Danish Ministry of the Environment
Environmental Protection Agency

DANISH WEEE MARKET

A study of markets, actors and technologies in treatment of WEEE in Denmark

Environmental project No. 1643, 2015

Title:

Danish WEEE Market

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Published by:

The Danish Environmental Protection Agency
Strandgade 29
1401 Copenhagen K
Denmark
www.mst.dk/english

Year:

2015

ISBN no.

978-87-93283-63-3

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Summary and conclusions

This report concerns the recycling of waste from electrical and electronic equipment. Electrical and electronic equipment is a very heterogeneous group of products ranging from large household appliances to small mobile devices. Some are incredibly complex – others more simple. Critical metals and rare earths are necessary to produce electrical and electronic equipment. In many cases however, there are no natural sources for these raw materials in Europe. Consequently, the materials are imported from competing economies, notably China. This has put "urban mining" and the recovery of critical metals and rare earths on the agenda.

With this analysis, we set out to gain a better understanding of the playing field for the actors involved in what is labelled "the golden triangle": EEE producers, technology suppliers and WEEE treatment companies. What are the values to be gained from material recycling? Who are the players in the golden triangle and who are their competitors? Which technologies can be used in recovery of the values? This understanding is necessary for all involved actors to better identify potential business opportunities in an enhanced exploitation of the resource potential in WEEE.

The Danish Technological Institute has estimated the value of the materials in the WEEE for products in category 3 IT and tele equipment, category 4 consumer equipment and photovoltaic panels, and category 9 monitoring and control instruments. The estimate is based on the following data for individual product types in the categories 1) amount of critical ressources as well as other materials per kilo product, 2) the marketed amount the product in Denmark 3) the sales prices for each material in the product (2014 prices). The total value of the materials in the categories above is then dependent on demand for the materials, the composition of the products and the amount of WEEE.

TABLE 1 VALUE OF MATERIALS IN WEEE CATEGORIES BASED ON MARKETED PRODUCTS IN DENMARK (MILLIONS DANISH KRONERS)

	Selected WEEE Categories		
	Products in category 3 IT and tele equipment	Products in category 4 Consumer equipment and photovoltaic panels	Products in category 9 Monitoring and control instruments
Material value (including plastics, iron and aluminium)	504	297	38-42
Value of critical materials	394	131	17-33
Scenario 1 (low loss)			
Value of critical materials	73	16	2-6
Scenario 2 (high loss)			
Value of critical materials	162	46	6-14

SOURCE: MATERIAL VALUES IN WEEE CATEGORY 3, 4 AND 9 ESTIMATED BY DANISH TECHNOLOGICAL INSTITUTE.

Scenario 1 is with a low loss of approximately 5% in the mechanical treatment and scenario 2 with a higher loss corresponding to typical values found in the EU (approximately 40% for LCD TVs, 28% for PCs and 39% for mobile phones).

The estimated values for a year based on marketed products are shown in millions of Danish kroners in the table above. For products in category 3 this is 504 million DKK including plastics, iron and aluminium. For critical resources alone, the amount for category 3 is 394 million DKK.

Whether or not materials can be obtained in a quality comparable to the pure materials is unknown. Moreover, the "unknown costs" for extracting the metals and refining must be subtracted to calculate the economy by improved recycling. The recovery rate will depend on collection, organisation and technology in the treatment of WEEE – but it is illustrative of the market size. Two scenarios has been calculated and for both scenarios it is assumed that 100 per cent is collected for recycling in Denmark, although there definitely will be some loss of e.g. small electronics from household waste treated in incineration plants and via other unknown pathways.

- Scenario 1 (Sc1) is a scenario with high recovery and only 5% loss in the mechanical treatment. This treatment could be a situation where some of the most valuable printed circuit boards (PCBs) are separated manually for separate treatment. The magnetic materials (neodymium) are assumed lost with the iron fraction.
- Scenario 2 (Sc2) is calculated with the recoveries shown in (I.Bakas, 2013), who estimated the expected European collection efficiencies and the recovery efficiencies for mechanical treatment and final treatment in melting ovens. The studies show that there is a considerable loss of critical resources during mechanical treatment; reducing the recovery efficiency to 60% for flat screens and mobiles phones, and to 72% for PCs (I.Bakas, 2013).

Thus, for the three categories, depending on treatment methodologies, critical resources of a value of 91 – 222 million Danish kroner can be recovered from Danish WEEE. In addition, plastics, iron and aluminium represent a significant value. Based on data for collected amounts of category 3, 4, 9 (DPA, Dansk producentansvarssystem WEEE og BAT statistik 2010, 2011) it has been assessed that the collected amount of materials corresponds to at least 90% of the marketed amounts. Thus, the potential value is assessed to be close to the value in the marketed products. However, at the moment approximately 50% are exported for treatment elsewhere. When assuming a loss in the collection of 10% and using the present market situation, only 45% of the products are available for improved recycling in Danish companies. This leads to corresponding lower values of the critical resources of 45-111 million DKK.

The most important critical resources depend on the types of products. For high tech products like computers, game consoles, mobile phones, LCD TVs and digital cameras the major loss is from gold. Examples of other significant losses are tantalum in capacitors and indium in large flat screens.

There are 1575 producers and importers of electric and electronic products listed in the DPA register. It has long been discussed if the extraction of resources from WEEE could be improved by for instance labelling components or through take-back arrangements directly between the producer and the WEEE treatment facilities. However, the analysis of the EEE registered companies showed that the vast majority are wholesalers and thus importers of products. This means that complicated information on components has to travel from sub-suppliers (that may change frequently) along the value-chain/or material cycle to multinational companies that sell the products globally to Danish importers and then further on to the WEEE- treatment companies and their employees. In addition to this complexity, many of the products change in design and composition with a very high frequency. Establishing financially viable business models for information or take-back arrangements for fast changing products in a global value chain seems to be a task beyond the individual WEEE-treatment company.

Looking at manufacturers based in Denmark, it turns out that that the vast majority of electronics manufacturers are small- and medium-sized enterprises. 158 manufactures have more than 100 employees in Denmark. Size does matter, because large companies are often more professionally organised and have better resources to engage in development work with a slightly longer time horizon. It is with these large Danish-based companies that there may be possibilities of creating business opportunities directly between manufacturers and the recycling industry. We know that these direct closed-loop circuits exist already. However, for competitive reasons these business models are confidential.

The collective schemes have created successful solutions for WEEE, which is collected very efficiently in Denmark. However, at the same time the schemes may intrinsically reduce the incentive for EEE producers to become more involved in exploiting the material resources more efficiently. The producers and importers of electric and electronic products are members of collective schemes that allow the producers to pass on the collection and treating responsibility for the products to these schemes. The cost of a membership in the scheme is the same for everybody involved and therefore the cost can be passed on to consumers without any loss of competitive advantage. This means that the incentive for companies to improve take-back schemes is reduced and there must be a clear financial gain, image gain, etc., before companies put their focus here.

Compared to the international market, the recycling industry in Denmark is very efficient when it comes to collecting electronic waste. The market research firm Frost & Sullivan even expects that the cost of collecting waste will decrease until 2020. Frost & Sullivan also foresees that the value of precious metals will fluctuate but still increase until 2020.

We have met WEEE treatment companies with manual sorting and disassembling lines that appear to be thriving due to a high degree of knowhow on both the material content of the WEEE and a widespread network of customers demanding specific material fractions of high standards. However, most literature indicates that the way forward for most WEEE treatment companies will be in automation and a high degree of technology use to be able to stay competitive in relation to low-cost countries. Technological development is expected to become a driver for increasing revenue in Scandinavia, and thus also in Denmark.

