are not part of B&O's competitive parameters, they have worked with several environmental initiatives during the years. They have worked with environmental issues in relation to their products and production focusing on issues such as working environment and the external environment.

Today, their focus has shifted towards considering the entire life cycle of their products along with corporate social responsibility, as illustrated in Figure 9. B&O works with the external environment mainly by decreasing energy consumption and waste generation from the production. Additionally, B&O complies with the existing environmental legislation in the countries, where they sell their products. The WEEE Directive, the RoHS Directive and the Ecodesign Directive in European Union are all eco-design related directives that are relevant for the product of B&O. In 2008 and onwards, B&O was affected hard by the financial crisis. One of the consequences of the crisis was a large restructuring of the company involving the Safety, Health and Environmental Department. In 2016 the product-related environmental competences were lost from the company (Product Environmental Consultant, 2016).

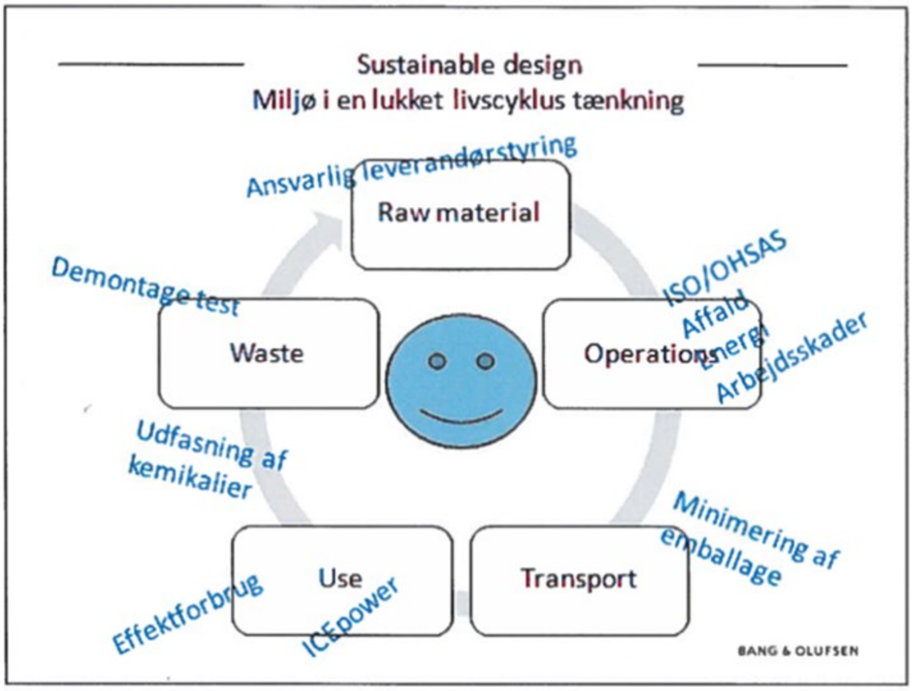


FIGURE 9. Illustration of B&O's work with CSR and environment (Bang & Olufsen, 2013: 1).

10.2 Mapping of Circular Activities in Bang and Olufsen

B&O already works with resource efficiency and initiatives that can be related to circular economy in their current work with corporate social responsibility and the environment, as expressed in their corporate social responsibility report from 2012/13 *"Bang & Olufsen considers the environment in a closed life cycle, where waste is a resource, which can be recycled in other products"* (Bang & Olufsen 2013, p. 1).

Several of their activities can be considered resource efficient. Therefore, the following section provides an outline of B&Os current activities (2013) in relation to the five strategies to improve resource efficiency outline in section 1.1. An overview is provided in Figure 10.

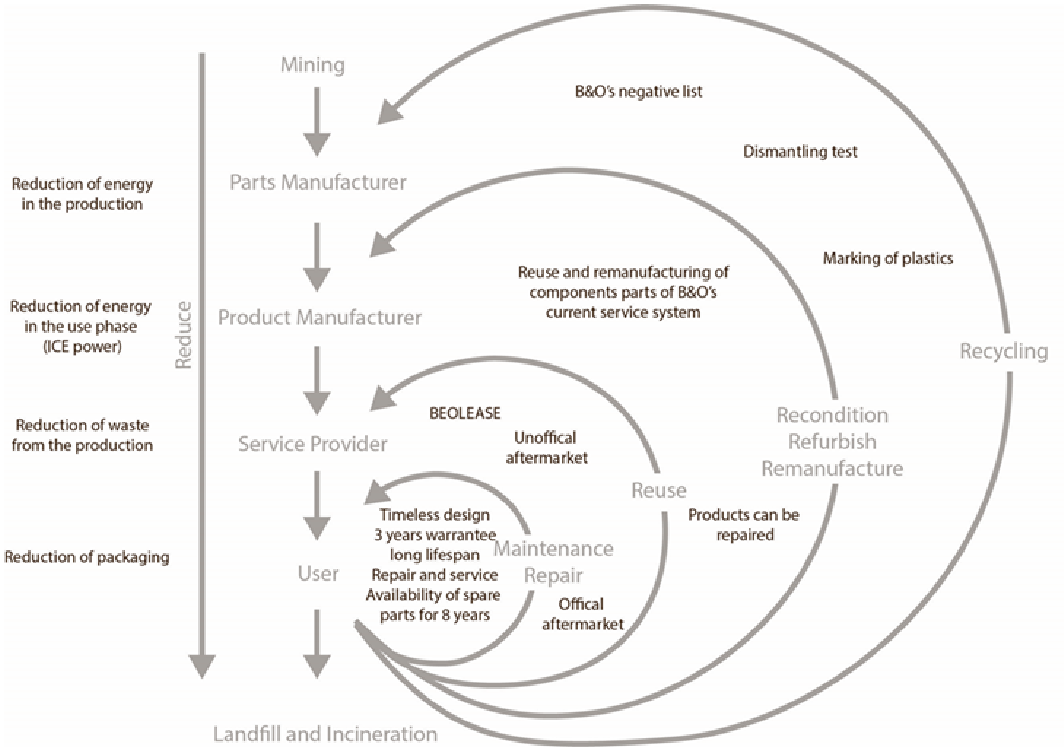


FIGURE 10. Overview of B&O's current circular activities

10.2.1 Reduce

B&O has worked with the more traditional environmental aspects in their processes such as reducing the energy consumption in their productions, minimising their production waste and reducing packaging materials. The development of the ICE power technology had resulted in energy reductions in the use phase for their sound system. Many of their products have a relatively high energy consumption in the use phase according to their energy label, and therefore improvements within this area are still possible.

10.2.2 Maintenance and repair

B&O core products have a long life span compared to other similar products with the same audio or video quality. A long life span can improve resource efficiency, because fewer products might be needed to perform the same service. B&O also strives for a timeless design, which can mitigate some of the risk associated with psychological obsolescence. Additionally, B&O has a repair and service scheme and has spare parts available for up to 8 years after the product went out of production. Again, the service scheme and the availability of spare parts potentially increase the life span of the products and thereby improve resource efficiency. It is however important to consider, if a long life span of a product will result in an increased energy consumption in the use phase compared to replacing the product with a more energy efficient product earlier, and if the increase energy consumption will outweigh the environmental gains from the longer life span.

10.2.3 Reuse

Due to their quality and long life span B&O's core products have a high resale value, which improves their potential for reuse. Consequently, a large secondary market for product resale and reuse exists. There is a large unofficial aftermarket for B&O's products through outlets such as "Den Blå Avis", but there are also more official aftermarkets for the resale of B&O's products through their own retailers, and the company BEOStæren has made a business from selling used B&O core products with a 1-year warrantee (BEOstæren, 2016).

10.2.4 Reconditioning, Refurbishment and Remanufacturing

It is possible to repair B&O's core products, and they have spare parts available for 8 years. This makes it possible to recondition, refurbish and remanufacture B&O's products. B&O has a repair and service system, where spare parts are remanufactured and reused (Sommer, 2013). The repair and service system is constructed around a modular design system, which enables easy repair and service of the products (Sommer, 2013). When a component fails in a product sold to a customer, the repairman goes to the customer and changes the component that fails with a "new component" (Sommer, 2013). Then, the repairman brings back the failed component to B&O. At B&O it is evaluated, if it is viable to repair the component (Sommer, 2013). If it is feasible to repair the component, it is repaired and the component enters the repair systems and is used to substitute another failed component (Sommer, 2013). The refurbishment of components is mainly used for circuit boards (Sommer, 2013). The refurbishment and reuse of component for repair and service potentially improves resource efficiency, because fewer components needs to be produced (Sommer, 2013). The main argument for creating this system is that it is economically a good solution, because B&O then has fewer components in stock, and it reduces the cost for repair both for B&O and for the customers (Sommer, 2013).

10.2.5 Recycling

Hazardous substances can significantly reduce the recyclability of materials, as they can contaminate the recycled materials. B&O complies with the European chemical legislation: the RoHS Directive and the REACH regulation. In addition to the legislation, B&O has a negative list with undesirable substances, which they have chosen to phase out. These substances include brominated flame-retardants, four phthalates (banned in all new products) and two phthalates in wires that comes into prolonged contact with the skin (Bang & Olufsen 2013). B&O marks all plastic components, so the waste managers can identify and sort plastic into the different fractions (Bang & Olufsen 2013, Bang & Olufsen 2012). Depending on the waste treatment system the product goes into, marking of plastics can potentially improve recyclability of plastic. B&O performs disassembly tests of their products, and based on these tests, the recyclability ratios of the products are calculated. These recyclability ratios can then be used to show compliance with the WEEE Directive. The calculated recyclability ratios only show the potential for recyclability and not the actual recycling rate, as it will depend on the specific waste treatment the product undergoes.

10.3 The Workshop

10.3.1 Planning the Workshop

In the Bang and Olufsen case study, the focus was on how to design product to improve their recyclability. This approach was the wish of the company. The purpose of the Bang and Olufsen case study was two-sided.

- Firstly, to examine on a practical level how the recyclability of B&O' products could be improved. Various ecodesign guidelines already exist on how to design products for improved recyclability, but the electronic technologies have changed, and the waste treatment system has also undergone large changes. Therefore, it was interesting to examine what could according to current waste management processes improve the recyclability of the products.
- Secondly, we wanted to examine how producers and waste managers could cooperate to improve knowledge sharing.

The process began with a meeting with the environmental manager Vivi Randrup Kristensen and the employee responsible for the product environment Lone Nielsen, where the project was presented and an introduction was made to the company. This was followed by a discussion of the focus of the project. Then qualitative interviews were made with four employees at B&O to identify the needs of B&O in relation to improved resource efficiency, and their current initiatives targeting resource efficiency. After the interviews, it was decided to focus on recyclability, as this was what the company wanted at the time. In the middle of the process, the contact person at B&O (Lone Nielsen) got a new job and Britt Gamskjær Vroue was employed instead as responsible for product environment. It was decided to continue the process and keep the same focus on recyclability, but to also include a discussion on more strategic considerations in the workshop.

TABLE 15. Interviews and meetings conducted at B&O.

Interviewee	Works function	Format	Documentation
Lone Nielsen Vivi Randrup Kristensen	Environmental Consultant (1999–2013) Environmental Manager	Meeting	Minutes
Britt Gamskjær Vrou Jesper Gregersen	Product Environmental Consultant (2013-2016) Senior Manager Product Quality Centre	Meeting	Minutes
Lone Nielsen	Environmental Consultant (1999–2013)	Interview	Recorded and transcribed
Birger Sommer	Manager, Technical Product Service	Interview	Recorded and transcribed
Søren Beck	Senior Technology Specialist	Interview	Recorded and transcribed
Klaus Mortensen	Technology Specialist	Interview	Recorded

Based on the meetings and interviews a workshop was designed. The workshop was made in collaboration with Averhoff (waste treatment company), B&O and Aalborg University. The program was as follows:

10.00-10.30: Introduction to waste treatment of electrical and electronic equipment by Tom Ellegaard from Averhoff.
10.30-12.00: Separating three B&O products: A television, a loudspeaker and a remote control
12.00-12.45: Lunch and summing up the workshop
12.45 -14.00: Strategy discussion, kicked off with a presentation of Apple's current work with sustainability as inspiration.

10.3.2 Workshop Results

This is an account of the design recommendations that came up and were discussed during the workshop, where we worked on separating three of B&O's new products: a television, a remote control and a loud speaker. Some recommendations are based on design challenges in relation to resource efficiency identified and some are based on good examples on how to design to improve resource efficiency. There might be other relevant design alterations that are not included in this description.

10.3.3 General Discussions

Rare earths and precious metals

The recovery of rare earths and precious metal requires special treatment processes. In order to ensure a good recovery of these materials, the component containing these materials ought to be easily identified, removed and treated separately. The waste treatment sector does often not know, which components contain rare earths and precious metals, and they need to rely on their experience and their network to locate the components with these materials and metals. This was also illustrated during the workshop, where the employee from Averhoff noticed a loud speaker in the containers. He knew from experiences that these small loud speakers could contain neodymium, but was not able to verify it visually, and he therefore began to dismantle it (Figure 11). It turned out that it did not, but it illustrates one of the problems experienced by the waste treatment sector, that it is often difficult to locate the components containing rare earths and precious metals. This is also the case for components containing hazardous substances that can contaminate the materials and need special treatment. Therefore, the following recommendations can be made.

Recommendations:

- Mark components that contain rare earths and precious metals and make it easy to disassemble the component
- Mark components that contain hazardous substances that requires 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. A recommendation is to make such a marking system in close collaboration with the waste treatment sector.

FIGURE 11. Employee from Averhoff working on disassembling a loudspeaker, to examine if it contains neodymium during the workshop

10.3.4 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 remove built-in batteries manually and easy to identify those products containing batteries.

Recommendations:
- Make it easy to remove built-in batteries manually
- Mark products that contain batteries

10.3.5 Information
A general aspect, discussed during the workshop, was the recyclers access to information on the product relevant for the recycling and recovery process. Generally, the recyclers lack information from the producers, that can help optimise the recycling of the product 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 way. One of the possibilities that was discussed is the use of radio-frequency identification (RFID). It is not possible based on this study to give a full account of the information that would be relevant for the recyclers to have access to and which solution would be the best, as it will require further study and collaboration with the recyclers.

Recommendations:
Make information easy accessible for the recyclers on:
- How to disassemble the product
- The content and location of hazardous substances, precious metals, rare earths and batteries

10.4 Disassembly of a Television

10.4.1 Screws and Different Slots
The process of separating the television showed that the television is assembled using many screws and screws with many different slots (Figure 12). 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 disassembled manually, because it will increase the time used making the recycling of the product less profitable. Screws can also be a problem, if the product is disassembled destructively in a shredder, because they can contaminate the fractions they are holding together. If for example a steel screw is used to hold pieces of aluminium together (Figure 13), what can happen is that in the shredder the aluminium parts break, but the screw is still attached to the aluminium. Then, the steel screw or part of the steel screw will contaminate the aluminium fraction. The use of many screws and many different slots is a problem, when the products are manually disassembled and can be a problem during destructive disassembly.

Recommendation:
- Reduce the number of screws used to assemble the product and use when possible the same slots for all screws

FIGURE 12. picture of some of the different screwdrivers used to separate the television

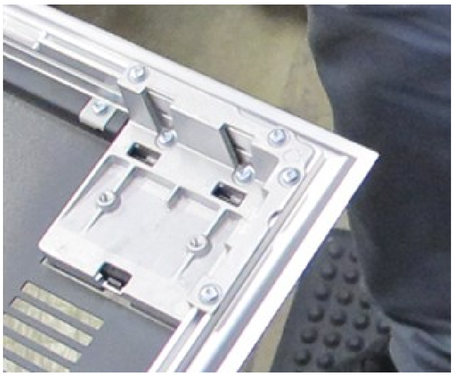


FIGURE 13. picture of aluminium parts assembled using steel screws

10.4.2 Printed Circuit Boards

The disassembly of the television also revealed that the printed circuit board are complicated to remove manually, because they were sealed of below several metal plates hold together by screws (see Figure 14). This makes it both difficult and time consuming to remove the printed circuit board manually and undamaged, 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. 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. 2009a, Chancerel, Bolland & Rotter 2011b, Cui, Forssberg 2003). Making the printed circuit board easily accessible and easy to remove manually could potentially improve the recovery of the precious metals in printed circuit board especially gold. In order to have an effect, it would require that the waste recycler did remove the printed circuit boards manually. Furthermore, the reparability of the product may also be improved in this case. One way to improve easy disassembly and removal of the printed circuit board could be to ensure (in this case of television) that the three different metal plates placed on top of the printed circuit board were fastened with the same screws. Then, if you removed the screws in the first metal plate the other metal plates would also be free see Figure 14.

Recommendation

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

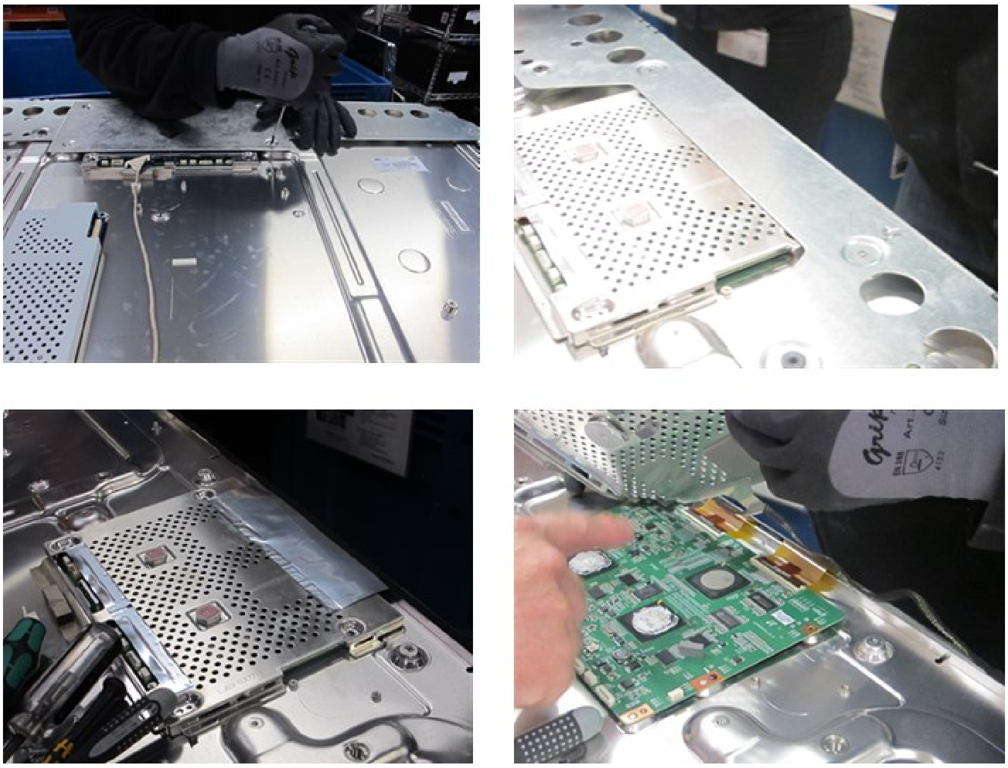


FIGURE 14. Disassembly of the television, the printed circuit board is sealed off by several metal plates hold together by screws and it is therefore both time consuming and difficult to remove them manually.

10.4.3 Easy Disassembly

The disassembly of the television also revealed other issues related to easy disassembly, which could be improved. Taking again the example of the ceasing 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. This again made it more time consuming and expensive to disassemble the products. The problem is illustrated in Figure 15, where the top plate covers the screw in the bottom plate, making it more complicated to separate the product.

Recommendation:

- Make screws easy accessible and avoid covering them

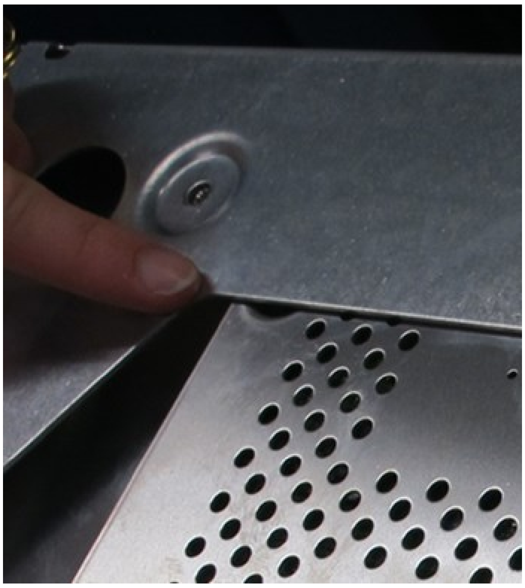


FIGURE 15. Picture of the top-plate covering the screw holding together the bottom plate making disassembly difficult.

10.4.4 Recycling of Glass in the Televisions

An important aspect of Bang and Olufsen televisions is the glass screen. Today the coating of the glass used in connection with the 3D technology implies that the glass cannot be recycled.

10.4.5 Plastic Back Screens

Part of the television's flat screen is made from plastic pieces, which are used to diffuse the light from the LEDs (see Figure 16). These plastic pieces are made of acrylic and have a considerable value when recycled. In the examined television, these parts of plastic were easy to disassemble and sort in the correct fraction, because they were not fixed to anything (e.g. glues together or assembled to other components) but just laying loose. Therefore, this was a good ecodesign example and a recommendation is:

Recommendation:

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

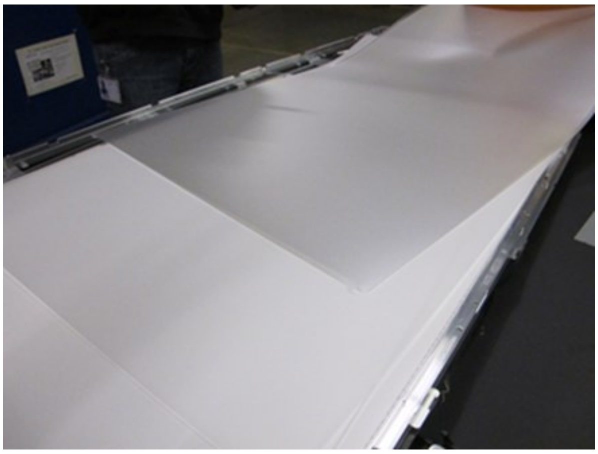


FIGURE 16. Plastic pieces used to diffuse the light from the LEDs.

10.4.6 The Use of Glue

The LEDs was fastened with screws and not with glue (Figure 17). 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, but this is not yet verified.

Recommendation:

- Avoid the use of glues that are under suspicion of causing environmental problems. This could be linked to the REACH classifications.

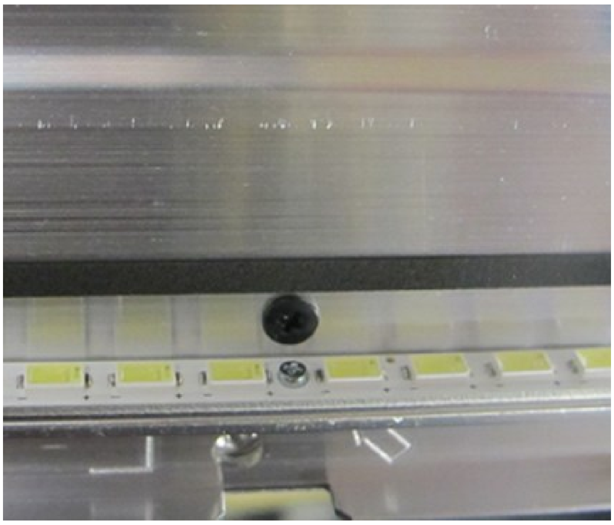


FIGURE 17. LEDs fastened with screws.

10.4.7 Contamination of Materials

Another possible design challenge identified was the screw thread of iron or stainless steel that were embedded in the aluminium elements see Figure 18 and 19. The problem with these threads made in another material is that they will contaminate in this case the aluminium fraction.

Recommendation:

- Avoid mixing materials, for example embedding iron or stainless-steel treads in aluminium elements

FIGURE 18. Screw thread of iron or stainless steel embedded in aluminium.

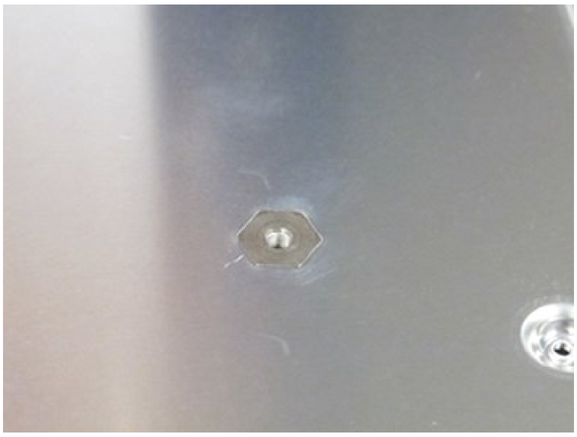


FIGURE 19. Screw thread of iron or stainless steel embedded in aluminium.