The recycling industry in Denmark has a number of business opportunities that can be effective in increasing the recovery of materials from WEEE. The opportunities are more or less intertwined:

- **Utilising the 'family'**: Companies that are part of an international family (Averhoff and Stena) could collaborate more closely internally across national borders). Specialisation in WEEE treatment processes can increase profitability, and being part of a large company means that financing is easier than for an SME. There is no guarantee that technologies and employment will be placed in Denmark.
- **Export to other EU Member States**[1]: Not all electronic waste is treated in Denmark. If, for instance, German or Swedish waste processors can process electronic waste more efficiently due to economies of scale, lower wages, or technologies that are more efficient, etc., the best business option could be to sell the waste. From a global or European

[1] The Regulation (EC) No 1013/2006 on shipments of waste applies to shipments of wastes for disposal and for recovery, as well as to hazardous and "green-listed" non-hazardous wastes. The shipment of hazardous wastes and of wastes destined for disposal is generally subject to notification procedures with the prior written consent of all relevant authorities of dispatch, transit and destination. However, as a rule, the shipment of 'green-listed' wastes for recovery within the EU and OECD does not require the consent of the authorities (See http://ec.europa.eu/environment/waste/shipments/index.htm). For shipments of waste for recovery within the EU, Member States have more limited possibilities for objecting to imports and exports (EEA report 1/2009: Waste without borders in the EU?). However, this analysis does not explicitly assess the regulatory framework.

resource point of view this is an excellent solution. However, from a national Danish point of view it costs jobs, revenue and knowhow.

- **Import from other EU Member States**: For the recovery companies, permanent agreements made with foreign collectors would be an indispensable resource for electronics waste.
- **Specialisation**: Specialisation is already happening today at the plants, and for some companies the business model is to collect and export WEEE to specialised plants within the company in Sweden, Germany or perhaps Poland. It is possible that there are additional specialisation options. A strong specialisation may mean that some categories of electronic waste may even be imported to Denmark for further dismantling or treatment - while others are exported. Possible specialisation could be knowhow on automated extracting of valuable electronic components from circuit boards such as capacitors with tantalum or ICs with gold. Other specialisations could be highly efficient and automated pre-sorting facilities to help recyclers make even cleaner fractions of WEEE for further processing– e.g. iPhone only or notebooks only. Both innovative technologies and a changed business model are necessary, but if WEEE or part of the WEEE can be treated more efficiently with a profit, then WEEE is also a valuable raw material that can be imported just as it is exported today.
- **International orientation**. The recycling industry can find opportunities by looking at the international market of technology vendors. There appears to be a strong concentration of technology providers along the Rhine from southern Germany to the Benelux countries and across to the UK. These companies do not necessarily interact with Danish technology providers yet. Moreover, as observed by Frost & Sullivan, European technology suppliers are struggling and competing to find cost-effective automation technologies as well. For technology suppliers in Denmark, this means that they must ensure that their solutions are state-of-the-art and that they maintain a close dialogue with the recycling industry. The companies along the Rhine will have a competitive advantage over Danish technology suppliers with their access to larger markets and employees with automation or metallurgical knowhow.
- **Delivery of clean fractions**. A more precise and targeted sorting can open up new business opportunities. It may require new technology, and/or more dialogue. Clean fractions are not only related to precious or critical metals but also glass, metals and chemical substances. Knowhow on how to dismantle combined with knowhow on who demands what and when is profitable. Therefore, both market insight and technological insight are required.
- **Better cooperation**: There may be business opportunities in streamlining the collection of electronic waste and the first rough sorting into categories. The definition of the categories that are appropriate and can add most value must be determined in close dialogue with the recycling industry and be based on the industry's market knowledge.
- **Attracting Investments**. The Scandinavian market is dominated by the three companies, Kuusakoski, Stena and Sims. This means that it can be difficult for small businesses to attract the necessary capital and knowhow to stay competitive. For small businesses, there are business opportunities to be had by engaging in international relations with major players, and eventually mergers may become necessary. While this can be positive from a company perspective, there is no guarantee that technologies and workplaces will be placed in Denmark.

To help WEEE treatment companies to a higher degree of automation and a more efficient technology use, technology suppliers are needed.

We have shown that technologies for automatic sorting and processing of electronic waste are being intensely researched throughout the world. Solutions may turn up from unexpected corners since the technologies used for electronic waste can also be used in many other industries, and vice versa. The technologies differ, but many evolve around robotics, vision solutions, etc. Major technological developments appear to be taking place in many parts of the world. In terms of patenting, Japan and China have been particularly active. It is an open question whether we in Denmark will have access to world-class technologies in the long term, and if not how this can be attained. Very few

Danish companies (7) hold patents relating to processing of electronic waste. This indicates that to gain a competitive advantage, Danish companies must work with companies in other industries or with international partners.

So far, Danish companies are succeeding in combining technologies from international partners into unique solutions that are tailor-made for clients. Clearly, patenting and innovative technology development is not the only successful business model, but without the IPR-protection Danish companies must be very innovative in their combination and implementation of technological solutions. Moreover, it should be noted that not all technological innovations are patented.

Danish technological suppliers seem to thrive without their own technological research and patents. The key to success is the ability to understand what the clients need, develop innovative tailor-made systems, and combine existing technologies into efficient solutions. Without the IPR protection from own patented technologies the Danish technology suppliers can only stay ahead of the competition by maintaining a close relationship with their clients and using state-of-the art technologies.

The international technology suppliers we have identified are located mainly in Europe's industrial belt in an oblique line from Manchester in England and then along the Rhine through the Benelux countries as well as Germany, Switzerland and Austria, ending along the Po River in Italy. They are also found in Norway and Sweden. For the Danish players, this may be beneficial, as they are geographically close to Denmark, and it might be here that new state-of-the-art business partners can be found for all Danish players in the network “the golden triangle”.

For suppliers of technology there may be attractive business opportunities in cooperating, especially with the WEEE-treatment industry. The suppliers have experience with automation in a range of sectors and the challenge is probably to establish technological solutions that are financially viable. The WEEE treatment industry can only find these solutions on its own to a limited degree. It will need technology suppliers with an international orientation and dedication to find and adapt technologies to fit the needs of the WEEE treatment industry.

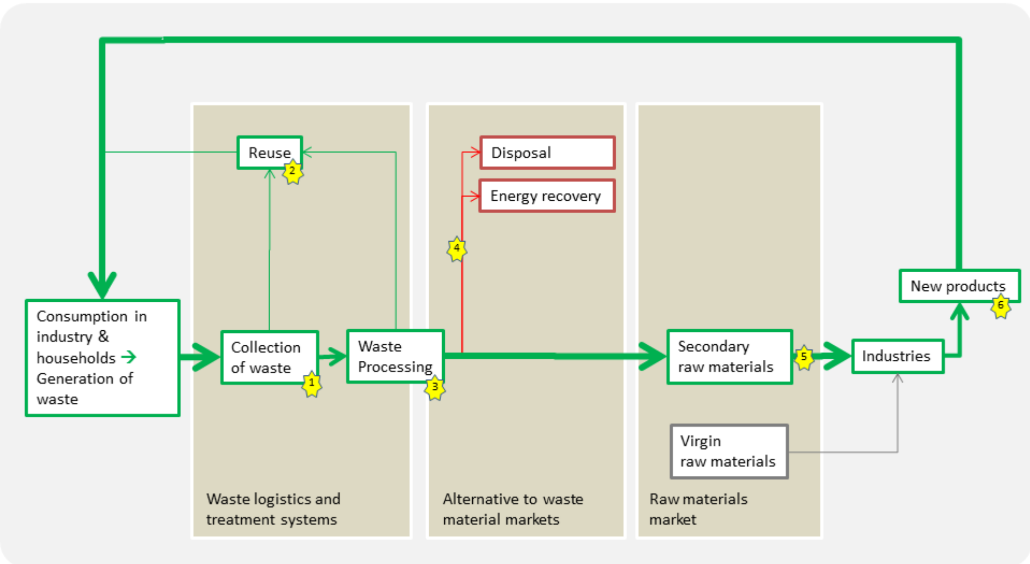
The reports from Frost & Sullivan document that the growth rates of the WEEE treatment industry in Europe are higher than those of the general economy. This is noticed by their international competitors, and developing attractive automation solutions for the WEEE industry may turn out to be very profitable for the first movers. With the intense international research, the merging of players, the political attention, the scarcity of resources and the availability of WEEE, there is no reason to believe that the international competition to find automated solutions will cease.