10.5 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. The environmental department had not been involved in the work, and it was not clear if easy disassembly had been a priority during the design process or if it was just “good luck”. The remote control is presented in Figure 20. On the back of the remote control there was a small hole (Figure 20), and if you poked a sharp small object into this hole; it was possible to separate the three main components, the remote control consisted of, very easily. From the small test made, it was possible to separate the remote control into the three parts within less than 10 seconds. The three main fractions are:

1. The casing of aluminium, which can go directly into aluminium recycling without any materials contaminating the fraction, and it is therefore a clean fraction.
2. The components containing the batteries, which according to the WEEE Directive needs to be separated and treated separately, because it contains hazardous substances.
3. The components containing the keys and the printed circuit board elements, which also can go into the same recycling process.

The remote control is designed in a way, that makes it easy to separate it into some main fractions, which will go into different recycling processes. The remote control is a good example of a product designed for recycling of the material fractions, but it is not possible to tell, if it was indeed the intention of the designer. Based on dismantling the remote control the following recommendation could be made.

Recommendation:

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

FIGURE 20. Picture of the remote control and the disassembly of the remote control.

10.6 Loudspeaker

The final product we worked on separating was a B&O loudspeaker see Figure 21.

FIGURE 21. Picture of the loudspeaker before the disassembly

10.6.1 Easy Disassembly

Disassembling the front of the loudspeaker was a time consuming process, because it was assembled using around 30 screws again with different slots. Some screws were submerged into the plastic front, which made it difficult to remove them (see Figure 22). According to the representative from Averhoff, it will not be separated manually at the waste treatment facility because it takes too much time to disassembly the loudspeaker. Unless, there are components within the loudspeaker, which need to be removed according to the WEEE Directive. Instead, the product will go more or less directly into the destructive and automated separating processes. As mentioned previously, different studies have shown that a better recovery of the precious metals in e.g. printed circuit board could be achieved, if they were separated before the product goes into the more automatized and destructive processes. If it was easier to separate the components that need different recovery processes, a better recovery of the materials may be achieved. Moreover, it was difficult to determine, which components to separate in order to dismantle the product or remove certain components. To meet this concern, a making system e.g. arrows could be used to indicate which e.g. screws to remove. It is something which has been used for other products.

Recommendations:
Make the product easy to disassembly, so 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 easy accessible
- Use a marking system to make it easy to determine, which screws to remove to disassemble the product or certain components.

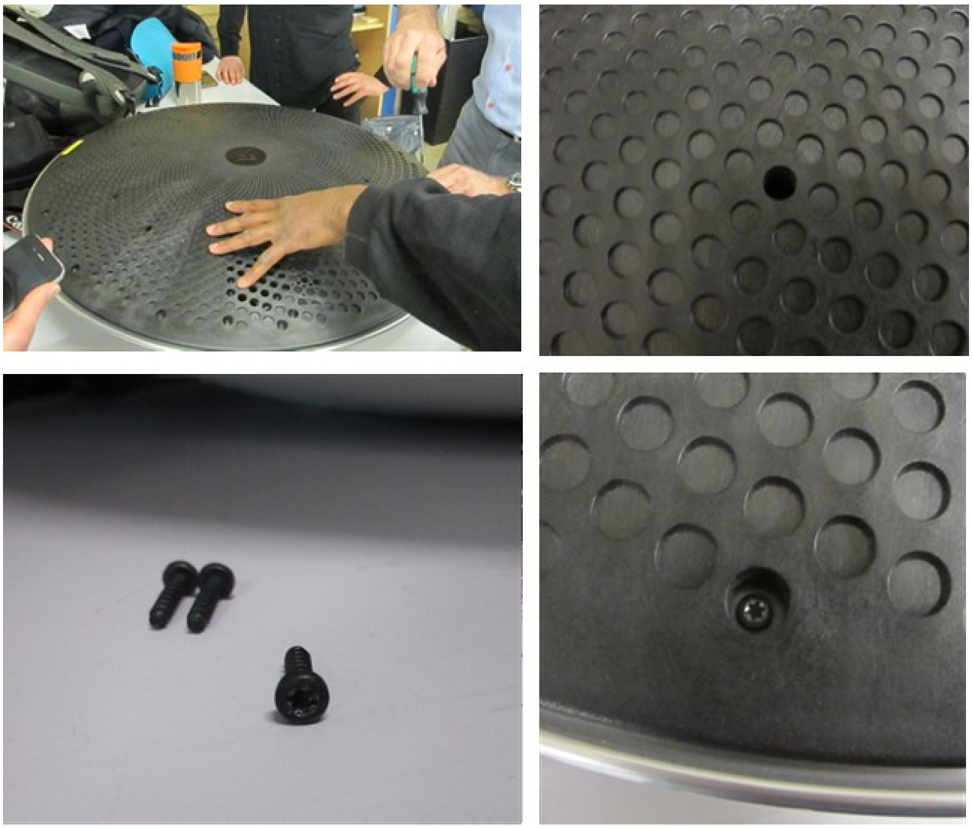


FIGURE 22. Disassembly of the loudspeaker's front cover.

10.6.2 Contamination of the Plastic or Metal Fractions

The fact that the screws were submerged into the plastic front or enclosed in plastic (see Figure 23) may also result in the screws not being separated from the plastic fractions during the destructive disassembly process. The screws could end up in the plastic fraction and contaminate it decreasing its value. Or the plastic could end in the metal fraction stuck to the screws and contaminate the metal fraction decreasing its value.

Recommendation:
- When using metal screws to assembly plastic parts, then design these assemblies in a way that the plastic and the screws are separated during the destructive disassembly process by e.g. avoiding submerged or enclosed screws in plastic.

FIGURE 23. A picture of the screws submerged or enclosed in plastic.

10.6.3 Contamination of the Recyclable Fractions by 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 the loudspeaker. In this case, some sort of foam made from plastic was used (see Figure 24). When this type of material enters into the destructive disassembly process, it will disintegrate and small bits of the foam will end in all the other fractions and contaminate them decreasing their value. The foam made from plastic is not the only soundproofing material that can cause problems for the automatic and destructive disassembly processes other soundproofing materials causes similar problems.

Recommendation:

- Avoid soundproofing materials that disintegrates into small bits during the destructive and automatic disassembly and contaminate the other fractions, or make is very easy to remove the soundproofing materials beforehand.

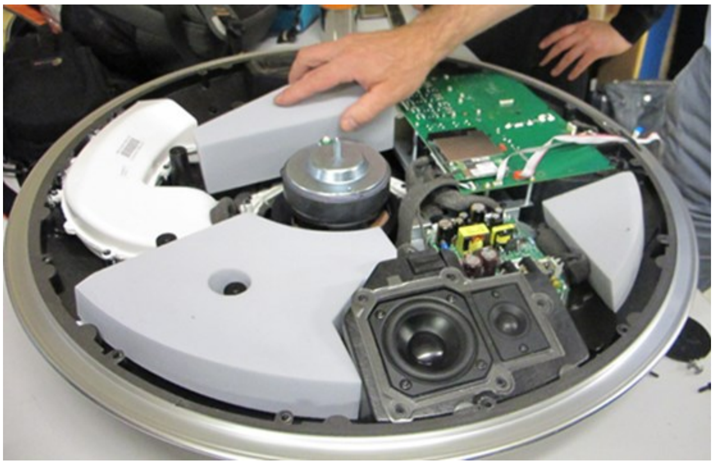


FIGURE 24. Picture of the soundproofing material found in the loudspeaker.

10.7 Sub-conclusion

As mentioned, the objectives of the B&O case study was two-folded; firstly we wanted to examine how to improve the recyclability of their products, and secondly we wanted to examine how producers and waste managers could cooperate to improve knowledge sharing. Both aspects were examined through the workshop, where the producers and the waste managers worked together disassembling new products to examine how to improve their recyclability.

10.7.1 Ecodesign Guidelines for Improved Recyclability Based on the Workshop

Based on the workshop, it was possible to establish some ecodesign guideline that could help improve the recyclability B&O's products and similar products. The recommendations are categorised and listed below:

Marking of components:

- Mark components that contain rare earths and precious metals and make it easy to disassemble the components
- Mark components that contain hazardous substances, that require special treatment, and make it easy to disassemble the components.
- Mark products that contain batteries

Information available on:

- How to disassemble the product
- The content and location of hazardous substances, precious metals, rare earths and batteries

Easy disassembly:

- Make the product easy to disassembly 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
- Reduce the number of screws used to assemble the product and use when possible the same slots for all screws
- Make screws easy accessible and avoid covering them
- 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 the easy disassembly
- Make the product easy to dismantle into material fractions that require the same recycling process
- Use a marking system to make it easy to determine, which screws to remove to disassemble the product or certain components

Contamination of the material fractions and hazardous substances:

- Avoid the use of glues that are under suspicion of causing environmental problems
- Avoid mixing materials, for example embedding iron or stainless-steel treads in aluminium elements
- When using metal screws to assemble plastic parts, then design these assemblies in a way that the plastic and the screws are separated during the destructive disassembly process by e.g. avoiding submerged or enclosed screws in plastic
- Avoid soundproofing material that disintegrates into small bits during the destructive and automatic disassembly and thereby contaminates the other fractions, or make is very easy to remove the soundproofing material beforehand.

The workshop provided a list of some ecodesign guidelines and recommendations that could be relevant to apply to improve the products recyclability, but many more may exist. Keep in mind that the product should not only be designed for improve recyclability, but also for improving repair, reuse, refurbishment, reconditioning and remanufacturing. This is especially important to remember, when returning to the design strategy hierarchy introduced in section

1.1, where prevention is above reuse and reuse is above recycling. There might be important design aspects that are no longer relevant for the recyclers such as easy disassembly, because they now have highly automatic process, but which are still relevant for the repair, reuse, reconditioning, refurbishment and remanufacturing of the products. Design for refurbishment will be illustrated in the Tier1Asset case chapter 8.

10.7.2 Knowledge Sharing and Collaboration Producers and Waste Managers

One of the project's hypotheses was that the cooperation between the waste managers and the producers are almost non-existing. Partly due to the fact that many producers have joined the collective schemes, and therefore are not in direct contact with the waste treatment sector. This hypothesis was confirmed in the interviews with the two Danish pre-treatment facilities of electrical and electronic equipment. There is limited knowledge exchange and collaboration between the producers of electrical and electronic equipment and the waste treatment sector.

In the workshop, an attempt was made to create this knowledge exchange between the waste treatment sector (Averhoff) and the producer (B&O). The first step was to create a shared knowledge basis by making the waste managers present the processes that WEEE undergoes when received at Averhoff. 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 television, and isolation material from their old loudspeakers, which if not removed would damage Averhoff's machinery. This worked very well and made the workshop relevant right away for B&O. Secondly, we all (representatives from Aalborg University, Averhoff and B&O) worked on disassembling three new B&O products, discussing as we came along the different problems the design of the products may cause for Averhoff's operations. This practical dimension, where we work together separating the products, helped illustrate the problems, which may otherwise have been difficult to comprehend.

The practical disassembly of the products worked as a boundary object making it easier to convey the waste manager's knowledge to the producer. Overall, the format worked well, what could be improved in future workshop was the composition of the participants. In the workshop, an employee from B&O's environmental department and one from service and waste treatment department participated. It would have been beneficial, if employees from different departments at B&O (e.g. design, product development and construction) had had the possibility to participate both to get their knowledge into play in the discussions, but also ensure that the knowledge exchanged during the workshop was spread more widely in the organisation. The actual dissemination of the ecodesign recommendations from the workshop was also affected by the large restructuring of the organisations, and the loss of the product-related environmental competences from the organisation.

11. Design for Refurbishment - a Case Study of Tier1Asset

This chapter provides an introduction to the case study of Tier1Asset and the main results attained. The chapter opens with an introduction to Tier1Asset and the process at Tier1Asset. The chapter ends with an account of the main results from the case study on how to improve the design of desktop and laptop computers to ease the refurbishment processes. The chapter is based on a chapter in Bundgaard (2016).

11.1 Introduction to Tier1Asset

Tier1asset refurbishes electronics and are located in Allerød in Denmark with around 50 employees (Head of Operations, 2014). Tier1Asset buys used IT equipment from e.g. private companies, public institutions and schools, refurbish it and resell it to new customers (see Figure 25), and they can refurbish up to 600 products a day (Head of Operations, 2014). They also resell excess spare parts from defect products or spare parts removed from the functioning products to customise them (Head of Operations, 2014). The company was established in 1999, and their main activity at the time was selling spare part to IT equipment (Head of Operations, 2014). From there, they began to focus on data deletion, because they found there was a market for this service (Head of Operations, 2014). It then developed into the company they are today, which will be described in the following sections.

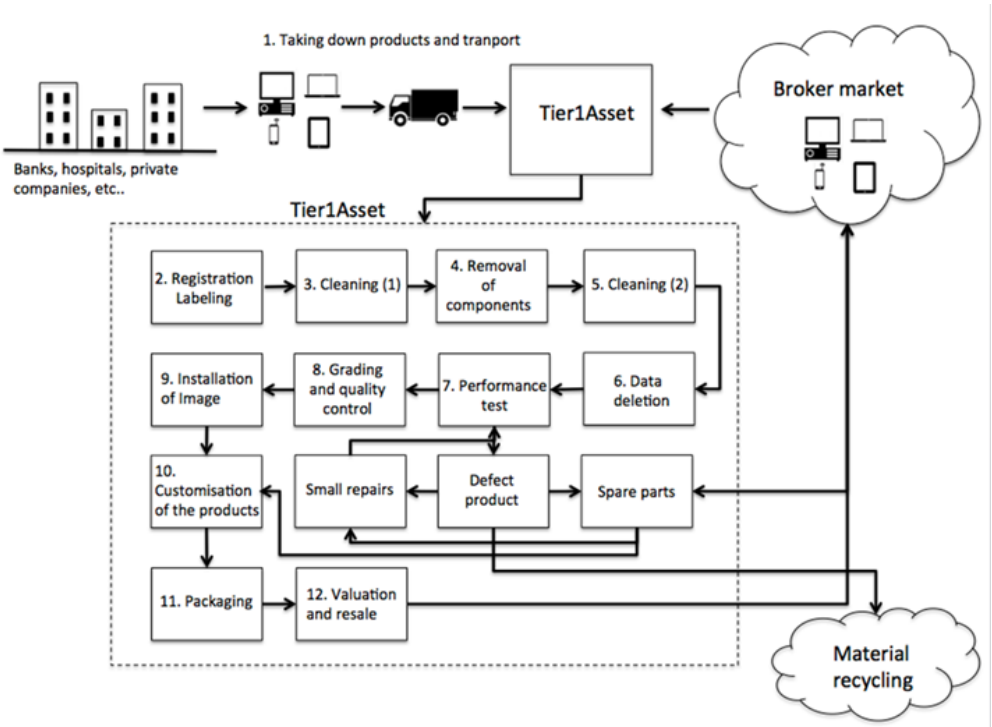


FIGURE 25. Overview of the processes at Tier1Asset based on(Employee from Cleaning, 2014; Head of Operations, 2014).

Tier1Asset mainly buys products from larger companies or organisation, because they typically have products of a higher quality and in larger quantities (Head of Operations, 2014). According to them, it is difficult to get a viable business from refurbishing consumer market products due to their lower quality, and because they cannot get large enough quantities of the same brands and same models (Head of Operations, 2014). The supply of use equipment will depend on when the producers release new models, because then the larger companies and organisations will typically change their equipment (Head of Operations, 2014).

The products they refurbish are desktops, laptops, servers, smartphones, tablets and printers (Head of Operations, 2014). Printers cause some difficulties, because if they are not used for 3 months, they will break down, and besides Tier1asset finds it difficult to resell the printers (Head of Operations, 2014). The main brands they buy and refurbish are Lenovo, Dell, HP, Fujitsu, Apple and HTC (smart phones) (Head of Operations, 2014). The equipment is from 2-3 years to 6-8 years old (Employee from Grading and Technique, 2014; Employees from Software, 2014). This implies that some products are still covered by the initial warranty provided by the producer, when Tier1Asset receives them (Employees from Software, 2014). If this is the case, Tier1asset has the possibility to get the product repaired by or get spare parts from the producer. In the outset, Tier1asset only buys equipment that is functioning. if they receive defect products, the seller will not receive any payment for the defect equipment. The seller can then choose to get the equipment back or Tier1asset can handle data erasure, using degaussing of the defect equipment, and the end of life recycling of the equipment.

Data erasure is part of Tier1asset's core business. They offer data erasure of the equipment in a secure and reliable way without destroying the reuse potential of the equipment. For this purpose, they use a software called Blancco that ensures 100% erasure of data and provides a detailed 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 scheme Common criteria (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 using a software certified by various organisations. This gives Tier1asset's operations credibility, which is important because the equipment may contain sensitive data. Another way Tier1asset creates credibility, when selling the refurbished products, is by being a Microsoft Authorised refurbisher. This also allows them to install new software at a certain reduced price. Furthermore, Tier1asset also has collaboration with Lenovo on buying their used products in Europe (Head of Operations, 2014).

Tier1asset strives to stand out from their competitors through their grading system. Tier1Asset distinguishes between four grades of the refurbished equipment: gold, silver, bronze and green (Tier1Asset, 2015a). The four grades are further described in Figure 26. According to Tier1asset, they have a stricter grading system than their competitions (Employee from Grading and Technique, 2014). This implies that a Tier1asset gold product (their top product), according to them, will be of a better quality than their competitor's top products (Employee from Grading and Technique, 2014). Strict grading of their products ensures high quality products and credibility to their brand, and thereby provides them with a competitive advantage. They believe that this is also partly why they just won a price for being England's best quality refurbisher (Employee from Grading and Technique, 2014). Tier1asset also just began using their name on all packaging materials for the refurbished products, because they believe that they have a good and credible brand (Head of Operations, 2014).

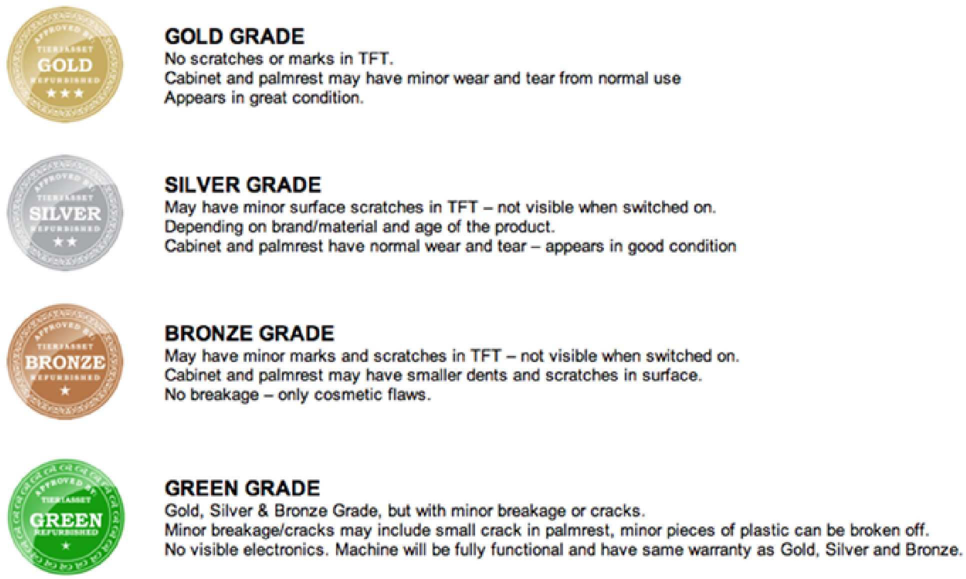


FIGURE 26. The four grades applied by Tier1Asset (Tier1Asset, 2015a).

Tier1asset sells the refurbished products at a broker market (Head of Operations, 2014). The market sets the value of the equipment depending on supply and demand, and if the market has confidence in the quality of the brand and model (Head of Operations, 2014). Tier1assset can experience rises and drops in the prices of the brands and models depending on how the market develops (Head of Operations, 2014). The equipment is then resold to private customers through external retailers (Head of Operations, 2014). Some of the main retailers are the British retailer Misco, the German retailer nobookbilliger and on the Danish market their equipment is sold through brugtecomputer.dk (Head of Operations, 2014). Many of their products are sold in England (Head of Operations, 2014). There is a larger market for used equipment in England compared to Denmark. It could be interesting to examine this further to establish how the Danish market for used equipment is developing and could be improved.

11.1.1 Key Processes at Tier1Asset

The refurbishing process encompasses cleaning of the products, data deletion, performance test, grading of the equipment, re-installation of Image and customisation of the equipment (Head of Operations, 2014). A more detail description of the processes is provided below. According to their head of operations, their recovery percentage is around 90% (Head of Operations, 2014). So, they waste around 10%, this includes equipment that does not work, batteries and cables. The recovery percentage varies depending on the product type (Head of Operations, 2014). Printers have a lower recovery percentage, whereas; smart phones have a very high recovery percentage (Head of Operations, 2014). The amounts of repair they carry out are limited, because they in the outset only refurbish functioning products, but they would like to increase the amount of repair (Head of Operations, 2014).

When Tier1asset resells the refurbished equipment, they provide a 1-2 years warranty (Head of Operations, 2014). Therefore, Tier1asset also has a unit repairing defect equipment sold by Tier1asset (Employee from Repair and Service, 2014). The main processes in their value chain are described below and in Figure 25 and are based on information available from their homepage (Tier1Asset, 2015b), interviews and a guided tour at the facility (Head of Operations, 2014).

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 in Allerød. The seller can also choose to take care of these steps themselves. They sometimes also buy used product on the broker market, if they have a large order and they lack certain products.

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 information on the product.

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

FIGURE 27. 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. During this process, the batteries in the laptops are also removed to ensure that they keep their performance during the time on storage and do not discharge and breakdown.

5. Cleaning 2: The next step in the cleaning process is dust removal using air pressure. Desktops are partly dismantled to ensure a better dust removal. Then finally, the surfaces, screens and keyboards are cleaned using water and soap.

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

FIGURE 28. Data deletion at Tier1Asset.

7. Performance test: A performance test registers, if the product is in good working conditions or if it 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 grading of the product. The grading of the products is made based on the information provided during the performance test and a visual grading made by employees. In the visual grading, aspects are considered such as scratches, tare and ware and dents in the top-cover and palm wrist, plastic parts that are broken off, broken pixels and tare and ware of the hinges on laptops. During this process, the equipment is also turned on to see if 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 a Microsoft authorised refurbisher, but if the buyer wants to have another operating system this is also possible.

FIGURE 29. Installation of Image at Tier1Asset.

10. Customisation of the product: Depending on the buyer, the product is then customised. This includes typically changing the keyboard to fit the relevant language, addition of extra

RAM and changing hard drive. Keyboards are repainted to fit the selected language and thereby refurbished and reused. Furthermore, batteries are re-inserted in the laptops. Prior to this the batteries were tested, and graded gold, silver, bronze, green or bold 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 in new Tier1Asset packaging materials (Figure 30).

FIGURE 30. Tier1asset's packaging material.

12. Valuation and resale: Based on the grading of the product 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 a side. If it can be easily repaired, it is repaired, and it then goes through the test process again. 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 physical deleted by degaussing equipment before it is sent for recycling. Tier1Asset does a minimum of repairs of the products and only repair the products if it is possible to change the component easily, but they believe that they could repair more products, which are currently used for spare parts.

11.2 The Process at Tier1Asset

Tier1Asset is a company, which in their outset helps improve the resource efficiency of electronics by refurbishing and reselling used electronics giving them a second use cycle. Therefore, the purpose of this case study was to, based on Tier1Asset's experiences with refurbishing electronics equipment, come up with ecodesign recommendations on how the producers could design their products to improve the refurbish and resale of electronic products.

The process started with a meeting with the head of operations, where the project was introduced and discussed. This was followed by a presentation of the company and a guided tour of the facility. This gave a good insight into the company, their operations and business plan. This was followed by qualitative research interviews with key employees from all major process steps at Tier1Asset to identify the main aspect that had an impact on the refurbishment of the product and its reuse and resell potential. A specific focus was on the design challenges that Tier1assset experiences, when they refurbished the used products. In total seven employees were interviewed. An overview of the interviewees is provided in table 16.

TABLE 16. Interviews and meetings conducted at Tier1Asset.

Interviewee/s	Purpose	Format	Date
Two employees from the production working with cleaning and changing components	To map their experiences with refurbishment and possible design improvements	Interview	November 17th 2014
Employee responsible for grading the products	To map their experiences with refurbishment and possible design improvements	Interview	November 17th 2014
Employee from service working with repair of sold products	To map their experiences with refurbishment and possible design improvements	Interview	November 17th 2014
Employee responsible for software	To map their experiences with refurbishment and possible design improvements	Interview	November 17th 2014
The head of operations	To gain a detailed understanding of the business model and to identify success factors and barriers	Meeting and guided tour at the facility	October 22nd 2014

11.3 Aspects Influencing the Refurbishment Process: Design Challenges and Recommendations

11.3.1 The Product's First Use Cycle and Packing and Transport of the Products

An important aspect influencing the product's resale potential is how the first user of the product has treated the product and the age of the product (Head of Operations, 2014). According to Tier1Asset, the quality of the products they receive varies considerably depending on, which type of organisation has used the product in its first use cycle (Head of Operations, 2014). Therefore, providing the first user of the product with information on how to keep and maintain the product could improve the resale potential and price. Also, the process where the products are taken down, packed and transported to Tier1Asset facility will affect their resale potential significantly (Head of Operations, 2014). Ensuring that the products are taken down, packed and transported in a gentle manner can improve their resale potential. This could be done by informing those involved in the process (first user, technician, caretakers) of the importance of keeping the products in good conditions and also providing the right conditions for packing the products down.

Recommendations:

- Provide the user with information on best use and maintenance recommendations of the equipment
- Ensure safe packing and transport of the equipment from the first user to the refurbishment facilities

11.3.2 Basic Input/ Output System (BIOS) Password

A challenge, which Tier1Asset has experienced, is the increasing use of BIOS password (Employee from Grading and Technique, 2014; Employees from Software, 2014). 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). Some companies choose for safety reasons to switch off the camera function, Bluetooth or the wireless network on all their computers using a BIOS password (Employees from Software, 2014), so the user of the computer cannot enable the functions themselves. Without the BIOS password it is not possible for Tier1asset to reboot the system, and thereby switch on these functions again (Employees from Software, 2014). Unless the seller of the equipment can provide the password to Tier1Asset or they can bypass the system, the products will be sold without these functions at a reduced price (Employees from Software, 2014). It results in a loss of value of the product and thereby also for Tier1asset and the company selling the products (Employees from Software, 2014). Sometimes the entire system is locked using a BIOS password, and if Tier1asset is unable to bypass it or get the password, it is not possible to reboot the system (Employees from Software, 2014). In these cases, Tier1asset has no other choice than to use the equipment for spare parts (Employees from Software, 2014). According to the employee responsible for software at Tier1asset, around 80% of the discarded equipment is due to BIOS password (Employees from Software, 2014).

Recommendations:

- Limit the use of BIOS passwords
- Make BIOS passwords available
- The producers provide a software that can reset the BIOS password

11.3.3 Easy Disassembly

Easy disassembly of the equipment was enhanced as important for the refurbishment processes by several of the employees (Employee from Cleaning, 2014; Employee from Grading and Technique, 2014; Employee from Repair and Service, 2014). Particularly, easy disassembly of central components that are often changed during Tier1asset's refurbishment process to repair, customise or update the products. Components that are typically changed on desktops and laptops are: screens, keyboards, RAM, processor, graphics cards, batteries, palm wrist and covers. Based on Tier1Asset's experiences are large variations in how easy the product is to disassemble between producers, but also between different models from the same producers (Employee from Cleaning, 2014; Employee from Repair and Service, 2014). So, they receive products, where these components are easy to remove and others that are very difficult. 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 screw slots requires that you change screwdriver several times during the disassembly process (Employee from Cleaning, 2014; Employee from Repair and Service, 2014). A robust click system was considered as a good design alternative to screws, and some producers do already use (Employee from Cleaning, 2014). The click system has to be robust, and can be taken apart and put together again several times without breaking or bending out of shape, which sometimes happened today (Employee from Cleaning, 2014).

Another design challenge in relation to disassembly was that it could be quite difficult to determine intuitively how to disassemble the product or change the components (Employee from Repair and Service, 2014). This type of information is typically available in repair manuals and according to Tier1Asset accessible (Employee from Repair and Service, 2014; Head of Operations, 2014). It can be time consumer to find this information, when they handle many different product brands and models. The large differences in the way the products are constructed and should be disassembled between the different producers and the models from the same producers makes it more complex to disassemble the products, because you cannot always apply experiences from older models to the new models (Employee from Repair and Service, 2014). Therefore, a ecodesign recommendation could be to make it more self-explanatory in the design or structure of the product, how to disassembly the product or remove certain components. This could be small indications on which screws to remove. A modular design was also highlighted as a good design solution that could ease Tier1Asset's refurbishment process (Employee from Repair and Service, 2014). Some producers already use modular design to some extent, but still there is a large improvement potential.

Recommendations
- Make it easier to disassemble the product
- Make it easy to remove and replace component such as: keyboards, RAM, processor, graphics cards batteries, palm wrist, screens and covers to ensure that it is possible to upgrade, customised and repair the products
- Make disassembly intuitive, ensure self-explanatory structures or provide instruction for repair, customisation and update of the product
- Reduce the number of screws and use the same type of slots
- Use when possible robust click systems that can be separated and put together again several times
- Use modular design

11.3.4 Safety and Security Tags for Anti-Theft Protection and Other Labels
One of the things Tier1Asset removes during the refurbishment process is 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 damage to the equipment. While, others are difficult and time consuming to remove and leave permanent marks on the product, decreasing the resale value. Safety and security tags can of course be a necessity as anti-theft protection to make it less viable to steal and sell the equipment, but 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 with up to 500 D.kr. (Employee from Cleaning, 2014). Therefore, the companies buying the product should reconsider, if they need this kind of protections, and if they do then choose tags that are less likely to leave permanent marks on the product. Especially, tags that are corroded or burned into the product are difficult to remove and leave permanent marks.

In these cases, Tier1asset needs to sand down the marks (Employee from Grading and Technique, 2014) resulting in a downgrading of the product; because, it will not appear visually as good as a product without permanent marks from safety and security tags (Employee from Grading and Technique, 2014). An approach could also be to place the tags a less visible place like on the bottom of the laptop instead of placing it on the front cover (Employee from Grading and Technique, 2014). Then, the permanent marks will be less obvious. Furthermore, it can also be time consuming to remove the tags depending on the type and age of the tag (Employee from Cleaning, 2014). According to an employee involved in cleaning the products, it can take up to 10 to 15 minutes (Employee from Cleaning, 2014). This is also an important aspect, because the more time spend on the product the less money Tier1asset can earn from its resale, and thereby decreasing the product's resale potential. Additionally, the process also requires the use of chemicals such as benzene, petroleum and alcohol (Employee from Cleaning, 2014). Sometimes they need to remove the tags using heat. It can then be a problem, if the tag is placed on two different materials like metal and plastic, because the plastic might melt during the process (Employee from Cleaning, 2014).

Recommendations:

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

11.3.5 Easy to Clean

Tier1asset also performs a thorough cleaning of the products, cleaning the surfaces and removing dust using air pressure (Employee from Cleaning, 2014). 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 clean (Employee from Cleaning, 2014). Therefore, a recommendation is to make the products surfaces easier to clean and avoid a design, where dust and dirt can gather and be difficult to remove again (Employee from Cleaning, 2014). Another step in the cleaning process is removal of dust from desktops and laptops using air pressure (Employee from Cleaning, 2014). In this process, the desktops are opened to get 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 (Employee from Cleaning, 2014). Therefore, the desktop should be easy to open and close by removing the sides of the desktop or by other means (Employee from Cleaning, 2014). 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 bent out of shape during the process. Screws can be a problem, because they tend to get lost during the process (Employee from Cleaning, 2014). Tier1asset does not disassembly the laptop before cleaning from dust using air pressure, but put air pressure directly on the keyboard (Head of Operations, 2014).

Recommendation:

- Make the surfaces easy to clean
- Avoid a design where dust and dirt can gather and be 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

11.3.6 Surfaces

Another aspect of importance for the resale potential of the equipment is the product's surface, and how resistant it is in terms of getting scratches and bumps (Employee from Grading and Technique, 2014). If a product visually does not represent itself well, then it cannot get a good grading and its resale price will fall as a consequence (Employee from Grading and Technique, 2014). 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 (Employee from Grading and Technique, 2014). Especially surfaces made from aluminium and magnesium easily get scratches (Employee from Grading and Technique, 2014). This can also be a problem during cleaning.

Recommendation:

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

11.3.7 Spare Parts and Standardised Components

Based on Tier1asset experiences, assess to spare parts is generally not a problem (Employee from Repair and Service, 2014; Head of Operations, 2014). They are most of the time self-sufficient with spare parts from the defect products or they buy spare parts from their competitors (Head of Operations, 2014). Occasionally, they buy new spare parts, and according to Tier1asset it is usually not a problem to get access to new spare parts (Head of Operations, 2014). It has to continue to be easy to get access to spare parts and therefore, this is also a recommendation for the producer to have spare parts available for an extended period. Another aspect important for the refurbishment process is that the components that are changed are standardised between the different producers and models. A refurbisher such as Tier1asset has to handle many different brands and models. According to Tier1asset, some components are standardised such as hard disk, RAM modules, graphics and drivers (Employee from Grading and Technique, 2014; Employees from Software, 2014). Other components such as screens, fans, plastic components and casings are individualised between brands and models (Employee from Repair and Service, 2014; Head of Operations, 2014). Hence, there is an improvement potential in using standardised components. Another component, that are not standardised between brands and models, are power plugs, which complicates Tier1assets processes, because they have to set up each computer with power before they run Blancco and Image (Employees from Software, 2014). If different power plugs are used, they need to change them, if they handle different brands and models.

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

11.4 Sub-Conclusion

Tier1asset is an example of a circular business model. They refurbish used equipment and resell it, and they also resell used components from used or defect equipment. Their main operations are cleaning, data erasure, customisation, reinstallation of image and performance testing. They mainly buy operative used equipment, and the amounts of repairs they conduct are limited. This is also emphasised by one employee who stated that they have a large improvement potential in terms of increasing their repair rates (Employee from Grading and Technique, 2014). According to him, they could with small and few repairs get more defect products back into the cycle, but they could also utilise the component from the defect product to a larger extent to give other products a better grading (Employee from Grading and Technique, 2014), but this would require a new set-up of their facility. A potential for Tier1asset is to increase the circularity of their business model and attain even higher resale/reuse rates. The question is however if it will prove to be a viable business as well or if it will require to high cost to increase repair rates.

For Tier1asset to have a viable business the used products need to have a high quality, and they need to be available in larger numbers. Therefore, they only buy products from larger companies and organisations. Typically, equipment from these places will also be in better conditions than equipment from the consumer market. There is a large unexploited potential in reselling equipment from the consumer market in Denmark, and it could be interesting to examine if this could be further developed and become a viable business model.

An aspect that seems central to Tier1asset business model is trustworthiness. It was central that the seller of the used equipment had faith in Tier1asset, and believed that they could ensure a safe and secure data erasure. A precondition for the reuse and resale of computers, smart phones and tablet is that complete data deletion can be secured and documented. The buyer of the used equipment also needs to have trust in Tier1asset, and that they delivered a good quality product. One of the strategies to attain this trust from the buyer was their strict grading system, which should ensure high quality products. Another strategy was to become a Microsoft authorised refurbisher.

Tier1asset also depend on a steady supply of used equipment, something they are unable to control, and which depends on the seller of the equipment and when the producers release new models. Tier1asset is depending on how the resell market for used equipment develops, which again depends on the supply and demand of used products and if there are faith in the quality of the brands and models.

A lot of the equipment Tier1asset sells goes abroad to Germany and England. It could be interesting to examine why there is not yet are large market for IT equipment in Denmark and how such a market could be developed further.

11.4.1 Overview of Ecodesign Recommendations

The user can get a higher resale value of their old computers, etc. if they

- Have information on best use and maintenance of the equipment
- Ensure safe packing and transport of the equipment from the first user to the refurbishment facilities
- Limit the use of BIOS passwords or make BIOS passwords available
- Avoid when possible safety and security tags and other labels
- Use safety and security tags and other labels that can be removed without leaving a permanent mark. Especially, avoid tags that are corroded or burned into the product
- Place the marks a less visible place e.g. on the back of product

The designer and manufacturer of the electronic equipment can prepare for reuse by

- Providing a software that can reset the BIOS password
- Making it easier to disassemble the product
- Making it easy to remove and replace component such as keyboards, RAM, processor, graphics cards batteries, palm wrist, screens and covers to ensure that it is possible to upgrade, customised and repair of the products.
- Making disassembly intuitive, ensure self-explanatory structures or provide instruction for repair, customisation and update of the product
- Reduce the number of screw and use the same types
- Use when possible robust click systems that can be separated and put together again several times
- Use modular design
- Make the surfaces easy to clean
- Avoid a design where dust and dirt can gather and be difficult to remove again
- 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
- Use materials for the casing that are resistant to scratches and bumps
- Have spare parts available for an extended period
- Use standardise components
- Standardise power plugs

Several of these ecodesign guidelines will, after the extended life time, make it possible to disassemble the products in a way that will make it possible to recover the materials to a higher value compared to the most common applied recycling methods.

12. An Environmental Strategy of Resource Efficiency for Lightyears

This chapter is an account of the activities conducted at Lightyears. The chapter begins with an introduction to Lightyears followed by a description of the workshop conducted at Lightyears and its main output.

12.1 Introduction to Lightyears

Lightyears produces designer lamps primarily for the premium to high-end market (Birkemose, 2014). They distribute their products in Denmark and export to 25 countries. Lightyears employs 18 employees at their facilities in Aarhus (Ipsen, 2014), and they are therefore a small and medium-sized enterprise (SME) under the European definition.

Lightyears was established in May 2005, on the remains of Horn Lighting A/S. Horn Lighting A/S was a lamp company with a focus on mass production and sales. In the 1980s, Horn Lighting A/S was the second largest producer of lamps in Denmark with an annual turnover of 100 million DKK and IKEA and Coop were their main customers (Dansk Design Centre, 2016). Their product line was a mixture of products produced by Horn at their production facility in Ålestrup and products purchased and produced in China. The products produced and purchased in China were mainly standard products at a reasonable price (Dansk Design Centre, 2016). This fact, made Horn Lighting's business plan easy to imitate, and the customers could buy the products directly from China avoiding Horn as a costly intermediary (Dansk Design Centre, 2016). When Lars Østergaard Olsen took over, Horn Lighting's turnover was reduced to 1/3, and a radical change was needed (Dansk Design Centre, 2016). This change lead to the closing of Horn Lighting and partial sale to Nordlux, a company with a similar profile as Horn (Østergaard Olsen, 2014).

Lightyears therefore represents a complete shift from the old Horn Lighting, that had proved to be an unviable business strategy. The new strategy was to produce quality lamps with a focus on design at a lower price than their competitors by using Horn's contacts with producers in China (Dansk Design Centre, 2016). Lightyears business plan was:

> *"To be the leading supplier in Scandinavia of modern designed lighting for homes Lightyears develops and markets unique lamps for consumers that are interested in design and quality. The lamps combine design, finish and light output in a league of its own. The lamps are market at a fair price, which is achievable for most people" (Lightyears, 2015).*

The new business plan and strategy led to a complete reorganisation of the company. The company moved the headquarter to Aarhus and changed their staff to fit the new profile (Østergaard Olsen, 2014). A design manager was hired (Rasmus Markholt), and design and collaboration with designers became a dominant strategy for Lightyears. In 2005, Lightyears launched their first collection, and since then new products have been added continually. In July 2015, Fritz Hansen took over Lightyears, but the plan is that Lightyears should remain in its present form (Skovgaard, 2015).

12.1.1 Lightyears' Value Chain

The change in business plan in 2005 resulted in significant changes to their value chain moving from a company producing lamps, to a company designing, developing and marketing lamps (Østergaard Olsen, 2014). All production facilities were closed. The production, logistic and stock management were outsourced, but product development, marketing, sales, service and financial management is still performed in-house (Østergaard Olsen, 2014). An overview of Lightyears' value chain and their artefacts is provided in Figure 31 and a detailed description is given in the sections below.

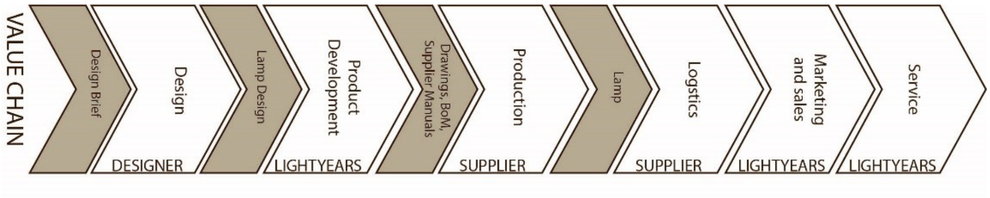


FIGURE 31. Overview of Lightyears' value chain (white) and their products (grey).

The design processes

An external designer typically designs the lamp, but the design manager at Lightyears follows the process (Markholt and Olsen, 2014). They have a long list of designers with whom they have worked including Cecilie Manz, Hans Sandgren Jakobsen, the design duo Gamfratesi, Monica Förster. Designers are typically paid through royalties (Markholt and Olsen, 2014). Lightyears also holds patents on old lamp designs from Horn including designs by Jørn Utzon (Laursen, 2014). The design process can also be based on old designs that need to be updated to comply with current requirements and regulations.

The first step in developing a new lamp design is typically the design brief, which is given to the external designer (Mansher, 2014). Lightyears specifies which type of new products they need in their product portfolio (Mansher, 2014) although the designer can also present a proposal. The design brief is specified by the design manager and can include a description of-Lightyears requirements and preferences to the new product (Mansher, 2014). These could be interesting materials that Lightyears wants to work with, special production methods, a specific surface treatment that breaks the light in a certain way, a type of lamp that Lightyears has missed in their product portfolio or which type of lighting should be used such as LED or halogen (Mansher, 2014). Basically, it can include all kind of the requirements that Lightyears would like to apply in their new lamp design, although the level of detail may vary from design brief to design brief. Based on the design brief and consultations with Lightyears' design manager, the designer comes up with a lamp design that may consist of loosely drawn sketches or detailed drawings depending on the designer (Mansher, 2014).

Product development

The new lamp design selected then continues to product development, where the detailed drawings and specifications are developed. The initial product development is made in collaboration with the external designer, Lightyears' design manager and employees from Lightyears' product development (Mansher, 2014). In this phase, the specific detailed design solutions are developed taking into consideration for instance light output, construction details, legal requirements, production methods and requirements for the materials. The process may also include developing prototypes to test different designs and technical solutions (Laursen, 2014). When agreement on a final design is reached, detailed drawings and specifications of the product design are made by Lightyears in their product development team. The result includes CAD drawings and a Bill of Material (BoM), which can be sent to the suppliers (Mansher, 2014).

Production
Lightyears has no production now. Instead, they buy the products ready-made from their suppliers. The main body of their products is produced in China, but they also have a glass supplier in Slovenia and a small supplier in Skals near Viborg (Østergaard Olsen, 2014). Lightyears has two main suppliers in China (Birkemose, 2014) who mainly buy the different components from sub-suppliers and assemble the products (Mansher, 2014). To ensure the quality Lightyears need, they have used the same two suppliers since 2008, and they have a close collaboration with them (Birkemose, 2014). Both suppliers are certified according to the BSI CEDEX certification scheme and third party audits are performed. One of the suppliers is also certified according to a specific certification scheme used by the Body Shop (Birkemose, 2014). Lightyears visits the two main suppliers regularly and all new sub-suppliers are inspected by Lightyears. Lightyears has access to their sub-supplier, but no control over the sub-suppliers, because they buy their products ready-made (Birkemose, 2014). Lightyears has a supplier manual, which the suppliers need to sign specifying the general terms with which all suppliers need to comply (Birkemose, 2014). A third party mainly in China checks whether the products comply with the requirements in the Lightyears supplier manual (Birkemose, 2014).

Logistics
From the production site in China, the lamps are transported by container ship to Aarhus, where they have storage facilities and from there the lamps are further distributed. Only if absolutely necessary, do they transport their products by air cargo (Markholt and Olsen, 2014). The logistics are also performed by a supplier.

Marketing, Sales and Service
Lightyears manages the marketing, sales and service in-house. They have two main market segments; the private market where customers buy perhaps 1 or 2 lamps through retail shops, and the project market where interior designers purchase perhaps 100 lamps for a large domicile or restaurant (Ipsen, 2014). When they design new products, they strive to target both market segments in their design strategy (Mansher, 2014). The servicing of sold products is conducted by Lightyears, and they store spare parts at their facility in Aarhus (Laursen, 2014).

12.1.2 Lightyears Environmental Aspects and CSR
Environmental aspects have not previously been an important to Lightyears, as they have focused on establishing a viable business (Markholt and Olsen, 2014). Recently, Lightyears has experienced increasing demand from customers as regard specific environmental aspects. These demands mainly come from the professional market; more specifically from larger companies with a green profile purchasing lamps for their shops, restaurants or offices (Birkemose, 2014). Lightyears is also encountering increasing environmental requirements from public procurers, and especially in relation to energy consumption (Birkemose, 2014). Finally, Lightyears has encountered increased legal requirements on environmental and energy aspects of their products through directives such as the Energy Labelling scheme and the Ecodesign Directive (Markholt and Olsen, 2014). Lightyears believes that they are at a time and place, where they need to further develop their environmental strategy. They had also included an activity to develop an environmental strategy in their last strategy session some years ago (Markholt and Olsen, 2014).

As Lightyears has no production facilities, the environmental and social impacts of production is controlled by their suppliers and their sub-suppliers, but Lightyears can and does set environmental requirements for their suppliers through their supplier manual and their code of conduct. Lightyears can set specific requirements in the BoM and in the drawings, and they can specify for instance, which materials and assemblies to use, making it possible to set requirements to environmental and resource efficiency aspects. Recently, Lightyears has made the BoM more specific to ensure the requested quality.

Lightyears' activities supporting resource efficiency
Even though Lightyears has not worked with resource efficiency and environmental initiatives systematically, their products include some characteristics of importance for resource efficiency.

Inner circles
Lightyears aims to use a standard E27 socket for the main parts of their lamps, which makes it possible to use various lighting sources (Laursen, 2014; Markholt and Olsen, 2014). This ensures that the main parts of the products do not become obsolete, when lighting technology shifts, and helps to make the lamps future-proof (Birkemose, 2014). Lightyears also produces lamps with build-in LED, which can limit the life span of the lamp to the life span of the LED (Mansher, 2014), but most of their lamp design are designed for a long life and intended for the high-end market with prices around 2,000 DKK (Ipsen, 2014; Markholt and Olsen, 2014). Consequently, their products are designed as high quality with longer life spans and classic designs (Birkemose, 2014). They offer spare parts for some products in the three to four years after the products are no longer produced (Laursen, 2014), but they have only phased out few of the lamp designs to date.

Outer circles
Lightyears has changed their packaging materials from polystyrene to recycled moulded cardboard (Birkemose, 2014; Markholt and Olsen, 2014), although this was not driven by Lightyears, but by the supplier of the packaging material. The supplier wanted Lightyears to change to recycled moulded cardboard, because one of their large clients wanted to change their packaging material in this way. To streamline their production the supplier was pushing Lightyears to change their packaging material as well (Birkemose, 2014). Lightyears has also recently designed and developed a new lamp named Lullaby. The lamp is produced from stone paper and ash wood. The stone paper is cradle-to-cradle certified, and the lamp design was intended to be biodegradable (excluding the socket and wire) (Laursen, 2014). Thereby, improving the recyclability of the lamp.

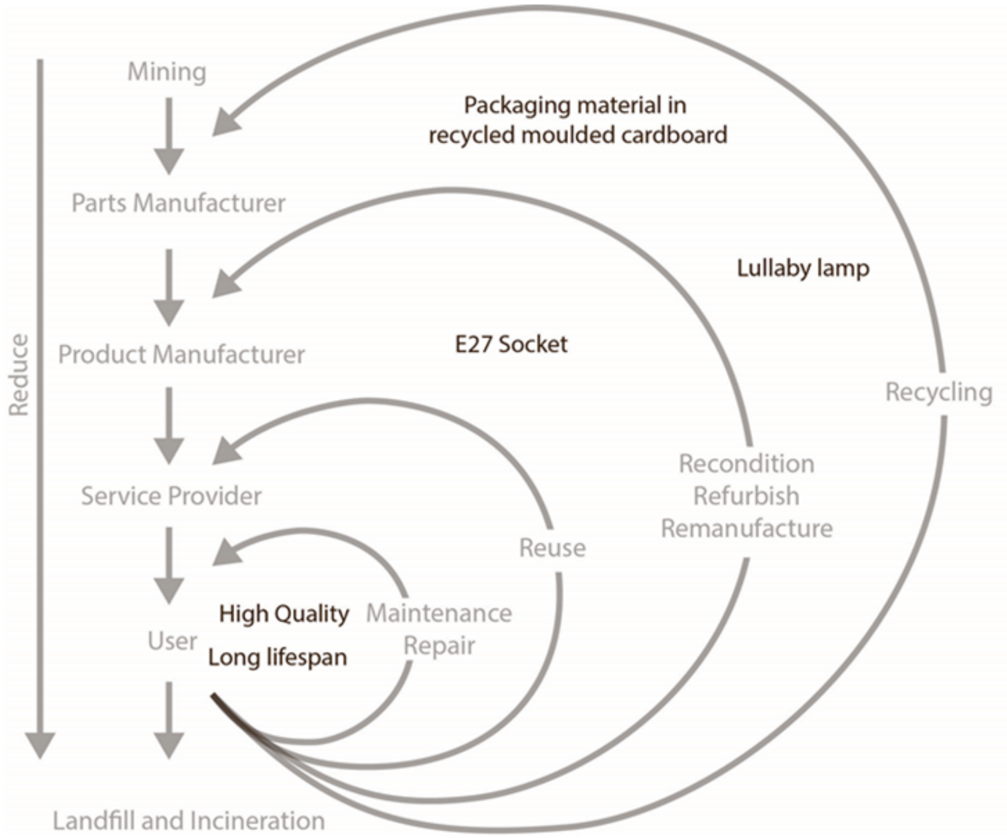


FIGURE 32. Overview of Lightyears' existing circular activities.