1. Introduction

High growth rates in the BRIC economies (Brazil, Russia, India and China) increase the demand for raw materials, also for electrical and electronic equipment. Access to raw materials may be limited for natural reasons (depletion of sources) or for economic reasons (monopoly, exclusivity). Access to raw materials is paramount to the industry and ultimately for growth and welfare. As a result, access to raw materials is high on the agenda in European (as well as Danish) politics for sustainability, competitiveness and security reasons. Concepts such as cradle-to-cradle, closed-loop waste as a resource, cascading of materials, industrial symbiosis and circular economy are all perspectives on how to use the raw materials that we have access to repeatedly.

A recent study for the European Commission on waste as a resource (Danish Technological Institute, Ecorys, CRI, 2013) used a diagram to illustrate the circular economy (Figure 1). The diagram illustrates how raw materials flow from virgin raw materials into products, into waste and after processing into secondary raw materials, which in turn are used as resources again. In a perfect circular economy, the material is circulated perfectly thus reducing the need or dependence on raw materials. The challenge is to reduce the loss of material to a minimum and keep as much as possible in the cycle. Material loss can stem from ineffective collection systems, technological challenges in restoring the material and its natural properties, or losing the material to energy recovery or simple disposal.

FIGURE 1: DIAGRAM FOR THE PRINCIPLE OF THE CIRCULAR ECONOMY



This graphic presents the overall principle of the circular economy in a global overview. In the report the graphic will be used to illustrated the flow of materials (green line) from new products to consumption and further through the waste logistics and treatment systems before they re-enter the raw materials market as secondary raw materials. Some materials and products are reused or refurbished before reaching end of life. Other materials will be disposed or recovered as energy (red lines) before reaching the raw materials market and thus be lost to the circular economy. Green flows will be expanded and red flows reduced in a circular economy.

The stars refers to "hot spots" in the flow, where the study has identified barriers or potentials for a more efficient circulation of raw materials.

SOURCE: DANISH TECHNOLOGICAL INSTITUTE; PRESENTED IN 'WASTE AS A RESOURCE' (DANISH TECHNOLOGICAL INSTITUTE, ECORYS, CRI, 2013)

This report concerns recycling of waste from electrical and electronic equipment (EEE), i.e. key products in modern industrialised societies. EEE is a very heterogeneous group of products ranging from large household appliances to small mobile devices. Some are incredibly complex – others more simple. A number of critical metals and rare earths are often necessary to produce EEE. In many cases there are no natural sources for these raw materials in Europe. Consequently, they have to be imported from competing economies. However, the critical metals and rare earths can be found in the EEE products or components that we import and use. Thus, an opportunity for Europe to gain access to the critical metals and rare earths is to recycle the waste from electrical and electronics equipment (WEEE).

If the raw materials can be extracted from WEEE after use, the pressure of finding virgin raw materials will be reduced. This will improve sustainability, competitiveness and growth in European economies.

The interest in extracting raw materials from WEEE (sometimes also labelled as 'urban mining') is present all over Europe and is illustrated by the expanding capacity in Europe to treat WEEE. A recent report on waste as a resource in Europe shows that the European WEEE management industry includes dismantlers and treatment as well as end-processors (extraction in highly specialised metal refineries). Due to the ever-growing quantities of WEEE and the inherent market possibilities, end-processing facilities are expanding. In 2011, the German Aurubis Group expanded its total recycling capacity from 275,000 tonnes to 350,000 tonnes per year. The recycling capacities at Boliden in Sweden are currently undergoing a considerable expansion from 45,000 tonnes to 120,000 tonnes of WEEE per year. In Belgium, Umicore processes over 350,000 tonnes of raw material (all kinds of WEEE) every year (Buchert et al., 2012). Consequently, considerable plant capacity for recycling of precious and critical metals is available and is currently being expanded. (Danish Technological Institute, Ecorys, CRI, 2013).

The market only has a few, large companies capable of end-processing WEEE and none of them is in Denmark. In Denmark, WEEE management includes dismantlers and pre-processers (such as DCR, DanWEEE or Averhof). There are thousands of dismantlers and hundreds of pre-processors in Europe as a whole.

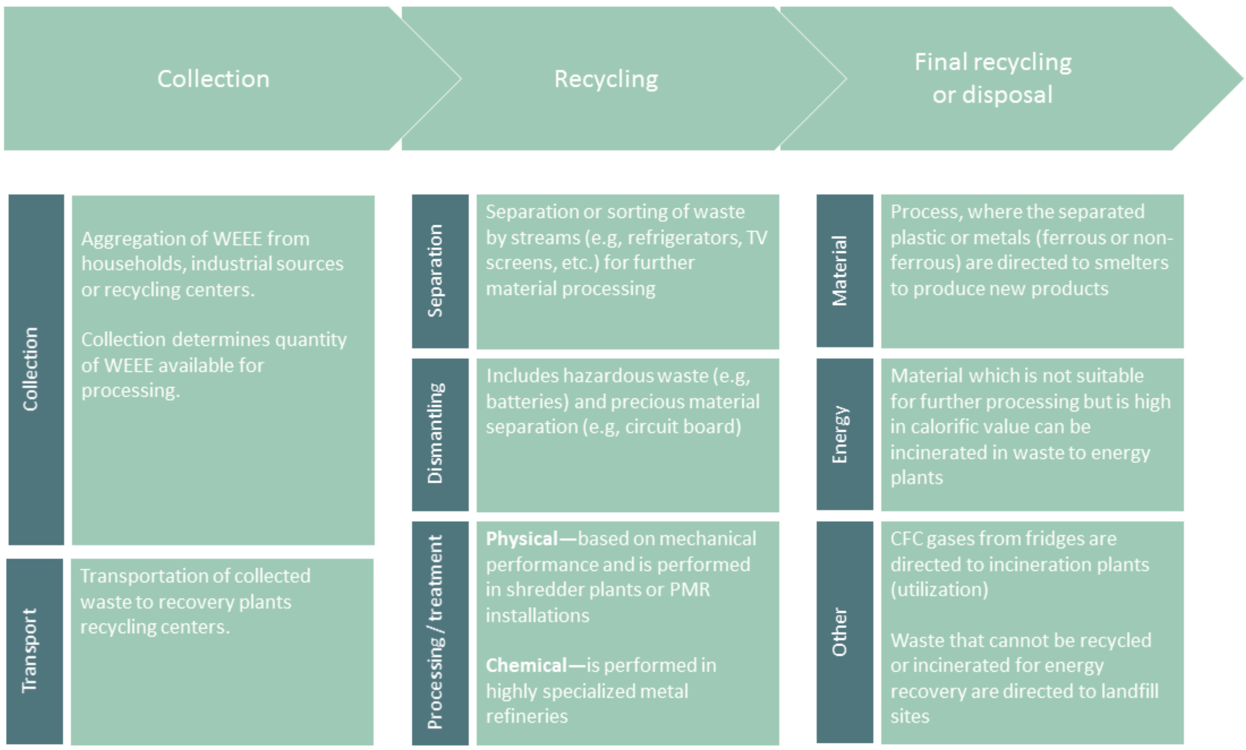
The same report on 'Waste as resource' further noted that 'in 2010, the total amount of EEE put on the European market was almost 10 million tonnes according to Eurostat. There is no official record of the amount of generated WEEE, but it is estimated to be approximately 7-8 million tonnes in 2008 (United Nations University, 2008) and probably higher in 2010. Of this amount, 3.2 million tonnes of WEEE were collected in the EU-27 in 2010, and the recycled and reused amount was approximately 2 million tonnes. Hence, less than one third of the generated WEEE is currently being reused and recycled.' (Danish Technological Institute, Ecorys, CRI, 2013) In other words, at EU level there does not appear to be a lack of WEEE that can be treated in the near future. Nevertheless, the report clearly mentions collection of WEEE as a hotspot for improvement. However, there are huge variations in collection rates among the countries and for different categories of WEEE. With regard to valuable WEEE categories or physically large WEEE (such as washing machines or refrigerators), the collection rates appear to be higher than for small and inexpensive WEEE categories. In their 2013 report, Frost & Sullivan show that Scandinavia has the most effective WEEE collective schemes in Europe, with approx. 17 kg WEEE per capita. The figure for Denmark is 16.4 kg per capita (Frost & Sullivan, 2013).

Thus, technological development is expected to become a driver for increasing revenue in Scandinavia and therefore also in Denmark. Recycling processes based on smart precious material recovery solutions are expected to become more efficient and reliable due to technological developments (Frost & Sullivan, 2013). This report presents suggestions on what these technological developments may be.