12.2 The Workshop at Lightyears

12.2.1 Designing the Workshop

Lightyears has not worked systematically with environmental issues and resource efficiency but has an objective to develop an environmental strategy. The purpose of the workshop at Lightyears was to initiate their work on developing an environmental strategy that also targeted ecodesign and resource efficiency.

The workshop at Lightyears was designed with inspiration from causal mapping (Hansen and Rasmussen, 2011). Causal mapping can be defined as *"a modelling technique used to represent a way of thinking by a series of interconnected causal relationships"* (Hansen and Rasmussen, 2011: 258), and the technique is helpful in structuring complex information to use in problem solving (Hansen and Rasmussen, 2011). Causal mapping has roots in George A. Kelly's individual constructs, and according to Hansen and Rasmussen (2011: 258) is comprised of the following seven steps:

1. A planning meeting, where an initial view of the situation is achieved and the possible outcomes are identified
2. Interviews with key actors to learn their opinion and view point on the situation
3. Development of individual maps based on the interviews
4. Check-back interviews to receive the interviewees' responses to the individual maps
5. Merging the individual maps to a joint map.
6. Presentation and interpretation of the joint map
7. Action planning and implementation

The process at Lightyear deviated slightly from this process since it began with a meeting, where the project was presented and the focus of the project was discussed. This was followed by qualitative research interviews with key employees at Lightyears. The main purpose of these interviews was to become acquainted with the company and their processes. Their design process and their existing work regarding environment and resource efficiency was central. In total five interviews were completed in addition to the first meeting. A list of the interviewees is provided in Table 17.

TABLE 17. Interviews and meetings conducted at Lightyears.

Interviewee/s	Position	Format	Documentation
Lars Østergaard Olsen	Managing Director	Interview	Recorded and transcribed
Gitte Skaarup Ipsen	Marketing Manager	Interview	Recorded and transcribed
Jens Brix Laursen	Product Development and Prototypes	Interview	Recorded and transcribed
Peter Manscher	Product Development	Interview	Recorded and transcribed
Jesper Birkemose	Production and Logistic Manager	Interview	Recorded and transcribed
Lars Østergaard Olsen and Rasmus Markholt	Managing Director and Design Manager	Meeting	Recorded and transcribed

Individual causal mapped were drawn regarding sustainability and environment relevant for Lightyears based on the interviews (Appendix 2). The individual maps were combined to four joint maps covering environment and resource efficiency in relation to:

- Strategy and company development
- Suppliers and supply management
- Product design and product development
- Market development

These maps were then presented to the employees at Lightyears during the workshop. The maps were also used as the basis for a brainstorm about what Lightyears could work with in their environmental strategy and actions related to the implementation of this strategy.

The final program for the workshop was as follows:
1. Introduction to environmental strategies in companies by Arne Remmen from Aalborg University.
2. Introduction to Lightyears, their business strategy, development strategy and ideas about a strategy covering sustainability by Lars Østergaard Olsen.
3. Presentation of causal mapping results for Lightyears, their activities and the challenges they are faced with by Søren Kerndrup, Aalborg University.
4. Presentation of ecodesign and circular economy by Henrik Riisgaard, Aalborg University
5. Workshop focused on identifying relevant aspects of Lightyears work on developing an environmental strategy and the environmental design requirements based on the causal mapping.

Participants in the workshop:
- Lars Østergaard Olsen (Managing Director) Lightyears
- Jesper Birkemose (Production and Logistic Manager) Lightyears
- Peter Mancher (Product Development) Lightyears
- The new Design Manager at Lightyears
- Arne Remmen, (Professor) Aalborg University

- Henrik Riisgaard, (Teaching Associate Professor) Aalborg University
- Søren Kerndrup, (Associate Professor) Aalborg University

12.2.2 Workshop Results

The following section with presents the workshop, and the main results and outcome of the workshop. It is organised according to the workshop program.

1. Introduction to environmental strategies in companies

The workshop began with an introduction to environmental strategies in companies. The purpose was to ensure that all participants had the same understanding of what an environmental strategy can be, and how to develop it. The presentation began with an introduction on how companies' preventive environmental efforts have developed over the years from cleaner production, environmental management, cleaner products and to sustainable development. Different perspectives on environmental and sustainability strategies were introduced. Practical examples of an environmental strategy were provided including NovaGrafs environmental policy and the Global Compact initiative (see Appendix 3 for further details).

2. Introduction to Lightyears, their business strategy, development strategy and ideas about a strategy covering sustainability

The general introduction to environmental strategies was followed by an introduction to Lightyears, their strategy and ideas about environmental aspects and sustainability from their managing director. Lightyears has five core values humanity, integrity, passion, entrepreneur and performance (an overview is provided in Table 18 with some keywords). Environmental aspects are not considered part of Lightyears core values, but the development of an environmental strategy was included as an activity in their most recent strategy. According to Lightyears' managing director, the current activities in Lightyears are that; they primarily transport their products by ship in 40 foot containers, they comply with REACH Regulation, the RoHS Directive and the WEEE Directive and their suppliers are BSI CEDEX certified. They are also encountering increased attention on environmental aspects in public invitations to tendering and from larger organisations with a green profile.

TABLE 18. Lightyears' five core values (based on Appendix 4).

1.	**Human**	**Life blood**
2.	**Integrity**	To behave with integrity Employees Keep promises – can be counted on
3.	**Passion**	Design, quality and functionality Proud, go the extra mile Explanations (excluding environmental aspect) They are enthusiastic Storytellers Emotions Not satisfied with mediocrity Curiosity
4.	**Entrepreneur**	Developer of new products and new markets Swift decision making process Innovation
5.	**Performance**	

3. Causal mapping of Lightyears, their activities and the challenges they are facing

The causal maps drawn up based on the interviews were presented to the participants in the workshop, and the participants had the opportunity to comment on the maps, if they disagreed with some of the synthesis made. The idea was that the presentation and consecutive discussions should serve as points four and six of Hansen and Rasmussen's (2011) seven steps to conduct causal mapping. The presentation and discussion should thus present and interpret the causal maps and give the employees involved an opportunity to provide feedback on the maps.

An example of the causal maps is presented in Figure 33, and the rest of the maps can be found in Appendix 5. The review of the causal maps created a mapping of Lightyears existing activities in relation to environmental and resource efficiency aspects and the challenges faced within this field. The main elements in the causal maps were recognised by the participants from Lightyears, and it facilitated a more detailed discussion of how these challenges could be dealt with.

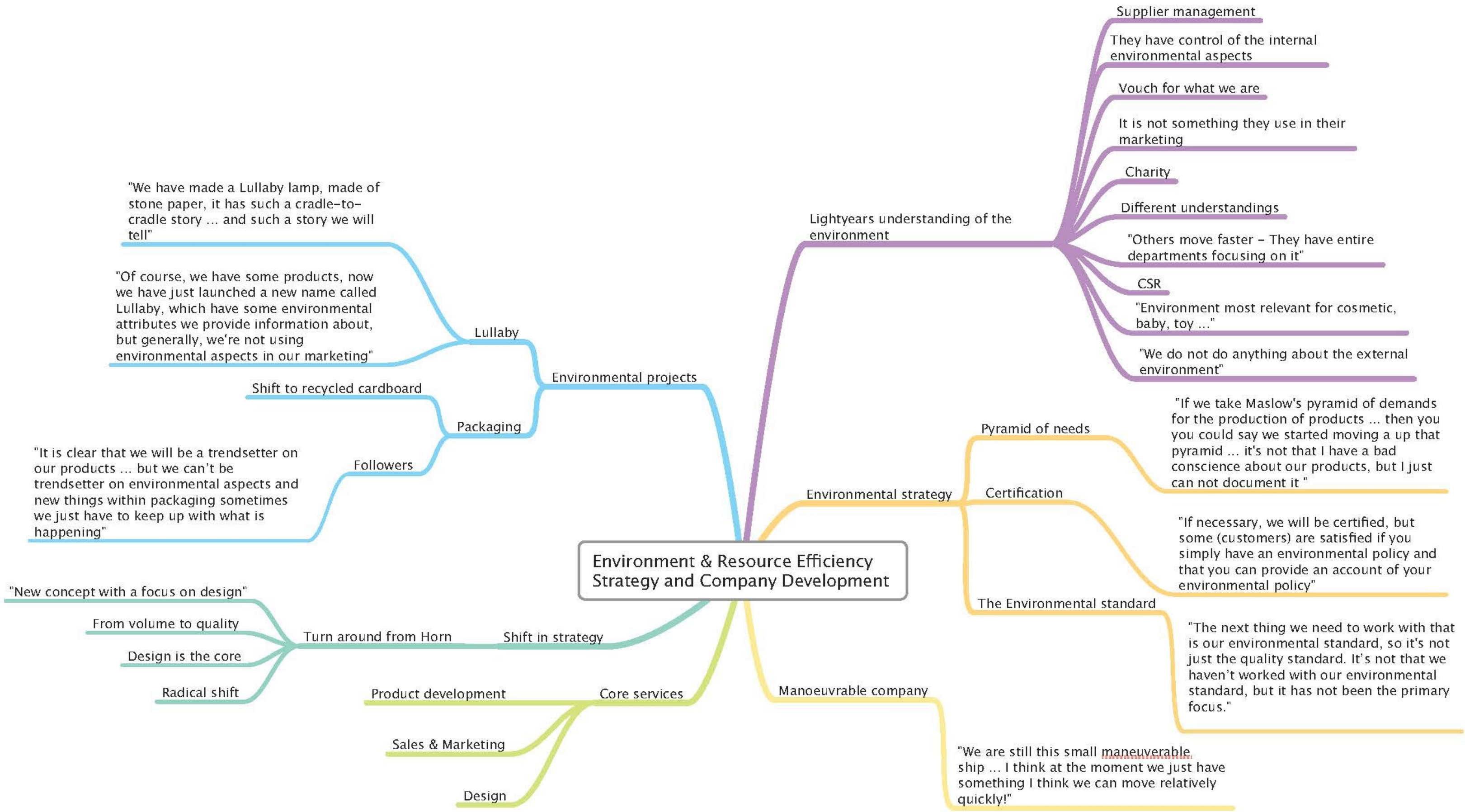


FIGURE 33. Example of a causal map for Lightyears' environmental and resource activities in relation to their strategy.

4. Presentation of ecodesign and circular economy

Ecodesign, environmental regulation and circular economy were then introduced. The relevant regulations were reviewed covering lighting equipment including the RoHS Directive, the WEEE Directive and the Ecodesign Directive. The intended synergies between the regulatory instruments were explained (see Figure 34). Then, a short introduction to circular economy was made based on the model developed by the Ellen MacArthur Foundation with some modifications (see Figure 35). The purpose of this was to create a shared knowledge platform for all participants in the workshop.

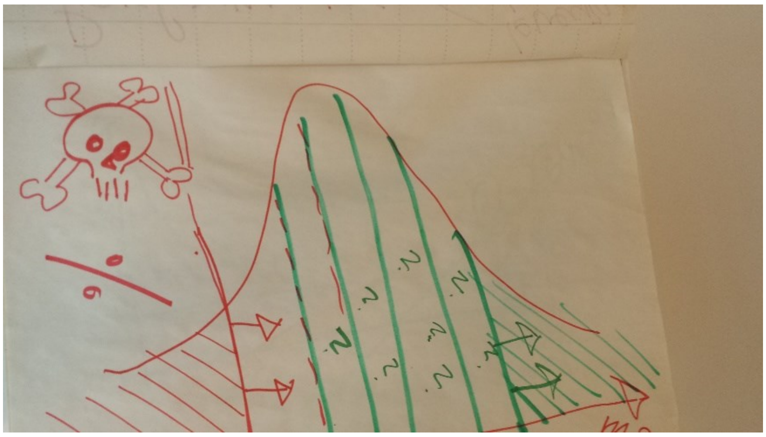


FIGURE 34. Illustration of the interlinkages in product environmental regulations related to electrical and electronic equipment.

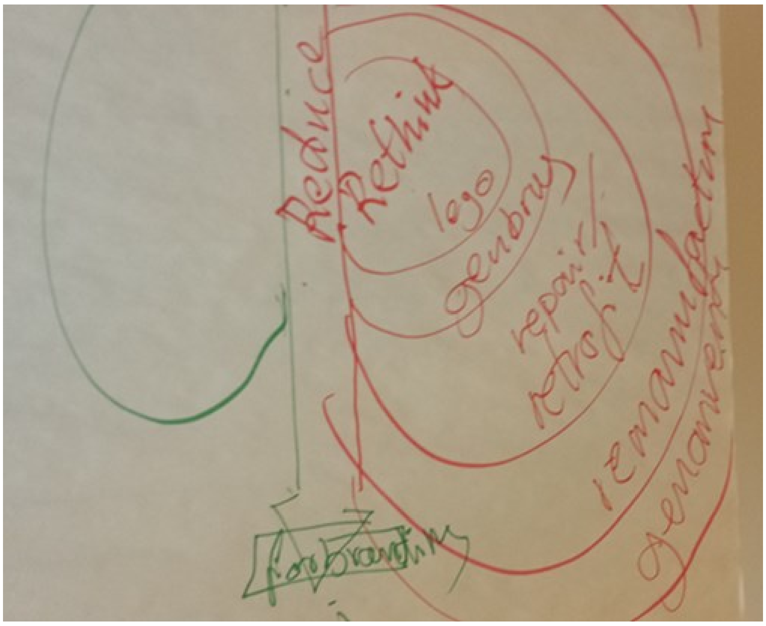


FIGURE 35. Explanation of circular economy.

5. Brainstorming process and the development of a strategy wheel for Lightyears

A brainstorming process was initiated based on the causal mapping and the introduction to ecodesign, circular economy and environmental strategies, and identifying relevant environmental activities that Lightyears could work with in relation to the life cycle phases of their products (design, raw materials, production, transport, packaging, administration and sales, use and reuse and recycling and waste). The results of the brainstorming are presented in Figure 36 and further details are available in Appendix 4. From the brainstorm, six aspects were selected as focus areas for Lightyears future work. These included:

- Management of suppliers
- Design strategy
- Code of conduct
- Design brief and BoM
- Knowledge of materials
- CE marking including the Ecodesign Directive, the RoHS Directive and the WEEE Directive

Lightyears has outsourced their production, and therefore reducing the environmental impact at their own facilities will not provide large environmental improvements. They can focus on the office site in Aarhus, and ensure that they minimise energy and resource consumption. Lightyears main environmental impacts are from the life cycle of their products, and it is thus more useful for Lightyears to look into the design of their products and how the products environmental performance can be improved. It will also be useful to examine, how they can affect and improve their supply chain in terms of environmental performance. The management of their suppliers and development of a design strategy targeting environmental aspects are key issues for Lightyears in order to improve their environmental performance.

Lightyears already has various artefacts, they can use when setting requirements and specifying their existing products and new products. They have a Code of Conduct specifying the requirements to their suppliers, which is inspired by the BSI CEDEX certification scheme. They have the design briefs and BoMs specifying the design of the product, how the product should be constructed and produced and material specifications. By specifying ecodesign or resource efficiency requirements already in the early stages of the design process, it is much easier and cost effective to implement (Tischner et al., 2000).

The design brief and BoM are two important tools, when improving the ecodesign of Lightyears products. Knowledge of the materials used in their products and a better specification of which materials to use in BoM is also important. The material specification in their BoM is gradually been made more detailed, but they need knowledge and competence development regarding materials (Mansher, 2014). Lightyears also needs more information on relevant environmental regulations e.g. the CE-marking scheme, the Ecodesign Directive, the RoHS Directive and the WEEE Directive.

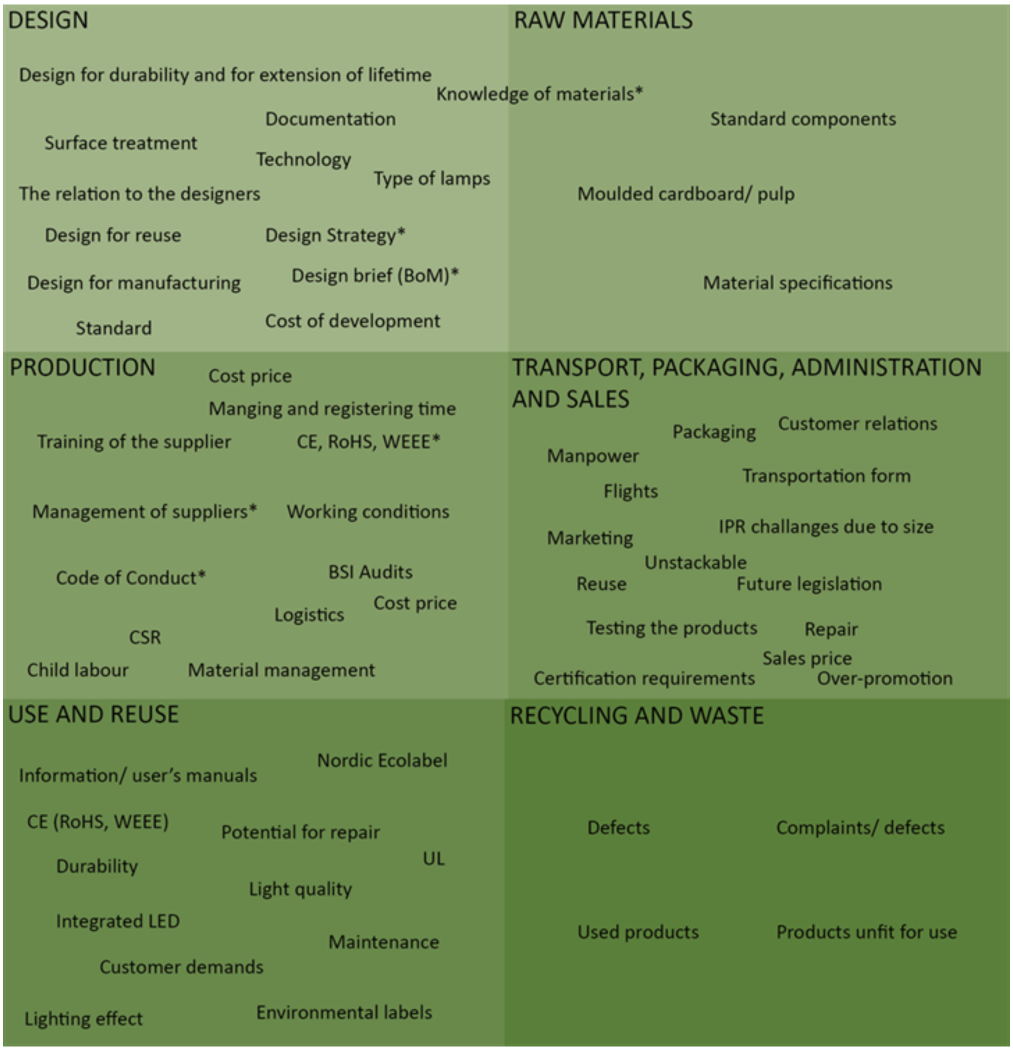


FIGURE 36. Results of the brainstorming: relevant aspects in relation to Lightyears environmental strategy and ecodesign. Six focus points were selected for their future works marked with an asterisk "*".

Specific activities were outlined that Lightyears could work with in the process of developing an environmental strategy:

- Overview of the legal environmental requirements for their products
- Development of a design-oriented sustainability strategy (inspiration from Apple as they are targeting a similar consumer segment)
- Identification and mapping of larger customer segments such as Google and the types of environmental and sustainability requirements that they are setting for their suppliers and a comparison with similar customers
- Fitness check
- Environmental profile

12.3 Sub-Conclusion

Lightyears has not previously worked systematically with environmental aspects and resource efficiency. They have developed the Lullaby lamps from a cradle-to-cradle certified material, they have changed their packaging materials to recycled cardboard, many of their lamps have a standard E27 socket and their lamps are designed for long life. They have products' properties that are important in order to improve resource efficiency and create a close looped economy. These initiatives have not been driven by a proactive environmental strategy formed by Lightyears.

Lightyears are currently experiencing increased demands for environmental documentation and greener products from public procurers, larger companies with a green profile and the environmental product regulations relevant to them, however, they are not sure how to proceed, and how to document their environmental performance. Lightyears included an activity to develop an environmental strategy in their latest strategy process. The purpose of the workshop was therefore to help Lightyears initiate the process of developing an environmental strategy relevant to their products.

The workshop design was inspired by causal mapping and based on qualitative research interviews with key employees at Lightyears. The workshop design was successful in creating a shared understanding of Lightyears and their current situation, which thereby could facilitate the dialogue on how Lightyears could begin their work on developing an environmental strategy targeting also resource efficiency aspects.

Six issues were highlighted for Lightyear to work with in the environmental strategy: management of suppliers, design strategy, code of conduct, design brief and BoM, knowledge of materials, and CE marking including the Ecodesign Directive, the RoHS Directive and the WEEE Directive. Specific suggestions for actions were developed regarding how Lightyears could proceed with their work. A single workshop is not enough to ensure the development and implementation of an environmental strategy, but in a case as Lightyears, the workshop can be considered the first step in a process to develop an environmental strategy. The take-over by Fritz Hansen in in 2015 resulted in a change in management, which had implications for the implementation of the workshop results.

13. Circularity and Rare Earth Elements in the Wind Industry

13.1 Introduction

Wind power is one of the fastest growing electricity generation technologies. From 2001 to 2016, the cumulative global wind power capacity increased from 23,9GW to 486,7GW with adding more than 50GW annually from 2014 to 2016 (Global Wind Energy Council, 2017). Several studies find that wind power is among the cleanest forms of electricity production with a low carbon footprint – both in comparison to fossil-based electricity generation and other renewable electricity generation technologies (Wiser, et al., 2011; Arvesen & Hertwich, 2012).

Wind power plants are installed either onshore or offshore. Onshore has the longest history and largest cumulative installed capacity (97%), but offshore installations are increasing and have reached 14.3GW (Global Wind Energy Council, 2017) and are expected to play a significant role in the future energy mix (International Energy Agency, 2016). Two main technologies are present within the wind turbine industry – geared and direct drive.

A key part of direct drive technology is the use of permanent magnets in the generator. Permanent magnets or neodymium-iron-boron magnets (NdFeB) are made up of 28-32% rare earths (dysprosium, neodymium/praseodymium) and the rest is a mix of boron and iron. Rare earths have been classified as critical materials by several governmental bodies including the European Commission (Raw Materials Supply Group, 2010), and business attention is given to the topic in order to reduce the risks associated with the rare-earth elements (REE) when it comes to both price – prices have been volatile with a peak in 2010-11 - and to accessibility since the majority of REE are in China.

Renewable energy and the regenerative use of resources are cornerstones in a circular economy that is gaining increasing attention in the pursuit of global sustainability (Geissdoerfer, et al., 2017). China was the first to enact a law promoting the circular economy in 2008 (Su, et al., 2013). The European Union is formulating a circular economy strategy in an attempt to achieve resource efficiency in a socio-economically way (European Commission, 2015) and organisations like the Ellen MacArthur Foundation have played a central role in engaging the business community in the transition towards a circular economy (Ellen MacArthur Foundation, 2012).

Bocken et al. (2016) divides the circular economy into three strategies: narrowing, slowing and closing the resource loop. *'Narrowing loops'* are related to the concept of resource efficiency to minimise the use of materials per output through eco-efficiency and the optimisation of resource use. This can be applied in combination with both product life extension / slowing loops and recycling / closing loops within a circular system. (Bocken, et al., 2016) '*Slowing loops'* target the extended use and reuse of products and materials over time, through designs for long durability and lifetime extension activities. Extending the lifetime of products is demonstrated to reduce environmental impacts compared to that of new products as production and distribution is delayed and the amounts of waste is being reduced (van Nes & Cramer, 2006). *'Closing loops'* focus on the recycling of materials and ultimately on eliminating 'leakage' from the system (Ellen MacArthur Foundation, 2013). Historically, the interest in a circular economy has been related to closing the outer loop of materials for example through industrial symbiosis. (Mathews & Tan, 2011).

Although circularity is a key concern, the demand for and use of virgin raw materials in the production is still rising, and the recycling rates of common metals does not even exceed 25%. The global recycling rate for rare earths elements is less than 1% (UNEP, 2011).

A transition towards sustainable resource use in a circular economy will take time, and will also have to battle with low material prices and 'business-as-usual'. A rethinking of business models and traditional design processes in industry can facilitate this transition, where participation, collaboration and shared understanding throughout the value chain can help increase the recovery and reuse of end-of-life products and their components.

The following research questions will be analysed in this case study of REE in wind turbines:

- *What is the current status of the end-of-life handling of NdFeB magnets?*
- *How can a wind turbine manufacturer undertake experiments with the narrowing, slowing and closing of rare earth elements in the magnets of direct drives turbines via workshops?*

The first research question is answered through a review of existing scientific literature, and the second is investigated through the four year longitudinal study of Siemens Gamesa Renewable Energy through observations, interviews and experiments at workshops carried out together with different partners from the waste handling industry.

13.2 Permanent magnets

There are several commercial technologies In the group of permanent magnets, including: AlNiCo (Aluminum-Nickel-Cobalt), ferrite, SmCo (samarium cobalt), NdFeB (neodymium-iron-boron) and SmFeN (samarium iron nitride) with the latter three being considered 'rare earth magnets' due to the content of one or more rare earth elements (Constantinides, 2016).

A significantly improved magnet material is invented approximately every 12 years. In 1931, the first alnico was invented, and in 1952 Phillips marketed a ceramic magnetic (Goldman, 2006), which is known today as a ferrite magnet. In 1965, the SmCo magnet was discovered, and this was optimised and commercialised through research and innovation by 1975 (Constantinides, 2016). The magnet used cobalt and conflicts in Zaire disrupted the supply, which led to 6.5 times increased prices, and a search for a cobalt-free magnet. The next commercialised magnet was the NdFeB, which the US Navy was granted the composition, process and product patent for (Koon, 1983). This was optimised by both Masato Sagawa (Sumitomo) and John Croat (General Motors), and the magnet was commercialised in 1984 (Croat, 1985). The SmFeN magnet was discovered and commercialised, but as of today the two major commercial magnets are ferrite and NdFeB and the others are less commonly used (Constantinides, 2016).

NdFeB permanent magnets are considered the best available magnets, due to their superior energy performance with a theoretical maximum of 512kJ/m3, which makes them efficient and suitable for lightweight mobile applications (Jiles, 1998). NdFeB magnets contain a magnetically hard phase, which is based on Nd, Pr and Dy, Iron and boron. The content of REE varies from 27 to 32 weight % (Peiró, et al., 2013). SmCo magnets are preferred over NdFeB magnets in high-temperature applications, where the lower Curie temperature of NdFeB magnets can be problematic (Zakotnik, et al., 2016). The main application of NdFeB magnets has changed from hard disc drives to motors (Sugimoto, 2011), which sets new requirements for the thermal stability properties. High coercivity grades means that the content of Dy must be increased, but Dy is scarce compared to Nd and more expensive, which is why it is sought to develop NdFeB with the lowest Dy content possible (Goto, et al., 2011).

13.2.1 Applications of permanent magnets

The application of NdFeB permanent magnets varies between large magnets for wind turbines and small magnets for consumer electronics. The lifetimes of products containing NdFeB magnets span from 2-3 years for small consumer electronics to 20-30 years for wind turbines. Similarly, the weight of the magnets differs from less than 1 g in small consumer electronics to about 600kg/MW in wind turbines. A 6MW wind turbine has around 4 tons of magnet material. The lifetimes and different sizes have implications for the handling of permanent magnets during the product life cycle (Yang, et al., 2016).

Constantinides (2016) has identified more than twenty applications, where NdFeB permanent magnets are being used and Yang et al. (2016) based on Binnemanns et al. (2013) provides an overview of the most common applications of NdFeB magnets, their mass per unit and total use in ton (Table 19).

TABLE 19. Adapted from Yang et al. (2016) based on Binnemanns et al. (2013)

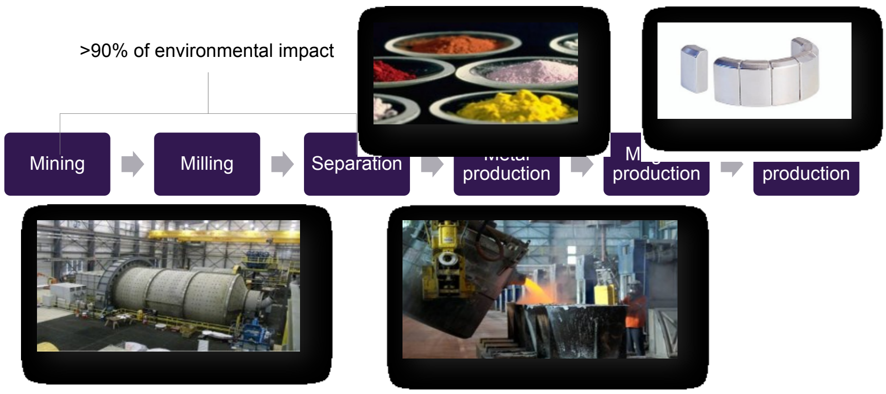
Sectors	Product	Application	Mass per unit	Total use in ton (Year)
Computers	HDDs (excluding CDs, DVDs)	VCM, SP motors	10 – 20 g	7500 (2015)
Consumer Electronics	Home electronics & electrical appliances - Air conditioners - Speakers - Cell phones and music players - Washing machines and refrigerators	Electric motors	Varies greatly from less than 1 g	- 4000 (2014) - 4500 (2015)
Wind turbines	Direct drive	Generators	400kg/MW	8500 (2015)
Vehicles	- Conventional automobiles - HEVs, PEHVs, and EVs (average)	- Small motors and sensors - Electric motors - Electric motors	250 g 1,25 kg 300 - 350 g	22000 (2015) > 7000 (2015) 6000 (2015)
Total (incomplete)				51000

The list is not complete, but accounts for the largest groups of applications. Small electrical motors have not been quantified, but can use up to 25% of the total NdFeB permanent magnets (additional 12750 ton). Further applications with a reasonable size includes optical appliances and MRI scanners, which together account for up to 10% of permanent magnet use (Sprecher, et al., 2014).

13.2.2 Production of rare earth oxide and NdFeB permanent magnets

The supply chain for NdFeB magnets, from mining to oxide production to magnets, is described below. Sprecher *et al* (2014) describes the processes used for the production of rare earth oxides, based on the ore compositions from the Bayan-Obo mine in China. The Figure below outlines a simplified overview of the process steps.

NdFeB magnet production (the short version)



Overall, the production process involves high energy demands, the use of acids and loss of rare earth elements during the process. Sprecher et al (2014) report that almost 50% of the REE mined is lost during the beneficiation of the ore (Sprecher*, et al*., 2014) and further, high losses of up to 30% are reported converted into bulk or scrap during the manufacturing process for example during pressing, sintering, grinding and slicing (Itoh, *et al*., 2009). As indicated above, more than 90% of the environmental impacts are occurs during the first three production steps, but increased recycling can “by-pass” most of these environmental impacts.

13.2.3 Recycling of rare earth elements in magnets

The NdFeB magnets are estimated to support an industry worth in the excess of US$1 trillion Worldwide (Kooroshy et al., 2015). Supply constraints and price volatility are a risk especially outside of China. Less than 1% of the rare earths are recycled worldwide (Binnemans et al., 2013), even though this could be a REE source in regions such as the EU, where REE are scarce. Several authors have estimated the global recycling potential for NdFeB magnets in the range of 14.000 to 20.000 tons per year by 2020. Based on global consumption, this would mean 2.000 to 3.000 tons per year in the EU (Schulze & Buchert, 2016; Sprecher, et al., 2014).

Recycling of NdFeB magnets has gained attention in recent years with a range of publications documenting the efforts such as described by ie. Schüler et al. (2011), Binnemanns et al. (2013) and Yang et al. (2016). These articles describe various recycling methods such as waste-to-alloy, pyro-metallurgical, hydro-metallurgical, melting, gas-phase extraction and magnet-to-magnet. So far, no commercially viable and environmentally friendly solutions have been established (Binnemanns, et al., 2013). Most recently, Yang et al. (2016) provided an overview of the possible recycling routes along with their advantages and disadvantages. Zahotnik et al. (2016) reported on a NdFeB magnet-to-magnet recycling technology with promising results. This does not focus on extracting the elements, but on recycling the magnetic material for new magnets.

Common to these studies is the connection to the design of the product that has implications before the actual recycling phase. The challenges are the dispersion of the NdFeB magnets, the relative small amount in many applications, and the difficulties of ‘dismantling’ the magnets. Another issue, reported by Lee et al. (2013) is the difficulty of handling waste NdFeB magnets due to their high magnetic power, and they recommend a demagnetisation before initiating a recycling process (Lee, et al., 2013). This can be done by using thermal treatment above the Curie temperature, which will disrupt the alignment and reduce the magnetisation.

NdFeB with low Dy content will have a Curie temperature close to 300C and it will increase accordingly with the amount of Dy added (Campbell, 1996).

13.2.4 Life cycle assessment of recycling NdFeB Permanent Magnets

Several studies have assessed the benefits of recycling of NdFeB permanent magnets. Sprecher et al. (2014) compare a primary NdFeB permanent magnet, a recycled NdFeB magnet via hand picking/manually and a recycled magnet via shredding. In the impact category of climate change (CO2-eq.), the first one emits 27 kg CO2-eq./kg NdFeB magnet, the second 3,3 kg CO2-eq./kg and the latter 10 kg CO2-eq./kg NdFeB magnet (Sprecher, et al., 2014). The case study is based on magnets from HDDs, and shows the clear environmental benefits of recycling the magnets. The recycling process applied is a hydrogen decrepitating process (Binnemanns, et al., 2013).

Another study focused on the recycling of electric drive motors from automotives. Here, the global warming potential using the solvent extraction route, compared to primary production, was 14 kg CO2-eq./kg NdFeB magnet for the recycled magnet (Walachowicz, et al., 2014).

A third study did not focus on making a life cycle assessment, but on assessing the energy usage following a magnet-to-magnet process. By recycling five tons of waste magnet material from consumer products through this process, the study showed a 45 % saving in energy compared to primary production (Zakotnik, et al., 2016).

Common to all studies is that energy and CO2-emissions can be saved compared to primary production of NdFeB magnets by eliminating the REE extraction part of the life cycle and some NdFeB magnet production steps – as indicated in the Figure above.

Siemens Gamesa Renewable Energy has experimenting with NdFeB magnets in relation to circular economy in terms of narrowing, slowing and closing the material loops due to the potential large economic and environmental benefits of NdFeB magnets.

13.3 NdFeB magnets and circular economy in the wind turbines

The following sections will describe the observations and findings by Siemens Gamesa Renewable Energy related to the ongoing optimisation of resource efficiency and narrowing of the loops in the design and manufacturing process. The possibilities for slowing the loops will be described. Finally, the potentials for closing the loop is described and analysed in more details based on experiments and tests made at the workshops related to increasing the recycling and recovery of NdFeB magnets.

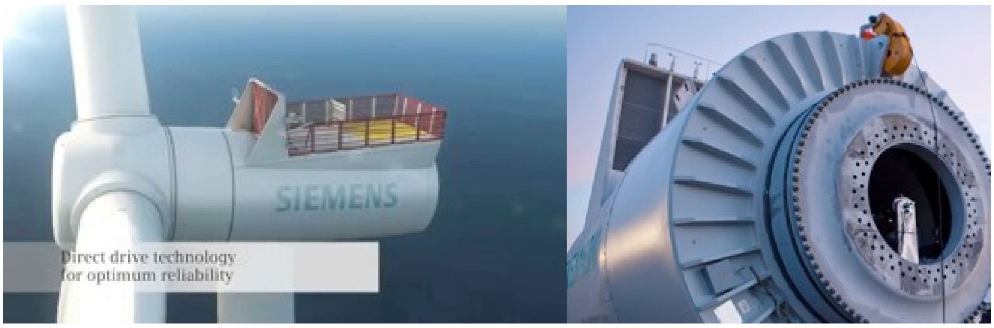


FIGURE 37. Direct drive generator and the magnets

13.3.1 Design of the generator – narrowing the loops

The direct drive generator is a variable speed, 3-phase permanent magnet synchronous generator with an outer rotor and an inner stator. Its main function is to convert rotation from the turbine rotor into electrical power, which is delivered to the converter and then to the grid. Due to their high field strength, rare earth magnets offer the most compact and lightweight means of excitation for electrical machines. The magnets are encapsulated to provide mechanical strength and protect against corrosion. The electrical current is generated as the magnets move past a coil of wire. The stronger the magnets, the more efficient the generation of power at lower speeds, thus optimising energy output.

Direct drive generators also reduce the number of moving parts used in comparable geared machines, as well as the overall weight of the nacelle. A reduction of weight has a positive impact on material use, infrastructure and installation costs. Rare earth elements comprise approximately one third of the magnet grade used in the direct drive technology, of which the traces of Dy provide stability to the magnetic properties at elevated temperatures.

Maximising the energy output and optimisation is an ongoing activity in the design of permanent magnets. Improving the magnets has been central in the development of the direct drive from 6MW to 8MW. From an index level of 100 in terms of kg NdFeB/MW for the 6MW, the 8MW wind turbine has an index level 86 of kg NdFeB/MW. In other words, it has *less kilo of magnet pr. MW.*

Decreasing the content of Dy is another focus of research, as it is perceived as 'difficult and costly to source' with a goal of getting close to 0% Dy content (Wilson, 2014; Semmer & Urda, 2014). So far, a reduction of 75% of Dy content has been achieved (Anonymous, 2016). Reduction in the numbers of different materials will also make recovering of the REE easier – all other aspects being equal. A reduction in Dy content reduces the applications the magnets can be used for afterwards as this reduces the temperature range the magnet can operate within without diminishing performance.

Several reasons for the design optimisation can be highlighted. First of all, technological improvements have introduced new grades of magnet material (from N35H to N52H). The number indicates their magnetic flux output per unit volume. The letter (in this case H) refers to the maximum operating temperature, which has remained unchanged in the design. Secondly, operating the generator and stator segments at lower temperatures (with improved cooling) has enabled the possibility of reducing the Dy content and improving the efficiency of the generator. In general, the design of the generator has been continuously improved with a close connection between cost optimisation of generator performance and improvements in resource efficiency.

13.3.2 Manufacturing/supply chain – narrowing the loops

Some of the magnet material is wasted in the manufacturing process. Normally after sintering, permanent magnets are ground from rectangular geometries into the desired shape needed for installation in the generator. In collaboration with suppliers, a new manufacturing process has been developed to correctly shape the magnets in the first step. This means pressing the powder into shapes that match the final magnet shape and thereby avoiding the grinding process and the associated waste. This is now possible and the magnets have the same properties as conventionally made magnets (Siemens AG, 2017).

Overall, when assessing the full life cycle of the magnet, this reduces the need 20-30% for rare earth oxide (traditionally lost in the shaping process), which will have positive impacts both in terms of prices of the magnets and on the environmental impacts. Again, *optimisation of the production process and increased resource efficiency goes hand in hand with cost reductions and improved environmental performance*.

13.3.3 Operation and maintenance – slowing the loops

Modern wind turbines have a "design lifetime" of 20-25 years. Actual lifetime may differ from design lifetime depending on application and variations. The design lifetime of magnets involves the electromagnetic properties of the component. During the life time of a wind turbine, it is assessed whether the magnets have irreversible flux losses. Irreversible flux loss is a partial demagnetisation of the magnet, which can be caused by too high a temperature, too high a current and time (International Electro-Technical Commission, 2009). The irreversible flux loss can be fully recovered by remagnetisation, but this is not possible when the magnets are mounted in the generator. High loads or high temperatures will impact the permanent magnet and then irreversible losses might occur. Test results show that a loss of less than 1% occurs during the design life time of a wind turbine (Haavisto, 2013). The implications are mainly that it must be compensated for in the design of generator and electrical system.

A slowing of the loops implies using a product for as long as possible. Testing the magnets shows that there are no technological barriers to extending the design lifetime of wind turbines. When the turbines are operated at controlled temperatures then the minimal losses in efficiency can be compensated for in the design of the generator and electrical system.

13.3.4 End-of-Life – closing the loops

The wind turbine will be decommissioned, when reaching its end-of-life. For most components, this is an easy case, except for the blades and the magnets in the generators. From February 2015 to February 2016, a series of workshops were held and with tests made on five end-of-life generators in a collaboration between Siemens Gamesa Renewable Energy and a waste handler. The workshops and tests were in Denmark and the first step was to separate the generator to extract the magnets. In this process, the outer rotor containing the magnets was separated from the rest of the generator with the active magnets still in place.

FIGURE 38. Dismantling the magnets

FIGURE 39. Extracting the magnets

In order to be able to demagnetise, two options were considered: thermal treatment above the Curie temperature while in the outer rotor, or separating each magnet before thermal treatment. The first option would avoid handling the magnetised magnets, which has implications related to occupational safety due to the strong forces of the magnets, but would also require heating the non-magnet parts. The first option was explored. The process was iterated several times based on continuous learning. In the first attempt, the rotor was sand blasted to remove the paint and was then heated until the magnets reached the Curie point. It was possible to demagnetise the magnets in this way in the first attempt.

A later stage included cutting of the back plate of the outer rotor in order not to spend energy on heating it (37% less material to be heated) and to make access to the magnets easier. Before being ready for thermal heating, it was found that perforation of the stainless-steel encapsulation was preferable as the magnets could crack during thermal treatment, if the encapsulation was not perforated. Different techniques for perforation were tested with a cutting torch proving the best as this was not affected by the magnetic field (made of brass) in the same way as a grinder or drilling machine.

After that, the outer rotor with magnets was placed in an oven with temperatures above the Curie point to demagnetise the magnets. It was heated to almost 400 degrees Celsius during four hours. When cooled down again, the encapsulation could be cut open with a grinder and the demagnetised magnets could be removed. The magnets were then cleaned with basic tools such as spatula, rags and brushes to remove obvious impurities. These first attempts established the baseline knowledge of how to demagnetise the magnets, so they could be fed into the existing production of NdFeB magnets (see below on supply chain aspects).

At a series of new workshops in August 2017 to January 2018, another demagnetisation testing was made. To avoid the need for a large oven to heat the full rotor (without the backplate), tests were undertaken with direct heating of the magnets with a blast torch, when the magnets were still mounted in the generator. This needed to be done as a two-step process, where the magnets were first heated until ‘relatively’ demagnetised until they could be safely handled, when not mounted in the rotor. The magnets were then heated above the Curie point one by one. This process also proved useful, but also more time consuming, but only using energy to heat the magnets and avoid the need for a large oven. In other words, this method can be applied, where the decommissioning the turbines takes place.

One aspect of the exercise was to find a technical solution to demagnetising the magnets, so they could be recycled into new magnet production. Another was to establish a value chain, into which the material could be fed. This was also examined in collaboration between Siemens Gamesa Renewable Energy and the waste handling companies. Various sources were evaluated, but only one magnet manufacturer was identified as suitable for the purpose within Europe. The intention was to re-introduce the material to the European market. The producer provided input into the demagnetisation process to ensure the highest possible content was recycled, and to avoid some of the problems identified in the first testing round such as the cracking of magnets, more extensive heating in the demagnetisation process and storage in closed containers.

FIGURE 40. The recovered magnets

The cracking of the magnets was identified as a problem during the workshops, which showed that the coating of the magnets was not removed during heating and in order to avoid recycling this coating into the new magnets, the magnets needed to be intact to ease the removal of the coating. Another issue identified was that even though the magnet appeared to be demagnetised, some of the grains were not fully demagnetised, which caused problems when re-introducing the magnet material into magnet production as these would stick to the machinery and create production challenges. Finally, storing the magnets in closed containers was crucial to avoid contact with oxygen, when taken out of the steel encapsulation.

The salvage value of NdFeB permanent magnets (which varies depending on Dy content) was in the range of 10-12 Euro/kg magnet material. In the tests, the value of the demagnetised NdFeB magnets was double the costs associated with the demagnetisation process; and the process is expected to be optimised further. Handling the steel of the rotor house and the value associated with recycling this has not been accounted for.

The experiments showed that the magnets could be retrieved from the generator with losses in the range of 5-8 % due to the brittle structure of the magnet material, but this could also potentially be reduced. Indicators showed that from the first attempt to third attempt (in the second round of tests), the cost of dismantling and demagnetising was reduced slightly more than 7% per kg magnet. Due to large amounts of magnets in the generator, the costs of dismantling and demagnetising were outweighed by a factor three times of the salvage value (only magnets, not including steel encapsulation, copper from stator, etc.). With the current level of REE prices, the recycling of magnet material is an attractive option.

In terms of ‘closing the loops’, testing recycling technologies was not yet part of the scope of Siemens Gamesa Renewable Energy. One clarified issue was that due to changes in magnet grade, composition and shape, the magnets were not directly suitable for the new direct drive generator turbines.

Another issue that became apparent was the small number of companies interested in the scrapped magnets. Within EU only two companies showed interest in the NdFeB, the rest was in China. This is probably linked to the ‘unknowns’ related to the recycling of the NdFeB magnets and the absence of commercial scale recycling plants within EU. In EU, the salvage price of the NdFeB magnets is determined by the content level of Dy rather than the Nd.

Designers and product developers were not directly involved in the workshops, since the experiments and tests were with the magnets from the first generation direct drive generators. Recovering the rare earth elements is therefore interesting from a resource perspective and in order to closing the loop of REE. From a product development perspective in a wind power company then inspiration to the product developers has to come from testing the newest designs of magnets at the workshops. The product developers have played a crucial role in the reduction of material use and in the narrowing of the resource flows.

13.4 Sub-conclusion: Narrowing, Slowing, and Closing the Loops of Permanent Magnets from Wind Turbines

Several conclusions can be drawn based on the literature review:

Different recycling technologies are available for recycling of NdFeB magnets, but the methods need to be proven at full scale to evaluate the economic and environmental viability. A prerequisite for efficient recycling is that the generators can be dismantled in order to gain access to the permanent magnets.

Life cycle assessments highlighted the positive effect on global warming potential and energy usage when recycling permanent magnets. The explanation is that the productions steps with the most environmental impacts are avoided when recycling the magnets compared to the primary production of permanent magnets. There are potential benefits even before the commercialisation and optimisation of the recycling processes.

NdFeB permanent magnets from wind turbines with direct drive generators can overcome the challenges related to recycling. The design of the generator allows for dismantling without harming the magnets and a large amount is available within the generator.

Furthermore, the practical experiments at the workshops showed:

Narrowing the loops will continue due to technological advances in introducing stronger magnet grades and will remain a potential innovation route. The maximum possible magnetic flux output per unit volume of NdFeB is calculated as the N64 grade. Another potential route is to further decrease the operating temperature of the generator, which could increase the efficiency of both the magnets and the stator material, and thereby reduce the need for magnet material per MW. The production of the magnets has already been optimised with around 20% saved, and the content of Dy, the most expensive REE, has been reduced from 4% to around 1%. Research, development and optimisation related to magnets will continue as long as the direct-drive technology remains central in the wind industry.

Slowing the loops of the magnets is bit complicated, since the magnets are heavy “stuff” placed in a direct drive generator on top of a wind turbine and often at sea, but in principle remagnetisation can be achieved. The wind turbines and the magnets in the direct drive generators have already a long technical design life of 20-25 years, and this is expected to be even longer in the future. Several ways exist to prolong the service life of wind turbines and to improve the performance and in this way slowing the resource loops (see Pagh Jensen, 2018). Direct drive generators and magnets are not exposed to the same wear and tear as wind turbines with a gear-box, and they have limited performance loss over time, when operated within a controlled temperature range.

Closing the loops becomes interesting when decommissioning wind turbines, and the practical tests of demagnetisation at the workshops and the use of these in new magnet production provides insights into potential next steps. The findings of the series of workshops were:

- Direct drive generators can be dismantled and give access to the magnets
- The process is rather time consuming and requires heating the magnets, but can still be done in a cost-efficient way compared to the prices of virgin magnet materials
- Few players (1-2) are currently on the European market for recycled magnets materials, and the sale price is dependent on the content of Dy
- Learning-by-doing reduces the costs of recycling magnets with around 15%
- Potential trade-off exists related to coating between durability versus recyclability

These learnings could be beneficially coupled with expertise from the relevant stakeholders in this field. A series of research networks in the EU including ERECON, REMANENCE, REProMAG, EREAN, DEMETER and SCRREEN have had different objectives, but all address aspects of recycling rare-earth materials in order to keep these materials within the EU and thereby decrease the risks related to sourcing. From the perspective of Siemens Gamesa Renewable Energy, a secure and stable supply of REE in the future is a priority.