The strategic cooperation for WEEE

In Denmark, the Environmental Protection Agency has initiated this study to identify business opportunities for exploiting the raw material potential of WEEE. In particular, it is expected that new technologies can drive the development in the Danish dismantling and pre-processing market. Relevant players in the market such as waste companies, technology suppliers and EEE producers, are invited to explore potential business opportunities. This triangle of players is referred to as the 'the golden triangle'. The work is a part of the resource strategy from the Danish government (The Danish Government, 2013). The report focuses on the market, the players and technologies related to recycling, i.e. separation or sorting and dismantling as well as some forms of physical treatment of WEEE. Figure 2 illustrates the recycling process. The collection and transport of WEEE is not included in the analysis nor is the final recycling or disposal. There is, however, no razor sharp borders for what is included in the analysis – i.e. different models of collection and transport may influence the profitability of business models for recycling.

FIGURE 2: DIAGRAM WEEE RECYCLING PROCESS



SOURCE: DANISH TECHNOLOGICAL INSTITUTE; INSPIRED BY FROST & SULLIVAN, 2013. "PMR" IS "PRECIOUS METALS RECOVERY SYSTEMS"[2].

We will not discuss the legal framework separately in this report. However, in short, WEEE management is regulated by the WEEE Directive (Directive 2002/96/EC), amended in 2012 by Directive 2012/19/EU. The WEEE Directives impose the responsibility for the disposal of WEEE on the producers. WEEE can be managed through either collective systems or individual systems and producers are free to choose between them as long as the principle of extended producer responsibility is applied. Under the principle of extended producer responsibility, the

[2] After sorting of WEEE, *shredder* plants cut separated bulk WEEE into fine particles. The shredded material can be further processed in *Precious Material Recovery Systems* (PMR). PMR systems separate precious materials (precious metals, high grade plastics or mix of valuable fractions) from the processed WEEE stream. Several technologies can be applied such as sieving (trammel), ballistic separation, air classification (Zig-Zag or counter-current), dry separation (magnetic separation, induction Eddy current, optical separation (based on Near-infrared (NIR), Visible Spectrum (VIS), or X ray)), wet separation (density difference) and manual sorting. Finally, the processed WEEE is further separated by type of metal in the waste stream, in refineries. *Chemical separation* is performed through processes, such as pyrometallurgy (high temperature), hydrometallurgy, or electrometallurgy (use of electric current). Only a few European companies can handle the final processing. (Frost & Sullivan, 2013)

manufacturers are responsible for the product in its lifecycle including take-back, recycling and/or final disposal.

Understanding the playing field for WEEE

The objective of this background document is to increase the understanding of the playing field for WEEE from the discarding of EEE to either reuse or treatment of WEEE to extraction of raw materials. The background document will provide the players in the golden triangle with a common understanding of the playing field. With this background document, we hope to inform and inspire at the same time.

The playing field is framed to one side by the **rules of regulation** of WEEE management (which we do not cover in any detail) and, on the other side, by the available **WEEE treatment technologies** (technologies that recognise, sort, divide and treat WEEE). We will show that the technological development is quite intense and new technologies may be available both in Denmark and abroad – and they may be necessary to increase revenue of WEEE companies (Frost & Sullivan, 2013). In addition, introduction of new technologies may provide new business opportunities. **EEE products** also define the playing field – the content of valuable materials, the ease or difficulties in getting to the materials, changes in design, product lifetime, product mix, etc., all have an effect on the business opportunities. At the other end of the material cycle, economic development, international trade, and technological development, etc., define the **demand for raw materials**. The demand fluctuates over time, and what WEEE recyclers can deliver in terms of waste fractions or metals will depend on what is economically feasible as well as the available WEEE. Some processes have high entry costs in terms of investments in technology, infrastructure and skills, and even though the process is technically feasible, its implementation will depend on financing and a profitable business model. This also influences the playing field. We have analysed the technological developments to inspire to new networks, business partners or innovation initiatives.

The players

Next, to understand the nature of the playing field and to identify business opportunities, it is important to understand who the players are. We have identified important and potential players in Denmark and in Europe. The players are primarily in the market such as the golden triangle of waste management companies, EEE producers, technology developers, and knowledge institutions in Denmark. Business opportunities are often created in cooperation between the players, so it is important to have a good overview of existing and potential partners' knowledge. We have analysed the market players to better understand who they are and what their specialties or strengths are. This has already inspired players to enter into new partnerships in the industry.

The business opportunities

There are many business opportunities for the players, and each player has to define and refine his own business model. Closed-loop and take-back schemes are general examples of business opportunities that exist between waste management and EEE producers, and waste management and technology providers may identify business opportunities in the development of new forms of WEEE treatment. The value of the different business models varies between waste categories and material categories, and over time it will vary depending on demand. We have analysed WEEE on the Danish market to estimate the potential value of precious metals, critical metals and rare earths in WEEE on the Danish market.

Readers' guide to the background document

- In chapter 2 “Analysis of resource potential in electronic waste”, we identify the residual materials that currently are lost during treatment of WEEE, but could be recovered by introducing new treatment technologies or improvement in existing technologies. We estimate the value of the materials in WEEE. The total material value is estimated with regards to loss of materials in collection or treatment systems.
- In chapter 3 ‘Danish players’, we give an overview of the Danish players with specific focus on technology suppliers.
- In chapter 4 ‘Danish competences’, we analyse Danish technological competences in sorting, dividing and treating WEEE to gain an insight into the technologies available on the Danish market.
- In chapter 5 ‘International players’, we analyse the European marketplace and map the major WEEE treatment companies to gain a better understanding of the competition or possible alliances available to Danish players. This is primarily technology and machine producers that market knowhow in sorting, treating and dividing WEEE.
- In chapter 6 ‘Technological development’, we analyse information on innovation and technology based on interviews and research in global literature and patent databases.

2. Analysis of resource potential in electronic waste

2.1 Introduction

The objective of this chapter of the survey is to identify the residual materials that currently are lost during treatment of WEEE, but that could be recovered by introducing new treatment technologies or by improving existing technologies. The results of the survey are used to identify areas for further improvement in the Danish recycling system with focus on areas where new business opportunities can be developed.

During preparation, input was used from a workshop with participants from the Danish WEEE industry. The workshop was prepared in close cooperation with the Danish EPA and the secretariat run by the organization DAKOFA for “Strategic cooperation regarding recycling of WEEE” (Det strategiske samarbejde).

An analysis of critical raw materials was published in 2010 by the Ad-Hoc Working Group on Defining Critical Raw Materials, a subgroup to the Raw Materials Supply Group (Critical Raw Materials for the Eu, 2010). 14 raw materials were identified from a list of 41 materials. The Commission formally adopted this list in 2011 ((COM (2011)25 of 2 February 2011). Moreover, the global demand in 2030 of critical resources was identified and listed in order of importance: gallium, indium, germanium, neodymium, platinum, tantalum, silver, cobalt, palladium, titanium and copper. Furthermore, the remaining platinum group metals were included as well as rare earths, antimony, beryllium and niobium.

In a new revision (Report on Critical Raw Materials for the EU, 2014), some materials have been added and tantalum has been removed.

In this survey, the main focus is on products from the WEEE directive:

- Category 3 (IT and telecommunications equipment)
- Category 4 (Consumer equipment and photovoltaic panels)
- Category 9 (Monitoring and control instruments)

2.2 Method

The survey is divided into four sections:

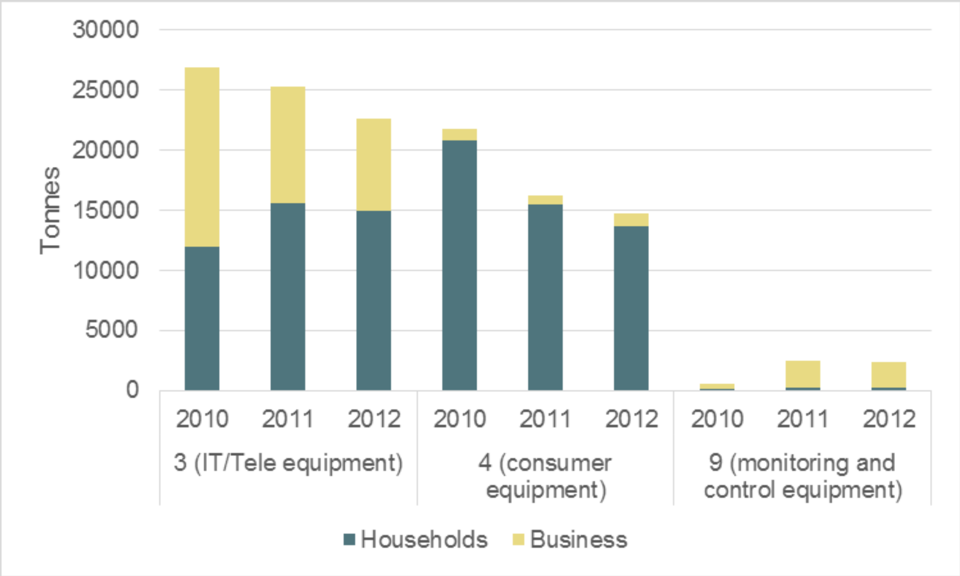
1. Estimation of the amounts of product types on the Danish market (t/y). The estimates are based on previous EU estimates and BFE sales numbers for marketed product types. Furthermore, amounts of product types sold to business are estimated and included in the calculations.

2. Based on a literature survey the material composition of the product types is estimated. Whenever data is available, non-critical resources (e.g., plastics, iron and aluminium) are included in the analysis.
3. Based on the amount (Re 1), composition (Re 2) and market price of the raw material, the economic value of the material in the products is calculated (DKK/kg product). In addition, the total value of the products in category 3 and 4 is calculated.
4. Finally, the economic value of material that is currently not recovered (lost during present recycling) is calculated by using two scenarios with different recycling efficiencies. Furthermore, the influence of losses in collection and changes in sales price of materials are discussed.

2.3 Number of WEEE products on the Danish market

The Danish Producer Responsibility System i.a. collects and publishes data on marketed EEE and on collected and waste handled WEEE on the Danish market. In Figure 3 the amount (tons) of products in the focus categories (WEEE directive 3, 4 and 9) marketed in Denmark is shown for the years 2010-2012 (DPA, Dansk producentansvarssystem WEEE og BAT statistik 2010, 2011), (DPA, Dansk producentansvarssystem WEEE og BAT statistik 2011, 2012), (DPA, Dansk producentansvarssystem WEEE, BAT og ELV statistik 2012, 2013). Detailed data is shown in Appendix 1.

FIGURE 3 MARKETED PRODUCTS 2010-2012



SOURCE: DATA FROM DPA.

The data from DPA illustrates that there is an almost even distribution of products sold to households and businesses in product category 3, whereas products from product category 4 are primarily sold to households. There seems to be a decreasing tendency in the amount of products sold to product category 3 and 4. The products in category 9 are mainly sold to businesses and make up a minor fraction compared to category 3 and 4.

Category 7, toys, includes comparable products such as handheld video game consoles and video games. It is assumed that Xbox, PS2, 3, 4 and Nintendo Wii consoles logically could be part the toy category. However, the new game consoles are also used for TV, video, music and video, and therefore they can also be used for the purposes belonging to category 4. The total amount of sold products in category 7 was 4570 tonnes in 2010, mostly sold to households. The game consoles are included in the present analysis without deciding which category they actually belong to.

A detailed list of the products in product categories 3, 4, 7 and 9 (according to WEEE directive) are shown in Appendix 2. Some of the listed products are no longer marketed in Denmark; however, the products are still expected to be present in the waste-stream for a number of years. In the sections below, the evolvement of each product category compared to the situation when the WEEE directive was initiated in 2003 is briefly discussed.

Products in category 3 (IT and tele equipment):
Mainframes/minicomputers are not common in companies anymore, as PCs are used in connection with servers and data storage facilities. In addition, net switches are used. Telex and fax machines are not common anymore, but they are to a large extent integrated in printers/scanners/copying machines.

Products in category 4 (Consumer equipment and photovoltaic panels)
Video recorders (VCR) using videotape are not marketed anymore. Instead, hard disk recorders or recording using built-in recording in TVs or computers are used. Game consoles (e.g., Xbox, PS2/3/4) are also used for playing music/video using CDs/DVDs and streaming video/sound from the internet as well as playing games.

Products in category 7 (Toys, leisure and sport equipment)
This category, originally not part of the survey, includes handheld video game consoles and video games. Game consoles can also play music/video or stream video/sound from the internet as well as play games. Consequently, the construction of the handheld consoles is comparable to computers and modern mobile phones with large screens in category 4. Consequently, game consoles in general have been included in the survey.

Products in category 9 (Monitoring and control instruments)
A number of products like smoke detectors and to some extent heating regulators and thermostats and electronic weights exist in households, but most of the equipment in this category is probably used in the business/industry sector. The marketed amount of category 9 is very small compared to category 3 and 4 and is considered less important based on the amount of products available.

2.3.1 Estimation of amount of product types in category 3 and 4 on the Danish market
In the subsequent section, the amounts of each product type in category 3 and 4 have been estimated for the Danish market. Category 9 has not been not been assessed as no data is available and as it only represents 1.2% of the marketed amount of category 3 and 4.

In 2.3.1.1 the estimate is based on downscaled EU estimate for the product types desktops, laptops and mobile phones which only covers a part of the products in category 3 and like wise LCD TVs which is as a part of category 4.

In 2.3.1.2 the estimate has been detailed by adding data for marketed products from BFE which covers more of the product types in category 3 and 4. Further estimates of amounts of products sold to business has been included in the estimate.

Finally in 2.9 the collected amounts of the marketed products and the amounts which are being treated in Danish plants with sorting facilities have been assessed.

2.3.1.1 Extrapolated using EU estimates
The amount of each product has been estimated by using previous estimates (I.Bakas, 2013) of the amounts of marketed products at EU level (data from single countries have been extrapolated to EU level) combined with a simple downscaling based on the inhabitants in EU (503 m) and Denmark

(5.6 m). The simple downscaling will not provide a precise estimate, as the consumption of these products in Denmark is expected to be higher than the average in the EU.

TABLE 2 ESTIMATE OF MARKETED AMOUNTS IN CATEGORY 3 BASED ON DOWNSCALED EU ESTIMATE

Product types	EU 2010 (t/y)	DK (t/y)
Laptops	154163	1715
Desktops	149161	1659
Mobile Phones	40535	451
Sum	**343859**	**3825**

The estimated product amounts for category 3 are given in Table 2, whereas the amounts registered by DPA are given in Table 3. For category 3, the amount of products calculated by downscaling (3825 t/y) only represents 14.2% of the marketed products registered by DPA (26899 t/y). Data is only available for flat screens in category 4. Using the same downscaling approach, the amount of flat screens corresponds to 4286 t/y, which is 19.7% of the marketed amount of products in category 4 registered by DPA (21725 t/y).

TABLE 3 DPA MARKETED PRODUCTS 2010 CATEGORY 3

	DPA (t/y)
Households	11930
Business	14968
Sum marketed grp. 3	**26898**

2.3.1.2 Estimation based on BFE sales number and average weight

In the following section, the number of marketed products is estimated by using Danish BFE sales numbers (BFE, 2012) and by estimating an average weight of the product types. The number of products sold to business is not covered by BFE sales numbers, and is therefore estimated below.