The above projects have not addressed the magnets in the wind turbines beyond a theoretical perspective. Practical experimentations at workshops with the specific challenges related to this recycling issue has further expanded the knowledge regarding ‘circular magnets’ and could contribute to advances in the recycling of rare-earth elements to a technology readiness level, where magnets become part of a circular economy.

14. Discussion and Conclusion

The four case companies represent four different outsets and backgrounds in terms of working with resource efficiency and ecodesign. Tier1Asset is a company that is “born circular” since the core of the company is the refurbishment of computers and ICT equipment, so working with resource efficiency is not something new to them. Their business model is circular in the outset, as their business is to buy, refurbish and resell used consumer electronics. B&O represents a company which has worked with environmental aspects for several years, and has taken the journey from a focus on environmental impacts in the production towards more attention on ecodesign and the products. They have an environmental strategy and an environmental management system, but environmental aspects, resource efficiency and circularity have not been part of their core business. Lightyears has only worked with environmental aspects sporadically and has no environmental strategy so far, but the workshop aimed at developing both an environmental policy and strategy. Siemens Gamesa Renewable Energy has a long tradition of environment initiatives related to the production process and partly also with eco-design and product development. Resource efficiency has been an element of this work, including how to reduce the use of resources (narrowing the loop) and extending the product life through improved service and maintenance (slowing the loop). Experiments and tests have been made at workshops towards advancing the circularity via recovering NdFeB magnets in the wind turbines.

Due to their diverse backgrounds, the processes and workshops in the four companies have also been different

- The B&O case examined how the recyclability of their products could be enhanced by testing existing ecodesign guidelines, and how producers and waste manager could improve knowledge sharing and cooperation through a workshop
- The Tier1Asset case examined the necessary conditions for refurbishment, developed recommendations for design for refurbishment of laptops and desktops and tested existing ecodesign guidelines
- The Lightyears case examined how a workshop, designed based on causal mapping, could support development of an environmental strategy focused on resource efficiency and eco-design
- Siemens Gamesa Renewable Energy has involved waste managers and tested the potentials of recovering the rare earth elements in the magnets of the direct drive generators via workshops, and at the same time reduced the amount of material necessary.

14.1 Design for Recyclability: The Bang & Olufsen Case Study

The purpose of the process and workshop at B&O was to examine how the recyclability of their products could be improved, and how producers and waste manager could increase cooperation and knowledge sharing. The focus of this workshop was on the outer circle of the strategies to improve resource efficiency - recyclability.

This was tested through a workshop, where producers and waste managers were brought together to increase knowledge sharing. The workshop consisted of two components: an introduction to the waste treatment processes which WEEE undergo by the waste manager and a workshop where the producers and waste managers worked together on separating and dismantling three products (a television, a remote control and a loud speaker). Based on the workshop, it was possible to establish fifteen ecodesign recommendations within the following four categories: marking components, information availability, easy disassembly, the contamination of the material fractions and hazardous substances. An overview of the ecodesign recommendations is provided in Table 19.

TABLE 20. Overview of the recommendations found during the workshop at B&O and a comparison of these recommendations with recommendations found in the Ecodesign Pilot and ECMA-341 standard based on Bundgaard (2016).

	Ecodesign recommendations	Included in existing guidelines
Marking of components	Mark components that contain rare earths and precious metals and make it easy to disassemble the component	Partly covered but more detailed (Ecodesign Pilot)
	Mark components that contain hazardous substances that require special treatment and make it easy to disassemble the components	Partly covered but more detailed (Ecodesign Pilot and ECMA-341)
	Mark products that contain batteries	Yes (ECMA-341)
Information availability	How to disassemble the product	Yes (ECMA-341)
	The content and location of hazardous substances, precious metals, rare earths and batteries	Yes (ECMA)
Easy disassembly	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 covered but more detailed (ECMA-341 and Ecodesign Pilot)
	Reduce the number of screws used to assemble the product and use the same slots for all screws when possible	Yes (ECMA-341)
	Make screws easily accessible and avoid covering them	Yes (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 the easy assembly	Partly covered but more product specific
	Make the product easy to dismantle into material fractions that require the same recycling process	Yes (Ecodesign pilot)
	Use a marking system to make it easy to understand, which screws to remove to disassemble the product or certain components	Partly covered but more detailed (Ecodesign Pilot)
Contamination of the material fractions and hazardous substances	Avoid the use of glues that are under suspicion of causing environmental problems	Partly covered but more detailed (Ecodesign Pilot and ECMA-341)
	Avoid mixing materials, for example embedding iron or stainless-steel treads in aluminum elements	No
	When using metal screws to assemble plastic parts, then design these assemblies in a way that the plastic and the screws are separated during the destructive disassembly process by e.g. avoiding submerged or enclosed screws in plastic	Partly covered but more detailed (ECMA)

	Avoid soundproofing materials that disintegrate into small bits during the destructive and automatic disassembly and contaminate the other fractions, or make is very easy to remove it beforehand	No

A hypothesis in the B&O case was that the old ecodesign guidelines, for instance the Ecodesign Pilot and the ECMA-341 standard, might be outdated due to the development within the recycling sector. A comparison was made of the ecodesign recommendations found during the workshop and the ecodesign recommendations in the two existing ecodesign guidelines the Ecodesign Pilot and the ECMA-341 standard. The result is provided in Table 19. The comparison showed that six of the fifteen ecodesign recommendations were already included in the two existing ecodesign guidelines. Seven of the fifteen ecodesign recommendations were partly covered by the existing ecodesign guidelines, but the recommendations developed during the workshop were more detailed or product specific. This showed that the existing ecodesign guidelines are still relevant when designing for improved recyclability, but that it can be useful to developed more detailed and product specific ecodesign recommendations. Two of the fifteen ecodesign recommendations were not covered by the existing ecodesign guideline. This was the ecodesign recommendation to “avoid soundproofing materials that disintegrates into small bits during the destructive and automatic disassembly”, which is mainly relevant in relation to loud speakers and the recommendation to “avoid mixing materials, for example embedding iron or stainless-steel treads in aluminium elements”, which is a more generic recommendation.

Another hypothesis was that collaboration between the waste management sector and producers is very limited, partly as a result of the collective schemes, where producers are no longer in direct contact with recyclers. This implies that the knowledge exchange and collaboration between the waste treatment sector and the producers are rather limited. This hypothesis was confirmed during interviews with representatives from the waste treatment sector.

The purpose of the workshop at B&O was therefore also to establish a knowledge exchange between the waste treatment sector and the producers. This was done in two steps. First a representative from the waste treatment sector presented the processes which WEEE undergoes. Secondly, the producers and the waste manager worked together on dismantling three B&O products. The practical exercise separating the products helped to illustrate the problems, which the waste treatment sector is experiencing. The practical exercise worked well as a boundary object facilitating the knowledge exchange between the producers and the waste manager. Overall, the workshop format worked well, but the composition of participants could be improved in future workshops with more representatives from the different departments in B&O’s design and product development.

14.2 Design for Refurbishment: The Case of Tier1Asset

The purpose of the process at Tier1Asset was to use their extensive experiences with refurbishing ICT products, and identify necessary conditions for refurbishment and develop design recommendations that could improve the refurbishment potential of laptops and desktops. The idea was that these experiences should be passed on to the producers and thus improve design for refurbishment.

A necessary condition for Tier1Asset to have a viable business is that they have access to products of high quality and in large numbers. As a consequence, Tier1Asset primarily buys used products from larger companies and organisations. Another precondition for Tier1Asset’s business model is trustworthiness from both the seller and the buyer of the used equipment. Tier1Asset is dependent on a steady supply of used equipment, but the supply depends on the seller of the used equipment and when the producer of the equipment releases new models. Finally, Tier1Asset is dependent on how the market for used equipment develops.

Different ecodesign recommendations were identified to improve the refurbishment potential of laptops and desktops based on the interviews with employees involved in the different processes at Tier1Asset. In total seventeen ecodesign recommendations were developed (presented in Table 20). A comparison between the ecodesign recommendations from the study and the existing ecodesign guidelines were made to determine whether the ecodesign guidelines from the Ecodesign Pilot, the ECMA-341 standard and the design for remanufacturing guidelines found in Ijomah et al. (2007) are relevant when designing for refurbishment.

The comparison is provided in Table 20. It showed that eight of the seventeen ecodesign recommendations found in the study were included in the exiting ecodesign guidelines, and eight of the seventeen ecodesign recommendations were partly covered by existing ecodesign guidelines, but were more detailed or product specific. This implies that the ecodesign guidelines found in the Ecodesign Pilot, the ECMA-341 standard and in Ijomah et al. (2007) are relevant when designing products for refurbishment, but that they could be made more detailed and product specific. One ecodesign recommendation found in the study was not included in the existing guidelines, and that was the recommendations to “Limit the use of BIOS passwords or make BIOS passwords available or provide a software that can reset the BIOS password”. This was identified by Tier1Asset as an important barrier to refurbishment, so this ecodesign recommendations should be emphasised.

TABLE 21. Overview of the design recommendations found during the study, and a comparison with existing design recommendations in the Ecodesign Pilot, the ECMA-341 and Ijomah et al. (2007). The Table is based on Bundgaard (2016).

Ecodesign recommendations from the study	Found in existing design guidelines
Have information on best use and maintenance of the equipment	Partly (Ecodesign Pilot and ECMA-341)
Limit the use of BIOS passwords or make BIOS passwords available or provide a software that can reset the BIOS password	No
Avoid safety and security tags and other labels when possible Use safety and security tags and other labels that can be removed without leaving a permanent mark Avoid tags that are corroded or burned into the product. Place marks in a less visible place e.g. on the back of the product	Partly covered but more detailed (ECMA)
Make it easier to disassemble the product	Yes (Ecodesign Pilot)
Make it easy to remove and replace component such as keyboards, RAM, processor, graphics cards, batteries, palm wrist, screens and covers to ensure that it is possible to upgrade, customised and repair of the products.	Partly covered but more product specific (Ecodesign Pilot and ECMA-341)
Make disassembly intuitive; ensure self-explanatory structures or provide instructions for repair, customisation and update of the product	Yes (Ecodesign Pilot and ECMA-341)
Reduce the number of screws and use the same slot for all screws	Yes (ECMA-341 and Ijomah et al. 2007)
Use robust click systems when possible that can be separated and put together again several times	Partly covered but more specific (Ecodesign Pilot and Ijomah et al. 2007)

Use modular design	Yes (Ijomah et al. 2007)
Make the surfaces easy to clean	Yes (Ecodesign Pilot)
Avoid a design where dust and dirt can gather and be difficult to remove	Partly (Ecodesign Pilot)
Make it easy to remove dust by easy access to central parts in the desktop and laptop	Partly covered but more product specific (Ijomah et al. 2007)
Easy disassembly of the desktop's sides	Partly covered but more product specific (Ijomah et al. 2007 and Ecodesign Pilot)
Use materials for the casing that are resistant to scratches and bumps	Yes (Ijomah et al. 2007 and Ecodesign Pilot)
Have spare parts available for an extended period	Yes (Ecodesign Pilot)
Use standardised components	Yes (Ijomah et al. 2007 and ECMA-341)
Standardise power plugs	Partly covered but more product specific (Ijomah et al. 2007)

14.3 Lightyears - Developing an Environmental Strategy for Resource Efficiency

Lightyears has not worked systematically with environmental aspects and resource efficiency but has had different initiatives with an environmental or resource efficient profile, such as their Lullaby lamp, the change to packaging material of recycled cardboard, the use of a standardised E27 socket, and a vision to design lamps for long product life for example via classical designs. These initiatives were not driven by an environmental strategy, and therefore the purpose of the process and workshop at Lightyears was to support their development of an environmental strategy focused on resource efficiency.

The workshop at Lightyears was inspired by causal mapping and made on the basis of qualitative interviews with central employees at Lightyears. The workshop design was based on causal mapping to help create a shared understanding of Lightyears' current status in terms of their work with environmental aspects. This shared understanding helped facilitate a dialogue between the workshop participants about how they could develop an environmental strategy targeting resource efficiency. Six aspects were highlighted during the workshop including: management of suppliers, design strategy, code of conduct, design brief and BoM, knowledge of materials and CE marking including the Ecodesign Directive, the RoHS Directive and the WEEE Directive. In addition to the six identified aspects, specific suggestions for actions was made. Although, a single workshop is not sufficient to ensure the development and implementation of an environmental strategy for a company, which has not previously work systematically with environmental aspect, the workshop can be considered the first step in this process.

14.4 Design for the Recovery of Rare Earth Elements in Magnets at Siemens Gamesa Renewable Energy

Material efficiency is a cornerstone in the development of wind turbines, and at the same time contribute to reductions in the levelised cost of wind energy. The amount of materials used to produce an 8MW wind turbine is in the overall picture more or less the same as for a 6 MW turbine. In other words, a strong connection exists between increasing resource efficiency and reducing the costs of producing electricity from wind turbines. The development of the wind turbines is somehow dependent on an optimised use of the materials: more outcome with less input of materials. This *narrowing of the resource loop* has also been implemented in the case of the magnets, where 20% has been saved by optimising the production, and the content of the most expensive REE used in the magnets has been reduced from 4% to around 1%. At the same time the performance of the magnets has been improved.

The decrease in performance of the magnets over the years is relatively low, and from a technical viewpoint it is possible to remagnetise the magnets and prolong their life time; if it was not for the fact that they are placed in generators at the top of a wind turbine that is frequently placed off-shore.

The decommissioning of wind turbines will become much more common in the future as several established wind turbine parks are around 25 years old. For that reason, *closing the resource loops* becomes interesting and necessary. The recovery process for most materials is relatively straight forward, but the recovery of magnets and blades are more complex. Practical tests were carried out with demagnetisation at the workshops and with the use of the old materials in new magnet production. The findings were that it is possible to dismantle the direct drive generators and access the magnets. The process is rather time consuming and requires heating the magnets, but can still be done in a cost-efficient way compared to the prices of virgin magnet materials. Learning-by-doing at the workshops showed that the costs of recycling magnets were reduced by around 15%. Impurities also have to avoided to secure the quality of the recovered REE, and this creates a potential trade-off related to the coating of the magnets in order to prolong their life time. Finally, few companies are on the European market for recycled magnets materials, and the sale price is dependent on the content of Dy; so, a market for recovered REE has to be created.

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Appendix 1: Design Recommendations to Improve Resource Efficiency

The design recommendations to improve resource efficiency identified in the ECMA 341 standard, Ecodesign Pilot, and from Ijomah et al. (Ijomah et al., 2007) are listed in Table 22.

TABLE 22. Design recommendations to improve resource efficiency based on 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. From Bundgaard (2016: 317-323).

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

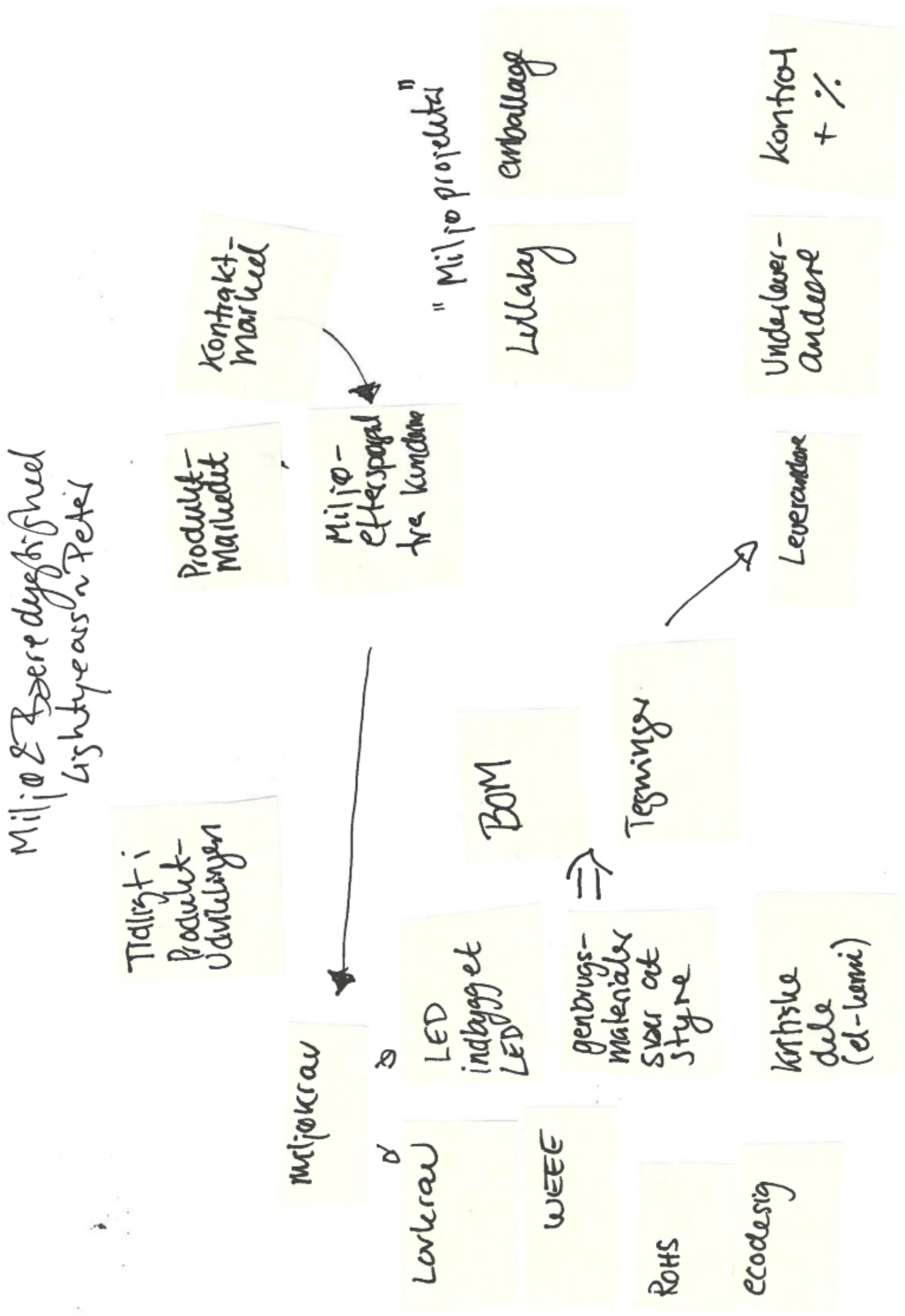
Ensure simple assembly by reduction of parts used	Ecodesign Pilot
Provide for testing and measuring devices for the refurbishing of components	Ecodesign Pilot
Provide for over measure of material with a view to the reuse of components	Ecodesign Pilot
Label components to indicate remaining service life	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 life span 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 batteries shall be considered	Ecma
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

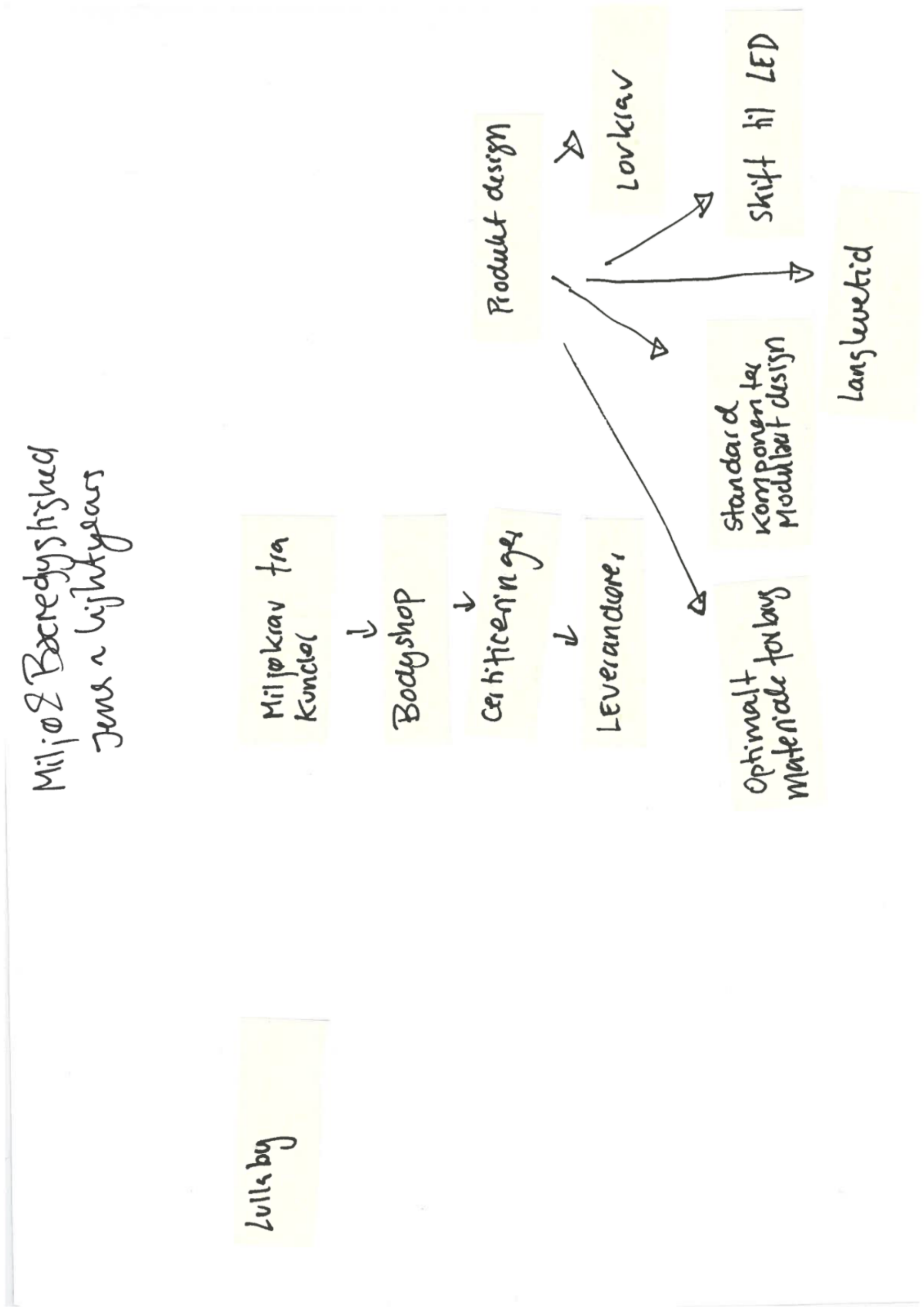
	Ensure that surface coating and base material are suitable for recycling	Ecodesign Pilot, ecma
	Make possible extraction of process materials and unavoidable harmful substances	Ecodesign Pilot
	Take into account end-user's opportunities for disposal and provide for instructions for disposal	Ecodesign 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 material	ecma
	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)

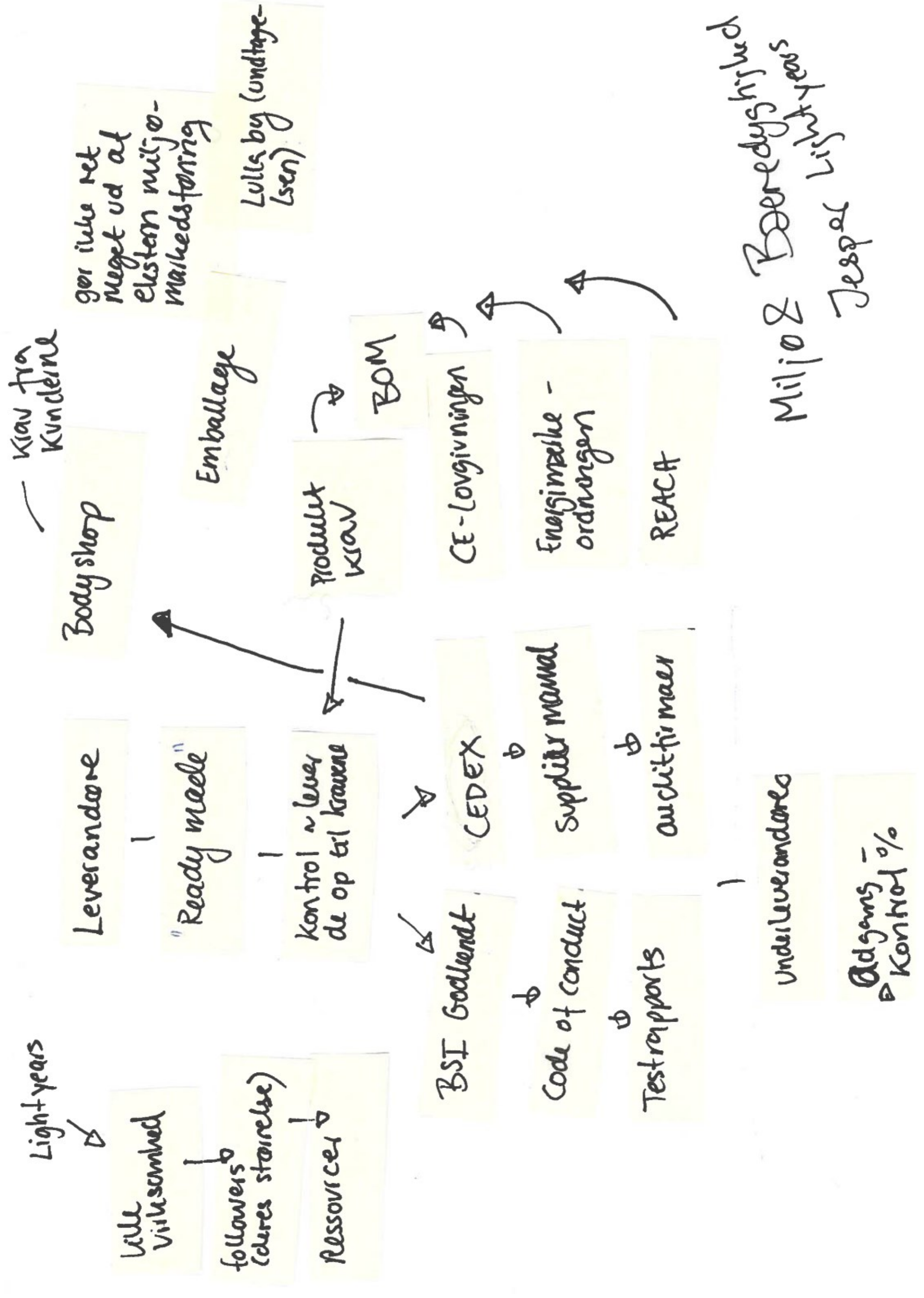
Remanufacture and test components	Use materials that are at least durable enough to survive the refurbishment process	(Ijomah et al., 2007)
	Use materials that do not prevent upgrade and rebuilding of the product	(Ijomah et al., 2007)
	Identify component materials	(Ijomah et al., 2007)
	Use assembly 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 Assemble productsubsystems 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)