Category 3

TABLE 4 AMOUNTS OF PRODUCTS SOLD IN DENMARK 2010 IN CATEGORY 3

Product cat.3	DK (t/y)	Sold to households (no.)	Sold to business (no.)	weight (kg)	Comment/source
Desktop PC	3281	270000*	0**	12.15	(I.Bakas, 2013)
Notebook	3370	820000*	375035**	2.82	(I.Bakas, 2013)
Mobile phones	451	1820000*	1147105**	0.152	(I.Bakas, 2013)
Monitors	3417	416667**	250000**	5	Data based on weight of 22 -24”
Printers	3120	520000*	Not included	6	Data based on a number of laser and inkjet printers
Mainframes		Not included			
Copying machines business printers		Not included			
Network gear, mouse, keyboards		Not included			
Sum	**13638**				

*: BASED ON BFE SALES NUMBER.
**: ESTIMATES

In order to estimate the total amount of products, consumption from businesses is included:

- **Desktop PCs**: It is assumed that most desktops were sold to households in 2010, and therefore the amount sold to businesses is set to 0 tonnes. Based on an average weight of 12.15 kg and BFE sales data, the total amount is estimated to 3281 t/y.
- **Notebooks**: The amount of notebooks sold to households have been calculated to 2312 t/y (see table above). For businesses, the amount is estimated to 1058 t/y, using the following assumptions:
  - Number of notebooks is estimated using the number of employees in 4th quarter 2010 (1.5 m) and assuming the fraction with a notebook (see Table 3). It is assumed that all new computers sold from 2010 are notebooks.
  - Assuming an average service life of four years and an average weight of 2.82 kg
- **Mobile phones:** For mobile phones, the estimation using BFE data results in 276 t/y, which is 175 t/y less than the downscaled estimate based on (I.Bakas, 2013) . In this case, it is assumed that the EU estimate of 451 tons/year is a more correct amount for the total Danish consumption corresponding to 1,150,000 mobile phones being sold to businesses or sold from sources not registered by BFE.
- **Monitors**: It is assumed that all 2.6 m households at least have one flat screen, and that all 1.5 m employees who use a PC have one flat screen at work. Using a service life of 6 years and an average weight of 5 kg that corresponds to 3417 t/y.
- **Printers:** It is assumed that one is present in each of the 2.6 m Danish households with a service life of 5 years and a weight of 6 kg. That corresponds to 3120 t/y. Business printers and copying machines have not been included due to lack of data.
- **Network gear like switches, wireless, mouse, keyboards etc.** has not been included.

The estimated amount of all marketed product types in category 3 is 13638 t/y; that corresponds to 51% of the marketed products (DPA, Dansk producentansvarssystem WEEE og BAT statistik 2010, 2011). That is 3.5 times more than the estimate based on a simple downscaling of the most common products in the EU estimate (14.7%). There is considerable uncertainty in the estimated amounts for business (notebooks) and for monitors and printers.

Business products such as copying machines and printers have not been included as no data are available.

TABLE 5 ESTIMATE OF EMPLOYEES WITH A COMPUTER. THE ESTIMATE IS RATHER UNCERTAIN

	Total	State	Regions	Munici-pality	Social service offices	Publ. business	Private business	Private not-for-profit org.	No information
employed	2177109	178162	117784	449904	1894	61634	1311414	56078	240
With PC (%)		90	90	90	90	90	60	100	80
PCs (No.)	1571559	160346	106006	404914	1704.6	55470.6	786848.4	56078	192

Category 4
The consumption of products from businesses is very limited (see Figure 3), and is therefore not included in the estimates.

TABLE 6 NUMBER OF MARKETED PRODUCTS IN DENMARK IN CATEGORY 4.

Category 4	Sold 2010 (no.)	Weight(kg)	weight ref.	DK (t/y)
LCD TV	810000	8.6	(I.Bakas, 2013)	6972
DVD player/Blu-ray/rec	280000	1	data from web shops	280
Receivers/amplifiers/home cinema	200000	5	data from web shops	1000
Transportable sound (boom box/DAB)	390000	1.46		570
Digital camera	490000	0.18	data from web shops	88
Video camera	40000	0.28	data from web shops	11
Mp3 players	440000	0.1	Weight of IPOD	44
Speakers	No data			
Game consoles with DVD/Blu-ray	240000	3	Xbox/PS3/WII	720
Sum				9685

The number of marketed products estimated in Table 6 according to the following assumptions:

- **LCD TV** is based on BFE sales numbers and the average weight in (I.Bakas, 2013)
- **DVD/Blu-ray players and rec** are based on the BFR sales numbers (sum of DVD players (180000) and Blu-ray players (100000)) and the average weight estimated by using data from various web shops.
- **Receivers/amplifiers/home cinema** are based on the BFE sales number (sum of home cinema (90000), receivers (25000) and stereo music players (85000)) all assumed to have an average weight of 5 kg without speakers (data from web shops).
- **Transportable sound** is calculated as the sum of DAB radio (240000, weight 1 kg) and transportable radios with/without DVD (30000/120000, weight 1/2.5 kg)
- **Digital camera** is based on BFE sales numbers (49000) and the average weight estimated using data from web shops.
- **Video camera** is based on BFE sales numbers (4000) and the average weight estimated by using data from web shops
- **MP3 player** is based BFE sales numbers (44000) and the average weight estimated by using data from web shops
- **Game consoles** with DVD/Blu-ray are assumed to be PS3, PS4, Xbox and Nintendo Wii with an average weight of 3 kg. Game consoles probably belong more to category 7 (toys) although they can also play music CDs, DVDs and connect to the internet.

The estimated amount of all marketed product types in category 4 is 9685 t/y, which corresponds to 45% of the marketed products (DPA, Dansk producentansvarssystem WEEE og BAT statistik 2010, 2011). This is 2.3 times higher than the amount obtained on the simple downscaling of the most common products in the EU estimate (19.7%). The data are based on BFE numbers and an estimate of the average weight of typical products. It is assessed that the largest uncertainty in the estimate probably can be found in the weight assessment. The estimate lacks data for speakers, navigation equipment and other household appliances. The amount of these products is unknown.

Photovoltaic panels

Photovoltaic panels are part of group 4, but are not registered in the DPA statistics; however, photovoltaic panels will be included in the future according to DPA. According to “energinet.dk” a total of 90232 plants were established in March 2013 with a total capacity of 578173 kW. Many of the plants were established between 2012 and 2013; however, a change in public funding has reduced the installation rate. Based on supplier data a 240W mono-crystallic cell with area of 1.6 m^2 weighs 20 kg. Using that number as an average weight, the total amount of photovoltaic panels is estimated to 48000 t. The cells are expected to have a service life of app. 30 years; consequently, it is foreseen than photovoltaic panels will become a significant Danish waste stream in the future.

2.4 Material composition in WEEE products

A literature survey was conducted in order to quantify the amount of critical resources in WEEE products. In the literature survey, several studies were identified and used for gathering data on the material composition of each of the products. Moreover, the content of non-critical resources such as iron, aluminium and plastics has been included in the recycling assessment.

2.4.1 Literature survey

As it was decided to include plastics and the construction materials iron and aluminium in the analysis, data was found for a number of product types in (M.Oguchi, 2011). This reference also includes data for the composition of printed circuit boards of a number of products.

In (M.Buchart, 2012), a number of different data are presented regarding the magnetic materials Neodynium, Praseodynium and Dysprosium, which are present in hard disks, DVD drives and speakers/microphones. Further data is presented for the luminescent materials Cerium, Europium, Lathan and Terbium, which are present in flat screens (LCD TVs and monitors).

In the EU report (I.Bakas, 2013) and in (P.Chancerel, 2010), further data are listed on some elements for desktops and laptop PCs, mobile phones and LCD TVs. In the report (I.Bakas, 2013), the concentration of 13 critical resources is calculated for these products.

The data were combined to estimate the content of 33 different materials including 23 critical resources in PCs, game consoles, LCD TVs/monitors and other product types.

2.4.2 Data basis

Using the literature described in section 2.4.1, the material composition (critical and non-critical) was found for:

Category 3

- Desktop PCs
- Notebooks/laptops
- Mobile phones
- Monitors (estimate for LCD TV)
- Printers
- Faxes

No data were found for copying machines and mainframes; furthermore, the number of each product was not estimated in Denmark either, and therefore it is not included in the survey.

Category 4

For Category 4, data for composition (critical and non-critical) was found for:

- LCD TVs
- DVD players, which are considered representative for Blu-ray players also
- Stereo systems, which are considered to be representative for amplifiers/receivers and home cinema amplifiers
- Radio cassette recorders (considered representative for transportable audio)
- Digital cameras
- Video cameras
- Portable players
- VCR and CRT TVs

An overview of the material composition for each of the different products can be found in Appendix 3. Where composition data are not available, products from category 3 are assumed to have a composition similar to a desktop PC and for category 4 the composition of a cassette recorder. Therefore the estimate is very uncertain. For game consoles with DVD/Blu-ray drive, an estimate of the composition was based on the composition of the printed circuit board in a notebook with the addition of magnetic materials of neodymium from the disk drives, but without the materials in the notebook display.

In Table 7, all 33 materials included in the assessment are listed. Materials shown in bold are considered to be critical resources.

TABLE 7 MATERIALS ASSESED IN THE SURVEY

Material	Description	Material	Description
Plastics		**Nd**	Neodymium
Fe	Iron	**Pr**	Praseodymium
Al	Aluminium	**Dy**	Dysprosium
Pb	Lead	**In**	Indium
Sn	Tin	**Pt**	Platinum
Zn	Zink	**Y**	Ytrium
Ba	Barium	**Gd**	Gadolinium
Bi	Bismuth	**Ce**	Cerium
Sr	Strontium	**Eu**	Europium
Li	Lithium	**La**	Lanthan
Cu	Copper	**Tb**	Terbium
Ag	Silver	**Te**	Tellurium
Au	Gold	**W**	Wolfram
Pd	Palladium	**Be**	Beryllium
Co	Cobalt	**Ru**	Ruthenium
Ga	Galium	**Ge**	Germanium
Ta *	Tantalum		

*TANTALUM IS NOT CONSIDERED A CRITICAL RESOURCE IN (REPORT ON CRITICAL RAW MATERIALS FOR THE EU, 2014)

2.5 Weighted material distribution of WEEE products on the Danish market

Figure 4 shows a weight-based distribution of materials for all products in category 3 and 4 in Denmark. As appears in the figure, the weighted distribution is dominated by iron, plastics, printed circuit board (PCB) resin, copper and aluminium. However, when looking at critical resources (Figure 5), the major materials on a weight basis are copper, cobalt, tantalum, neodymium, silver, praseodymium and gold. According to a weight based recycling strategy, the most important materials are iron, plastics, aluminium and copper. However, that does not reflect the value of the recycled materials. In the next sections, the value of the materials is considered.

FIGURE 4 ESTIMATE OF WEIGHT-BASED DISTRIBUTION OF MATERIALS IN PRODUCTS IN CATEGORY 3 AND 4 IN DENMARK

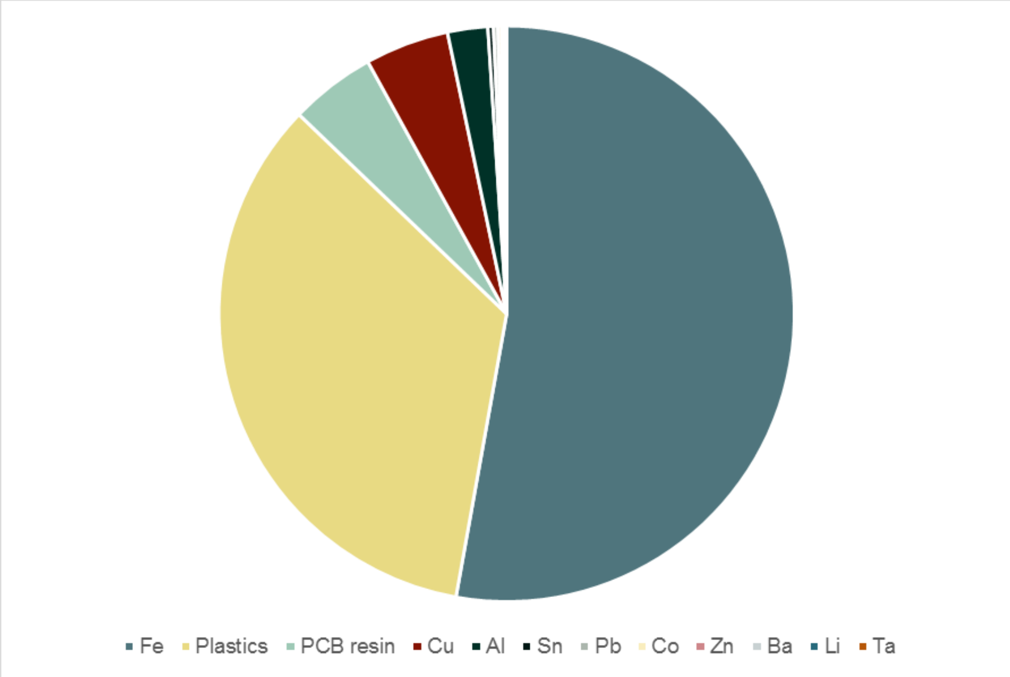
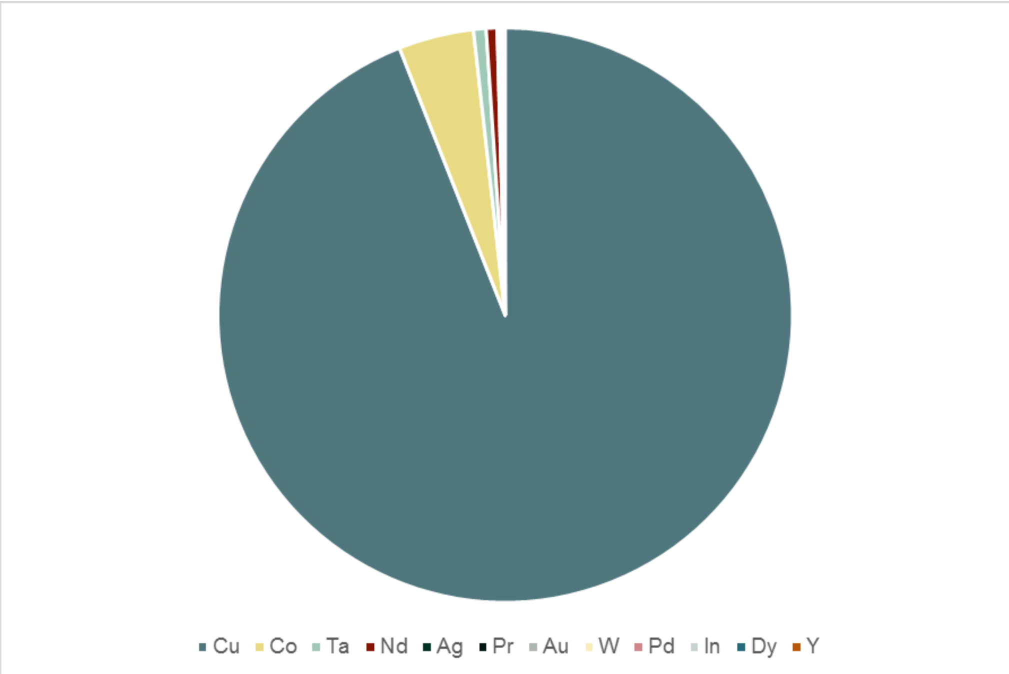


FIGURE 5 ESTIMATE OF WEIGHT BASED DISTRIBUTION OF CRITICAL RESOURCES IN PRODUCTS IN CATEGORY 3 AND 4 IN DENMARK



2.6 Economic material distribution in WEEE products

2.6.1 Material sales prices

To assess the value of the materials in the products, sales prices for each material were collected. Prices for metals are from databases for metals in the period 2013-2014 and plastics are estimated to have the same price as virgin ABS (recycled ABS pellets price is around 11 DKK/kg at present). An overview of the material prices appears in Table 8.