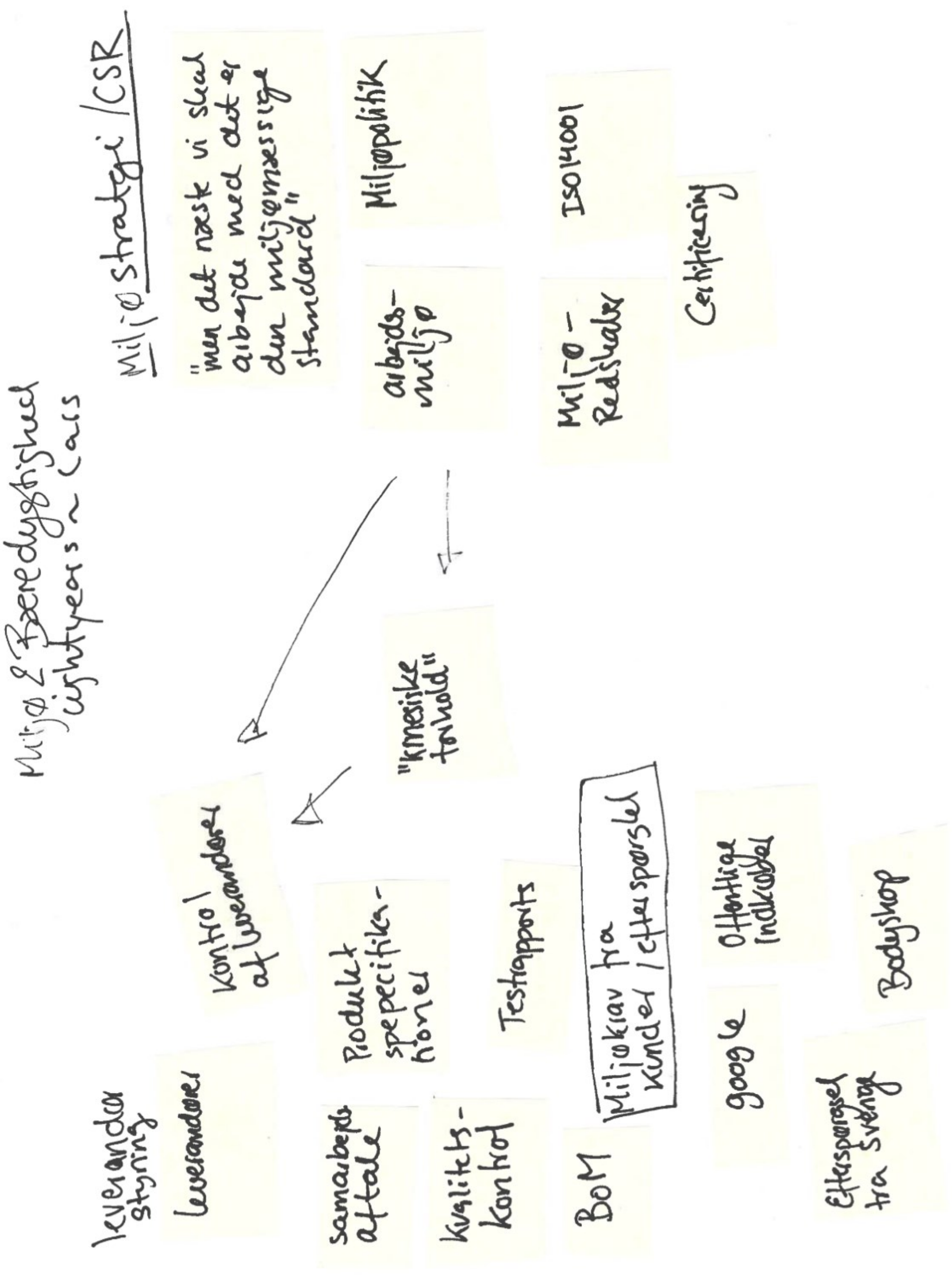
Appendix 2: Individual Causal Maps from the Workshop of Lightyears

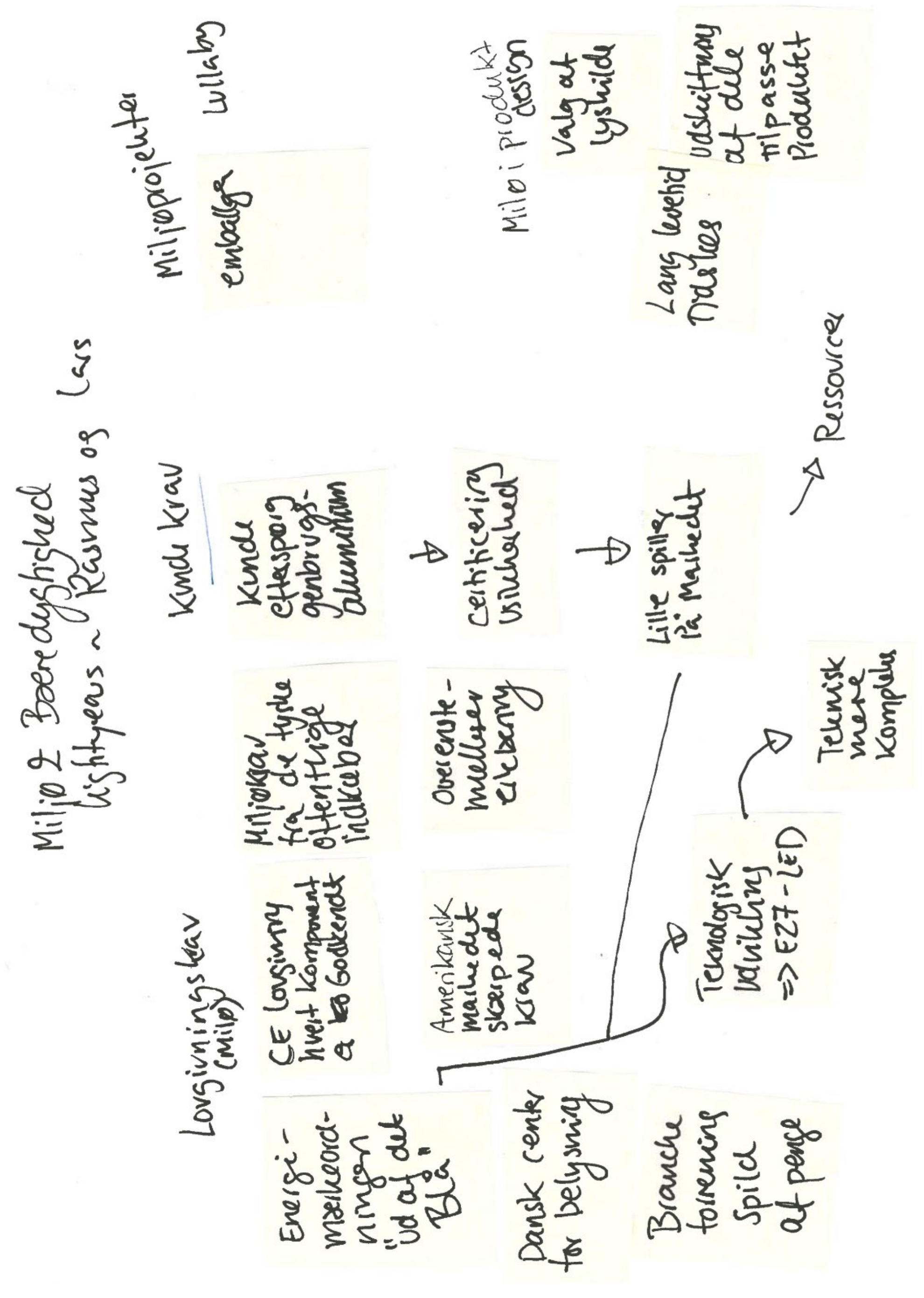


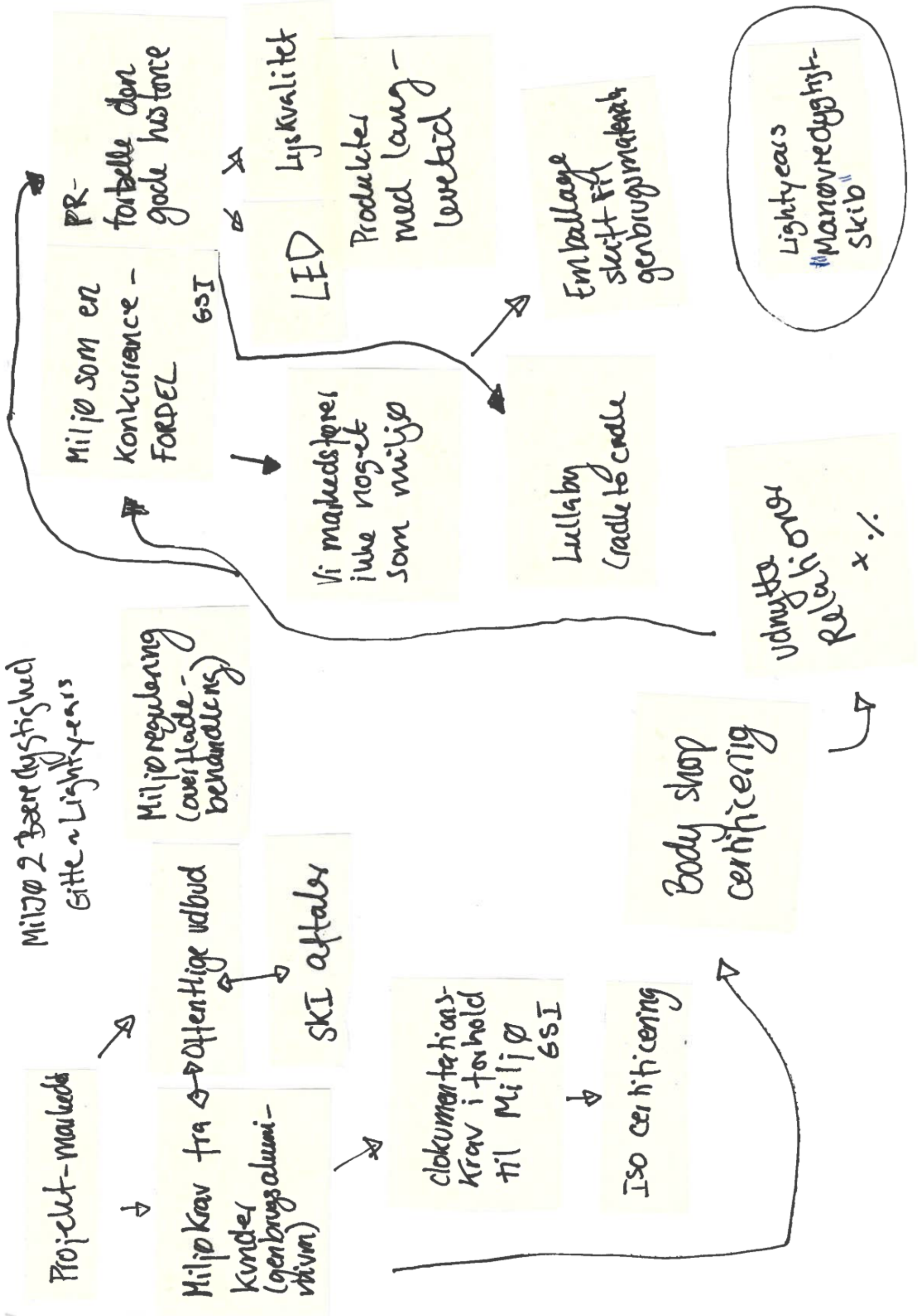


Miljø & Bæredygtighed
Jens & Lightyears
Miljøkrav fra Kunder
Bodyshop
Certificeringer
Leverandører
Lullaby
Produkt design
Lovkrav
Skift til LED
Langlevetid
Standard komponenter
Modulært design
Optimalt materiale forbrug


Miljø & Børnesikkerhed
Jesper Lightyears
Krav fra Kunderne
Bodyshop
Emballage
gør ikke ret meget ud af ekstern miljømarkedsføring
Produkt krav
BOM
CE-lovgivningen
Energimærke-ordningen
REACH
Leverandøre
"Ready made"
CEDEX
Supplier manual
BSI Godkendt
Code of conduct
Testrapports
Underleverandører
Adgangs-Kontrol %
Lightyears
Lille virksomhed
followers (deres størrelse)
Ressourcer


Miljø & Bæredygtighed
Miljø strategi / CSR
"men det næste vi skal arbejde med det er den miljømæssige standard"
Miljøpolitik
ISO14001
Certificering
arbejds-miljø
Miljø-Redskaber
"kinesiske forhold"
Kontrol af leverandører
Produkt specifika-tioner
Testrapports
Miljøkrav fra kunder / efterspørgsel
Offentlige indkøber
Bodyshop
google
Efterspørgsel fra Sverige
leverandør styring
leverandører
samarbejds aftale
Kvalitets-kontrol
BoM


Kunde krav
Lovgivningskrav (miljø)
Miljøprojekter
Miljø i produkt design
Valg af lyskilde
Lang levetid
Dansk center for belysning
Teknologisk udvikling => E27 - LED
Teknisk mere Komplex
Ressourcer
Amerikansk myndighed skærpede krav
CE lovgivning


Miljø 2 Bæredygtighed
Gitte ~ Lightyears
Projekt-marked
Miljøkrav fra kunder (genbrugsaluminium)
Offentlige udbud
SKI aftaler
Miljøregulering (overflade-behandling)
dokumentations-krav i forhold til Miljø GSI
ISO certificering
Body shop certificering
Udnytte Relationer +/-
Miljø som en konkurrence-FORDEL GSI
Vi markedsfører ikke noget som miljø
PR- fortælle den gode historie
LED
Lyskvalitet
Produkter med lang levetid
Emballage skift til
Lullaby Cradle to cradle
Lightyears "Manøvredygtigt skib"

Appendix 3: Presentation Environmental Strategy at Lightyears

AALBORG UNIVERSITY www.aau.dk

Mest miljø for pengene

Miljø som *omkostninger*

- 3P: Polluter Pays Principle – rensning

Miljø som *ressource besparelser*

- 3P: Pollution Prevention Pays – renere produktion

Miljø som *forbedret image*

- Miljøledelse: ISO 14001/EMAS

Miljø som *konkurrencefordele*

- Renere produkter & miljømærkning

Miljø som *fælles ansvarlighed*

- 3P: Profit, People and Planet

3

AALBORG UNIVERSITY www.aau.dk

Miljø- /Bæredygtighedspolitik

1. **Fabrikken**
   - Nedbringe ressourceforbrug og udledninger
   - Overholde lovgivning
   - Løbende forbedringer
2. **Produktet og leverandørkæden**
   - Produktets miljøaspekter (EU krav og evt miljømærkning)
   - Leverandørstyring
   - CSR
3. **Netværk og cirkulærøkonomi + deleøkonomi**
   - Mangesidige samarbejdsrelationer - partnerskaber
   - CSV – creating shared value
   - Doing good by doing new things **with others**

4

AALBORG UNIVERSITY www.aau.dk

NOVAGRAFs miljøpolitik

MED VORES MILJØPOLITIK SIKRER VI:

- at vi kan tilbyde *tryksager*, der er blandt de mest miljøvenlige
- at *kunder*, i det omfang der er ønsker herom, rådgives og vejledes om miljømæssige spørgsmål, herunder spørgsmål om den enkelte tryksags miljøpåvirkning
- at vores *medarbejdere* inddrages i virksomhedens miljøarbejde – og er medbestemmende i arbejdet omkring miljø
- at vi løbende sætter nye *miljømål* og kontrollerer, at målene nåes
- at vi ved *indkøb* bestræber os på at vælge råvarer og hjælpestoffer med mindst mulig miljøpåvirkning
- at lade miljøhensyn veje tungt, når vi *investerer* i ny teknologi og udpeger nye *leverandører*
- at vi som en selvfølge overholder lovgivningen og *informerer vores interesseparter om vores miljøarbejde*

5

AALBORG UNIVERSITY www.aau.dk

Bæredygtighed i leverandørkæden

Global Compact

Tilslutningen til Global Compact betyder, at vi vil arbejde for disse ti principper

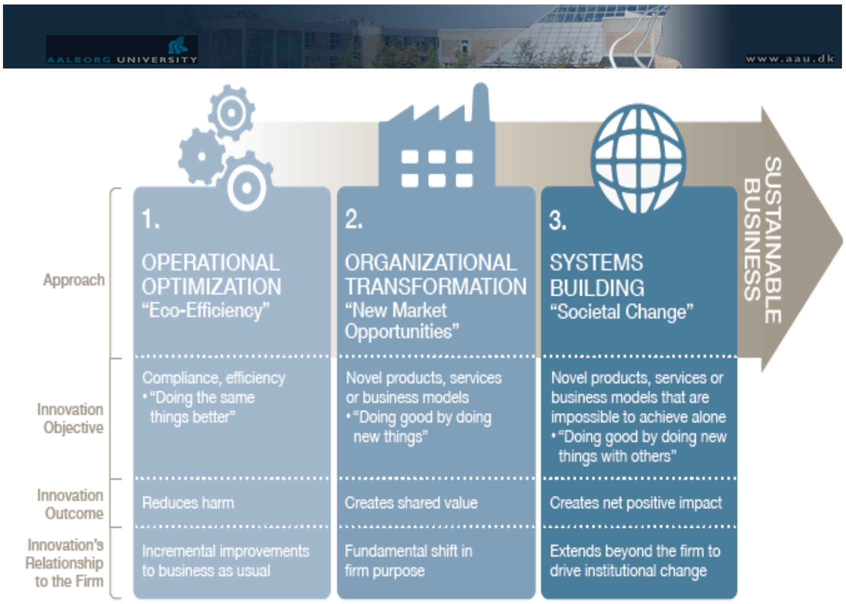
1. Vi vil støtte og respektere de internationale menneskerettigheder inden for vores indflydelsesområde
2. Vi vil sikre, at vi ikke er medskyldige i brud på menneskerettigheder
3. Vi vil opretholde medarbejdernes ret til at organisere sig og anerkende deres ret til kollektive forhandlinger
4. Vi vil aktivt kæmpe mod alle former for tvangsarbejde
5. Vi vil aktivt kæmpe mod børnearbejde
6. Vi vil afskaffe diskrimination på arbejdspladsen
7. Vi vil støtte forebyggende tiltag i forhold til de miljømæssige udfordringer
8. Vi vil tage initiativer til at fremme større miljømæssig ansvarlighed
9. Vi vil støtte udvikling og spredning af miljøvenlige former for teknologi
10. Vi vil arbejde imod korruption, herunder afpresning og bestikkelse.

We strive to leave the world better than we found it, and that means considering everything we do—from the design of our products to the processes we use to make and recycle them. Our passion for innovation is also reflected in how we think about environmental responsibility. Our goal is to make not just the best products in the world, but the best products for the world.

Apple's 2015 Environmental Responsibility Report, covering fiscal year 2014, highlights the progress we've made. We have set three priorities where we believe Apple can make the most impact:

- Reduce our impact on climate change by using renewable energy sources and driving energy efficiency in our products.
- Conserve precious resources so we all can thrive.
- Pioneer the use of greener materials in our products and processes.

This report details how we are approaching each of these priorities and highlights some of our key accomplishments to date.



Forretningsmodeller og cirkulær økonomi

Forretningsmodeller og cirkulær økonomi

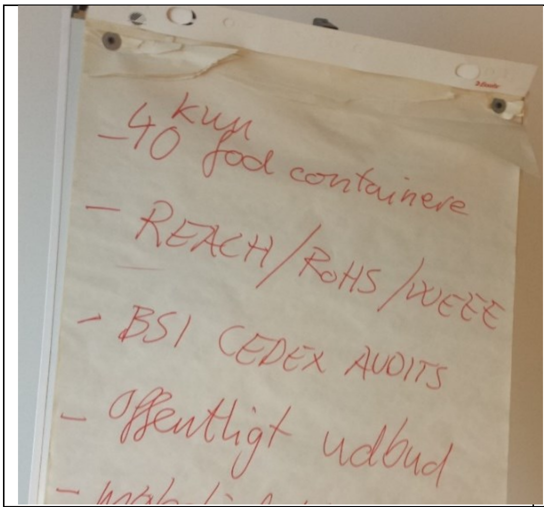
- Re-pair og vedligehold
- Re-use / Re-sale
- Re-trofit / Re-furbish
- Re-manufacturing
- Re-cycle og materialegenindvinding

Forretningsmodeller og produkt-service systemer

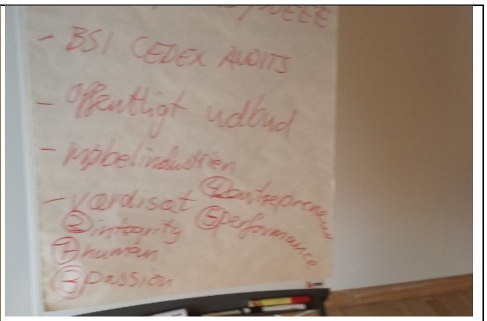
- Leasing **(deleøkonomi)**
- Efter-salg (service og opgraderinger)
- Functional sales (ESCO, RESCO, osv)
- Product sharing

9

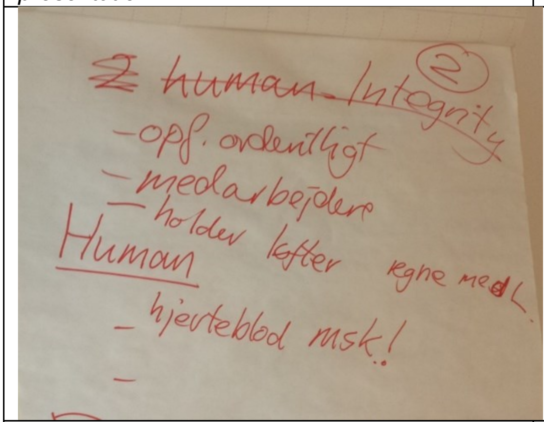
Appendix 4: Photo Documentatiuon of the Workshop at Lightyears



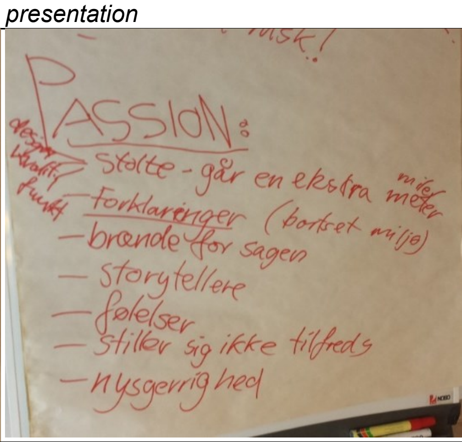
Notes from Lars Østergaard Olsens presentation



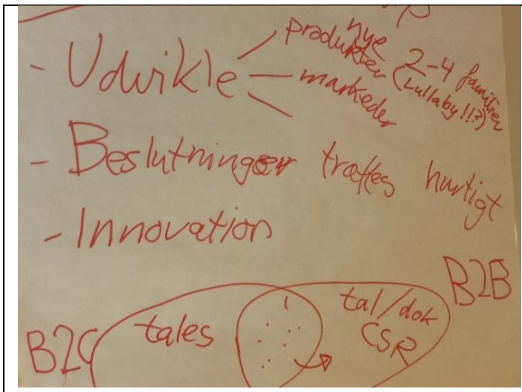
Notes from Lars Østergaard Olsens presentation



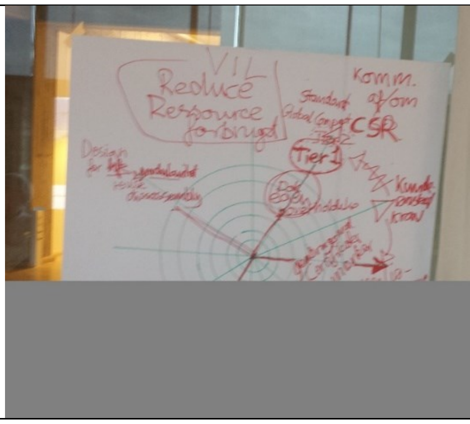
Notes from Lars Østergaard Olsens presentation



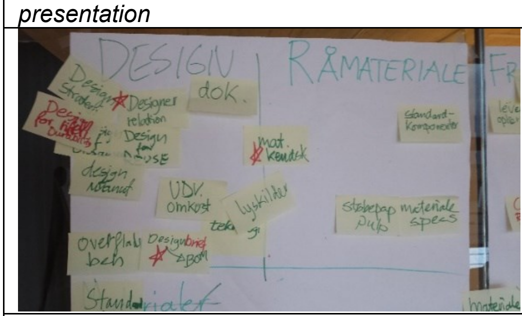
Notes from Lars Østergaard Olsens presentation



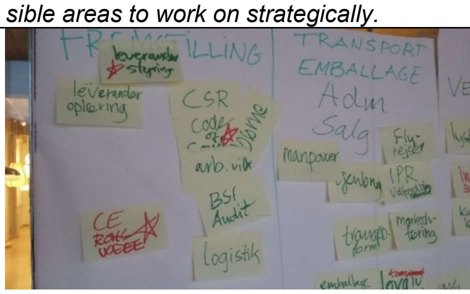
Notes from Lars Østergaard Olsens presentation



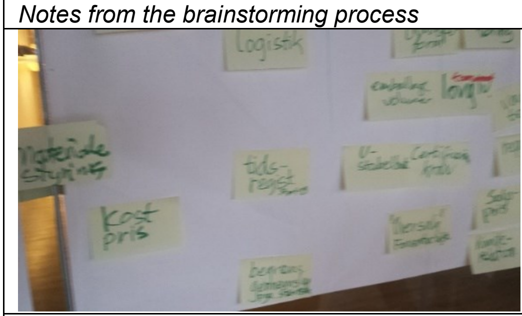
A photo of the mapping of Lightyears possible areas to work on strategically.



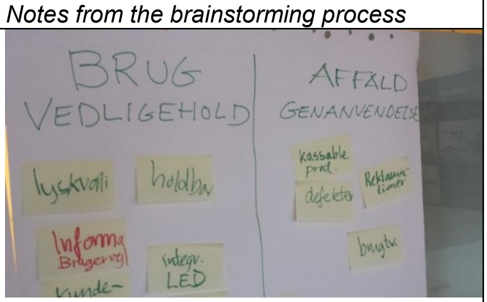
Notes from the brainstorming process



Notes from the brainstorming process



Notes from the brainstorming process



Notes from the brainstorming process

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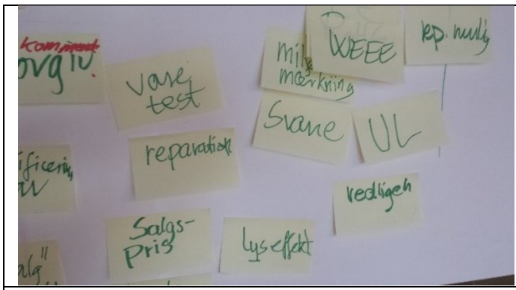
<tr><td>
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<tr><td>Notes from the brainstorming process</td><td>A photo of the mapping of Lightyears possible areas to work on strategically.</td></tr>
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<tr><td>A photo of the mapping of Lightyears possible areas to work on strategically.</td><td></td></tr>
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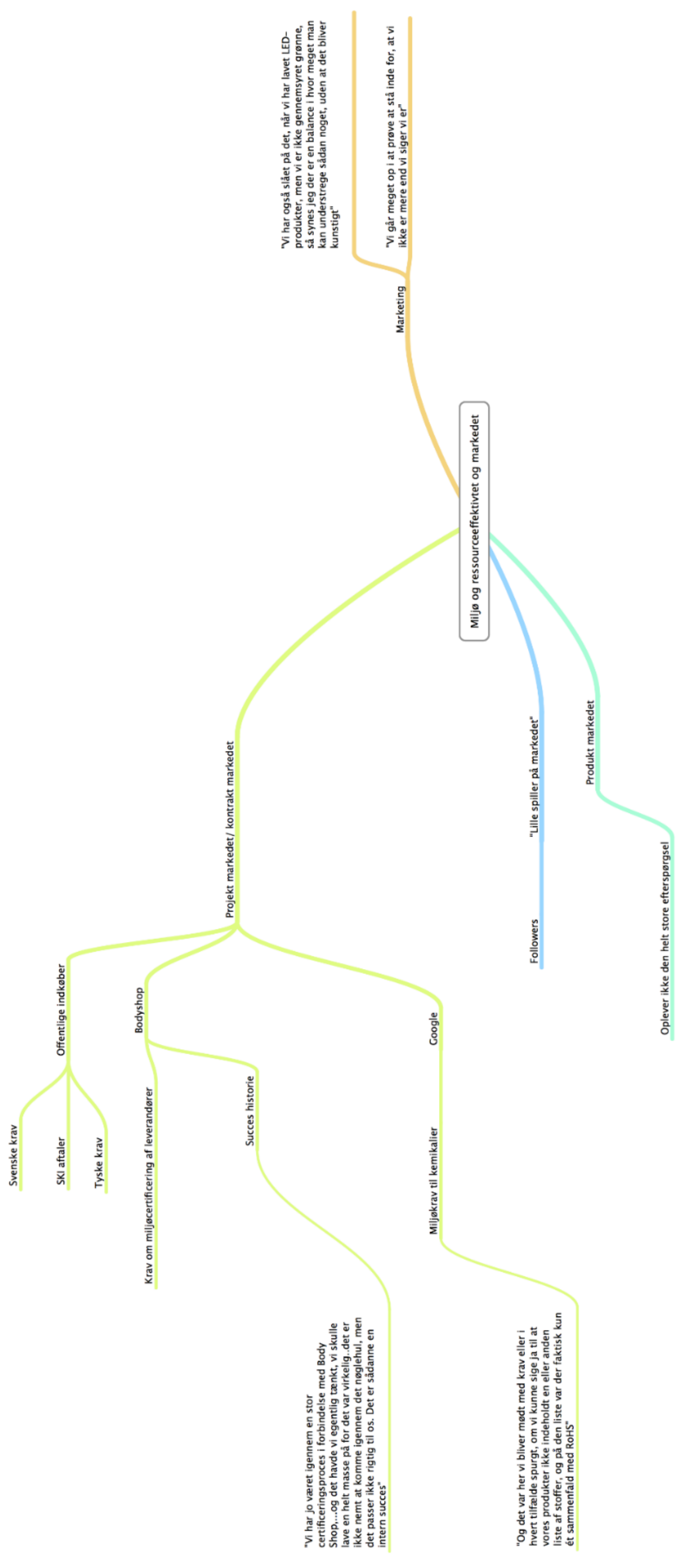
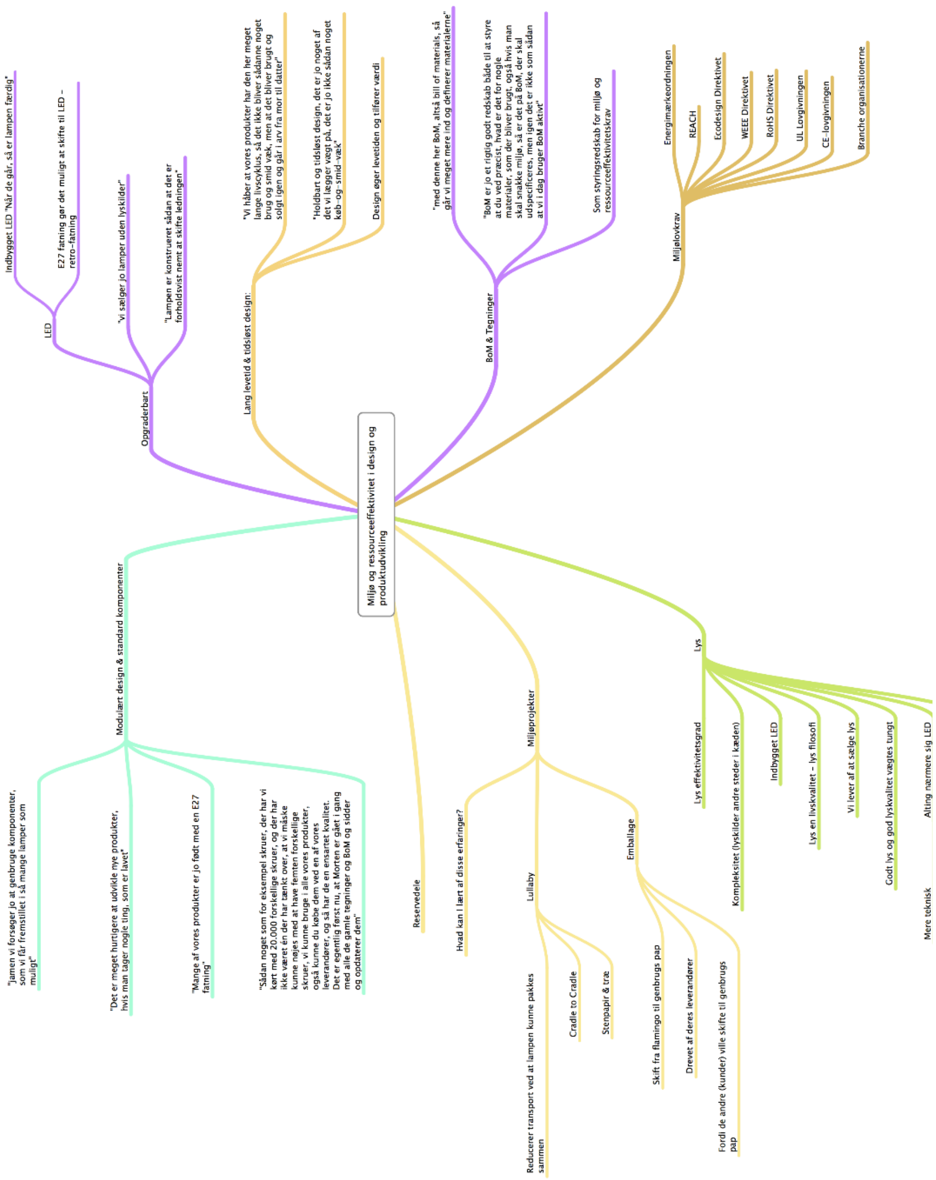
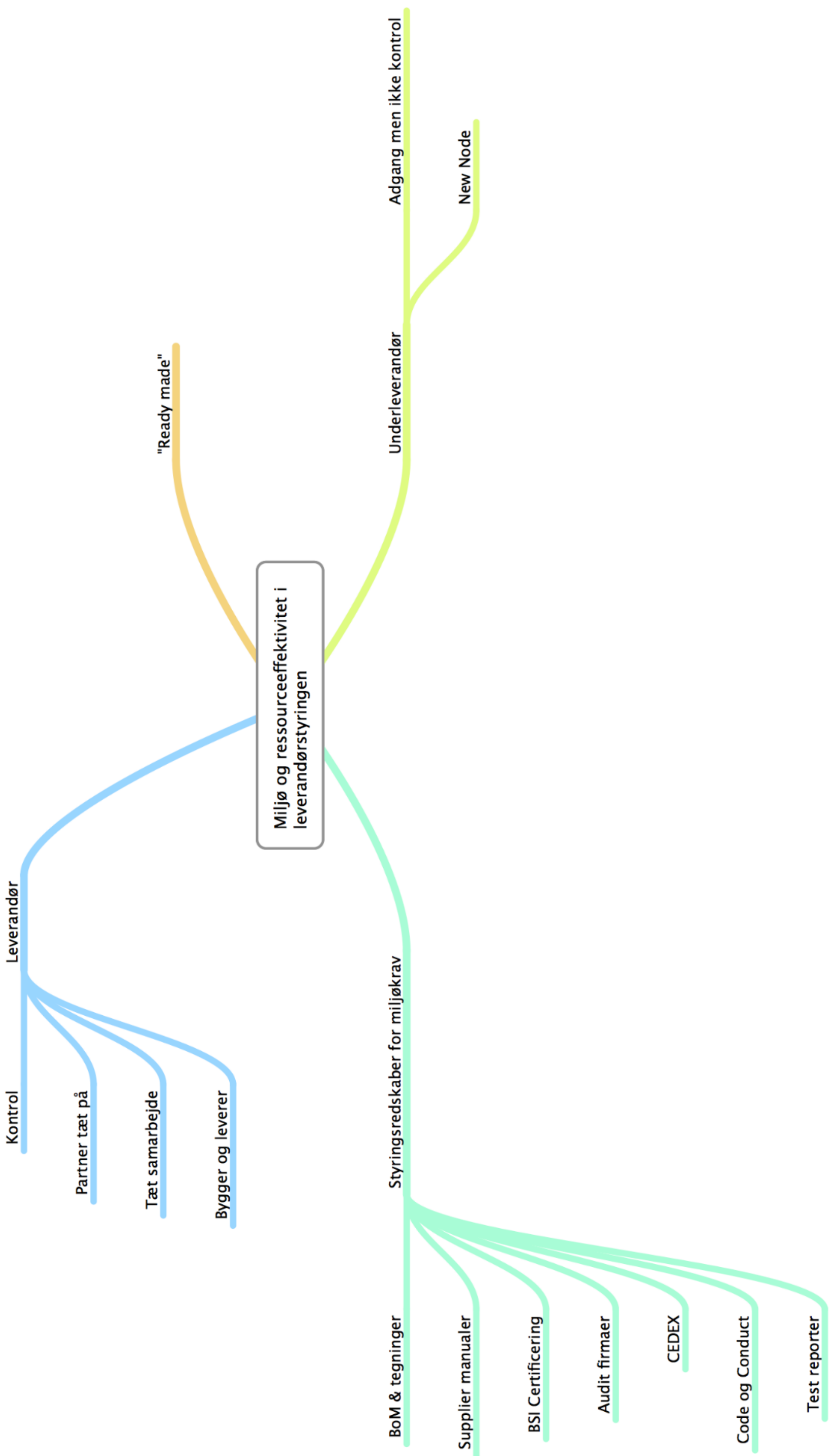
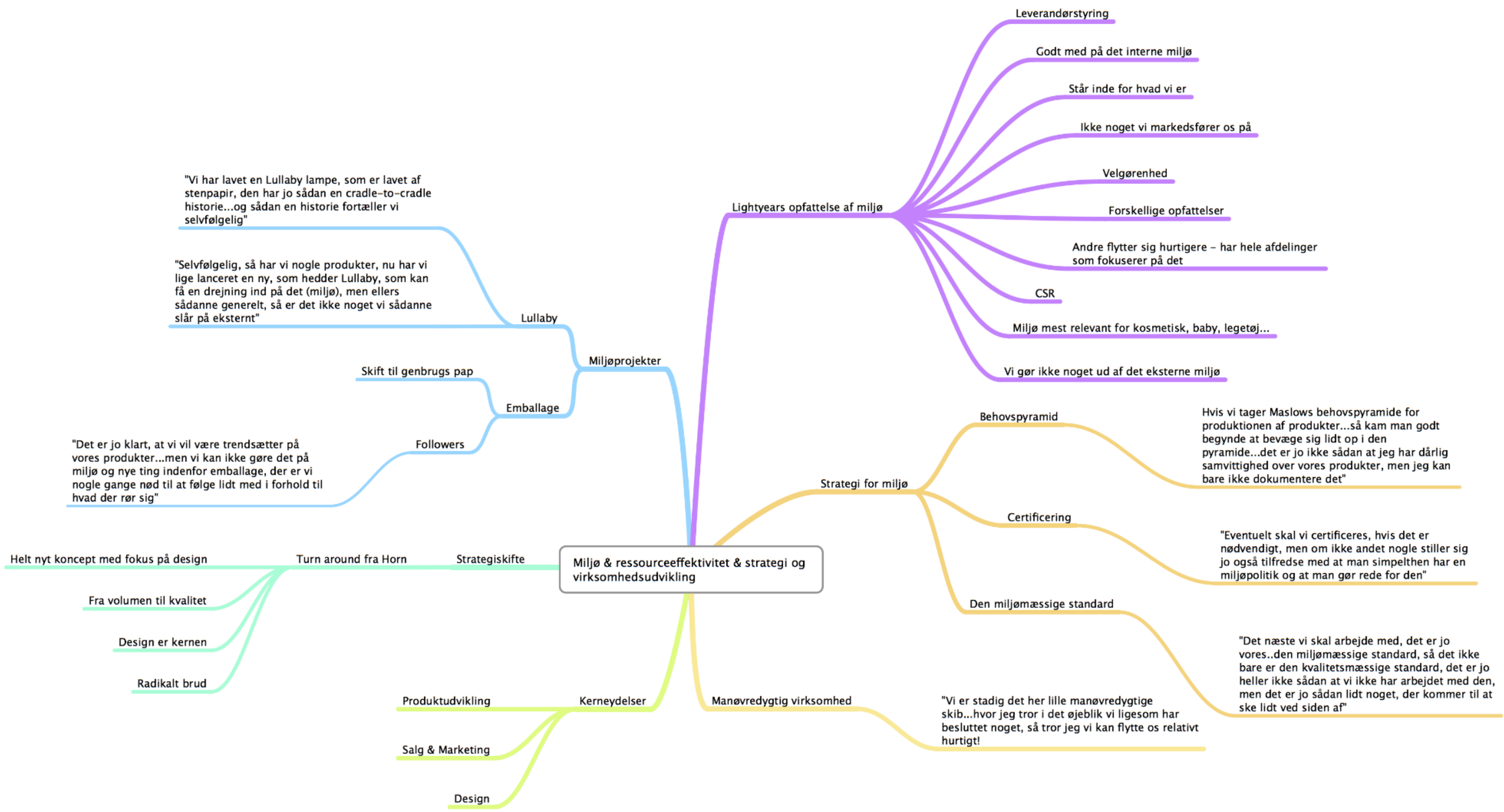
Appendix 5: The Merged Casual Maps from Lightyears




Miljø og ressourceeffektivitet i design og produktudvikling
Opgraderbart
LED
Indbygget LED "Når de går, så er lampen færdig"
E27 fatning gør det muligt at skifte til LED – retro-fatning
"vi sælger jo lamper uden lyskilder"
"Lampen er konstrueret sådan at det er forholdsvist nemt at skifte ledningen"
Lang levetid & tidsløst design:
"Vi håber at vores produkter har den her meget lange livscyklus, så det ikke bliver sådanne noget brug og smid væk, men at det bliver brugt og solgt igen og går i arv fra mor til datter"
"Holdbart og tidsløst design, det er jo noget af det vi lægger vægt på, det er jo ikke sådan noget køb-og-smid-væk"
Design øger levetiden og tilfører værdi
BoM & Tegninger
"med denne her BoM, altså bill of materials, så går vi meget mere ind og definerer materialerne"
"BoM er jo et rigtig godt redskab både til at styre at du ved præcist, hvad er det for nogle materialer, som der bliver brugt, også hvis man skal snakke miljø, så er det på BoM, der skal udspecificeres, men igen det er ikke som sådan at vi i dag bruger BoM aktivt"
Som styringsredskab for miljø og ressourceeffektivitetskrav
Miljølovkrav
Energimærkeordningen
REACH
Ecodesign Direktivet
WEEE Direktivet
RoHS Direktivet
UL Lovgivningen
CE-lovgivningen
Branche organisationerne
Modulært design & standard komponenter
"Jamen vi forsøger jo at genbruge komponenter, som vi får fremstillet i så mange lamper som muligt"
"Det er meget hurtigere at udvikle nye produkter, hvis man tager nogle ting, som er lavet"
"Mange af vores produkter er jo født med en E27 fatning"
"Sådan noget som for eksempel skruer, der har vi kørt med 20.000 forskellige skruer, og der har ikke været én der har tænkt over, at vi måske kunne nøjes med at have femten forskellige skruer, vi kunne bruge i alle vores produkter, også kunne du købe dem ved en af vores leverandører, og så har de en ensartet kvalitet. Det er egentlig først nu, at Morten er gået i gang med alle de gamle tegninger og BoM og sidder og opdaterer dem"
Reservedele
Miljøprojekter
Hvad kan I lært af disse erfaringer?
Lullaby
Reducerer transport ved at lampen kunne pakkes sammen
Cradle to Cradle
Stenpapir & træ
Emballage
Skift fra flamingo til genbrugs pap
Drevet af deres leverandører
Fordi de andre (kunder) ville skifte til genbrugs pap
Lys
Lys effektivitetsgrad
Kompleksitet (lyskilder andre steder i kæden)
Indbygget LED
Lys en livskvalitet – lys filosofi
Vi lever af at sælge lys
Godt lys og god lyskvalitet vægtes tungt
Alting nærmere sig LED
Mere teknisk


Miljø og ressourceeffektivitet i leverandørstyringen
Leverandør
Kontrol
Partner tæt på
Tæt samarbejde
Bygger og leverer
"Ready made"
Underleverandør
Adgang men ikke kontrol
New Node
Styringsredskaber for miljøkrav
BoM & tegninger
Supplier manualer
BSI Certificering
Audit firmaer
CEDEX
Code og Conduct
Test reporter



Miljø & ressourceeffektivitet & strategi og virksomhedsudvikling
Lightyears opfattelse af miljø
Leverandørstyring
Godt med på det interne miljø
Står inde for hvad vi er
Ikke noget vi markedsfører os på
Velgørenhed
Forskellige opfattelser
Andre flytter sig hurtigere – har hele afdelinger som fokuserer på det
CSR
Miljø mest relevant for kosmetisk, baby, legetøj...
Vi gør ikke noget ud af det eksterne miljø
Strategi for miljø
Behovspyramid
Hvis vi tager Maslows behovspyramide for produktionen af produkter...så kam man godt begynde at bevæge sig lidt op i den pyramide...det er jo ikke sådan at jeg har dårlig samvittighed over vores produkter, men jeg kan bare ikke dokumentere det"
Certificering
"Eventuelt skal vi certificeres, hvis det er nødvendigt, men om ikke andet nogle stiller sig jo også tilfredse med at man simpelthen har en miljøpolitik og at man gør rede for den"
Den miljømæssige standard
"Det næste vi skal arbejde med, det er jo vores..den miljømæssige standard, så det ikke bare er den kvalitetsmæssige standard, det er jo heller ikke sådan at vi ikke har arbejdet med den, men det er jo sådan lidt noget, der kommer til at ske lidt ved siden af"
Manøvredygtig virksomhed
"Vi er stadig det her lille manøvredygtige skib...hvor jeg tror i det øjeblik vi ligesom har besluttet noget, så tror jeg vi kan flytte os relativt hurtigt!
Kerneydelser
Produktudvikling
Salg & Marketing
Design
Strategiskifte
Turn around fra Horn
Helt nyt koncept med fokus på design
Fra volumen til kvalitet
Design er kernen
Radikalt brud
Miljøprojekter
Lullaby
"Vi har lavet en Lullaby lampe, som er lavet af stenpapir, den har jo sådan en cradle-to-cradle historie...og sådan en historie fortæller vi selvfølgelig"
"Selvfølgelig, så har vi nogle produkter, nu har vi lige lanceret en ny, som hedder Lullaby, som kan få en drejning ind på det (miljø), men ellers sådanne generelt, så er det ikke noget vi sådanne slår på eksternt"
Emballage
Skift til genbrugs pap
Followers
"Det er jo klart, at vi vil være trendsætter på vores produkter...men vi kan ikke gøre det på miljø og nye ting indenfor emballage, der er vi nogle gange nød til at følge lidt med i forhold til hvad der rør sig"

Designing out Waste

The objective of the MUDP-project was to disseminate already existing knowledge on how to design products more resource efficiently through ecodesign; and to engage in a practice-based research to further develop and disseminate methods for resource efficient design. More specifically the project aimed to increase resource efficiency and to convert waste into a resource. Through the examination of four case studies, the current project found that ecodesign tools developed 20-25 years ago are still relevant, waste managers are interested in improved design but are not proactive, and that collaboration between product designers and waste handlers is non-existent. Additionally, this project identifies the role of refurbishment companies as bridge-builders and sees the potential for new business opportunities related to high product quality, durability and reparability in combination with business models such as leasing and product service.

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