TABLE 8 MATERIALS USED IN THE ASSESSMENT AND THE SALES PRICES FOR 2013-2014

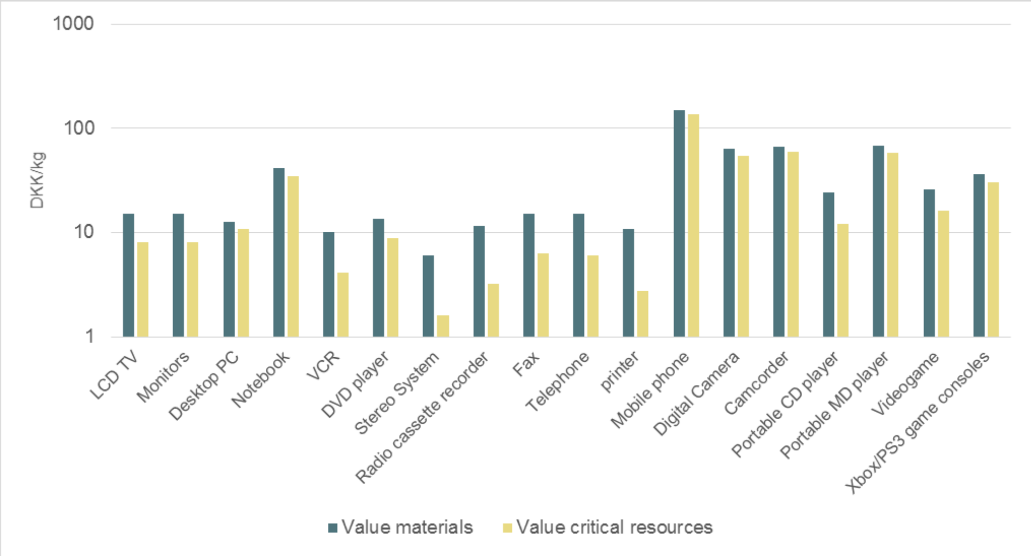
Material	Description	DKK/kg	Material	Description	DKK/kg
Plastics		15	**Nd**	Neodymium	507
Fe	Iron	2	**Pr**	Praseodymium	897
Al	Aluminium	11	**Dy**	Dysprosium	3245
Pb	Lead	13	**In**	Indium	4248
Sn	Tin	135	**Pt**	Platinum	270312
Zn	Zink	11	**Y**	Ytrium	354
Ba	Barium	825	**Gd**	Gadolinium	782
Bi	Bismuth	150	**Ce**	Cerium	71
Sr	Strontium	34	**Eu**	Europium	6490
Li	Lithium	375	**La**	Lanthan	60
Cu	Copper	42	**Tb**	Terbium	5310
Ag	Silver	3794	**Te**	Tellurium	767
Au	Gold	246600	**W**	Wolfram	254
Pd	Palladium	151754	**Be**	Beryllium	6263
Co	Cobalt	182	**Ru**	Ruthenium	15674
Ga	Galium	1564	**Ge**	Germanium	9750
Ta	Tantalum	2419			

FE :WWW.METALPRICES.COM PIGIRON AUGUST 2013
AL,PB,SN,ZN,CU ;EWID MAGAZINE APRIL-JULY 2014
BA,SR: WWW.ALIBABA.COM
AG,AU,PD,PT: WWW.MONEX.COM
LI,BE,RU,GE:WWW.METALPRICES.COM MARTS 2013
CO,GA,TA,ND,PR,DY,IN,Y,GD,CE,EU,LA,TB,TE,W:WWW.METAL-PAGES.COM APRIL-OCTOBER 2014

2.6.2 Value of critical and non-critical resources in WEEE products

In Figure 6 below, the material value per kg of product was calculated for the main products in category 3 and 4 (using sales prices and the data from 1.4). A clear tendency is observed, namely that the value of critical resources is very high in compact and advanced products, e.g., mobile phones, digital cameras, video games and notebooks (DKK 16-137/kg product), while LCD TVs, monitors, DVD players and desktop PCs have values of around 10 DKK/kg product. The product types VCRs, stereo systems, cassette recorders and printers have values of critical resources < 5 DKK/kg product. For these products, the value of other materials is significant, giving a total material value comparable to LCD TVs. A significant part of the material value of these products comes from the content of plastics.

FIGURE 6 TOTAL VALUE AND VALUE OF CRITICAL RESOURCES IN A NUMBER OF PRODUCTS FROM CATEGORY 3 AND 4.



2.6.3 Value distribution of critical resources

In Table 9 and Table 10, the value of all materials, critical resources, and gold have been calculated in DKK/kg product for the main products in category 3 and 4. As it appears in the table, the value in the high tech products (e.g., mobile phones, digital cameras, video games and notebooks) is dominated by gold, representing around 50% of the material value.

TABLE 9 VALUE OF MATERIALS IN PRODUCTS

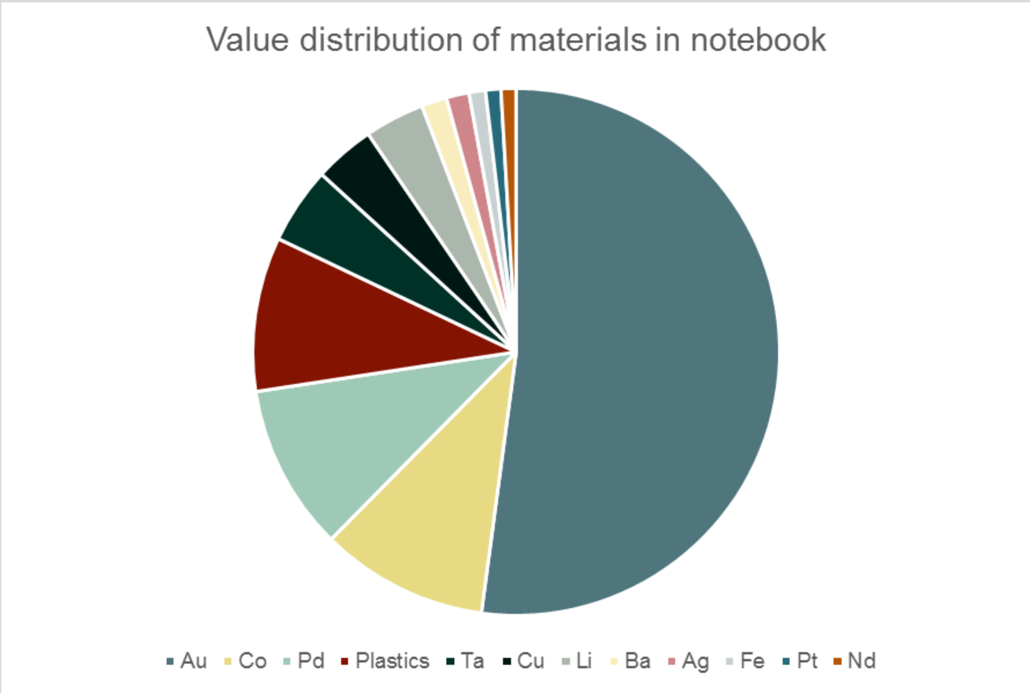
	LCD TV	Monitor	Desktop PC	Notebook	VCR	DVD player	Stereo system	Radio cassette rec	Fax
All materials (DKK/kg product)	15.1	15.1	12.7	41.8	10.0	13.5	6.0	11.6	15.2
Critical resources (DKK/kg product)	8.1	8.1	10.8	34.6	4.1	8.8	1.6	3.2	6.3
Value of gold out of total value (%)	38.0	38.0	43.8	50.9	8.9	38.4	2.7	5.7	6.9

TABLE 10 VALUE OF MATERIALS IN PRODUCTS

	Tele-phone	printer	Mobile phone	Digital Camera	Cam-corder	Portable CD player	Portable MD player	Video-game	Game consoles
All materials (DKK/kg product)	15.2	10.9	149.3	63.0	67.0	24.4	67.2	25.6	36.1
Critical resources (DKK/kg product)	6.0	2.7	136.6	53.7	58.8	12.0	58.6	16.0	30.5
Value of gold out of total value (%)	0.0	6.4	75.1	61.7	34.6	37.8	54.1	45.6	60.2

As an example of the value distribution in a high tech product, the value distribution of notebooks is presented in Figure 7. The composition and value (DKK/kg product) of a notebook is shown in Appendix 4. The image clearly shows that gold represents the highest value (also indicated in Table 9 and Table 10) followed by cobalt, palladium, plastics, tantalum, copper, lithium, barium, silver, iron, platinum and neodymium.

FIGURE 7 DISTRUBUTION OF MATERIALS IN NOTEBOOKS ACCORDING TO ECONOMIC VALUE



2.7 Economic value of materials in products from category 3 and 4 on the Danish market

The estimated value of all materials (critical and non-critical) and critical resources for each product in category 3 and 4 on the Danish market has been calculated (using the data from section 1.3 and 1.6). In Figure 8 and Figure 9, the total value of all materials and critical resources is shown for the main products in category 3 and 4, respectively. Moreover, the exact numbers are presented in Appendix 5.

FIGURE 8 VALUE OF CRITICAL RESOURCES IN MARKETED PRODUCTS IN CATEGORY 3

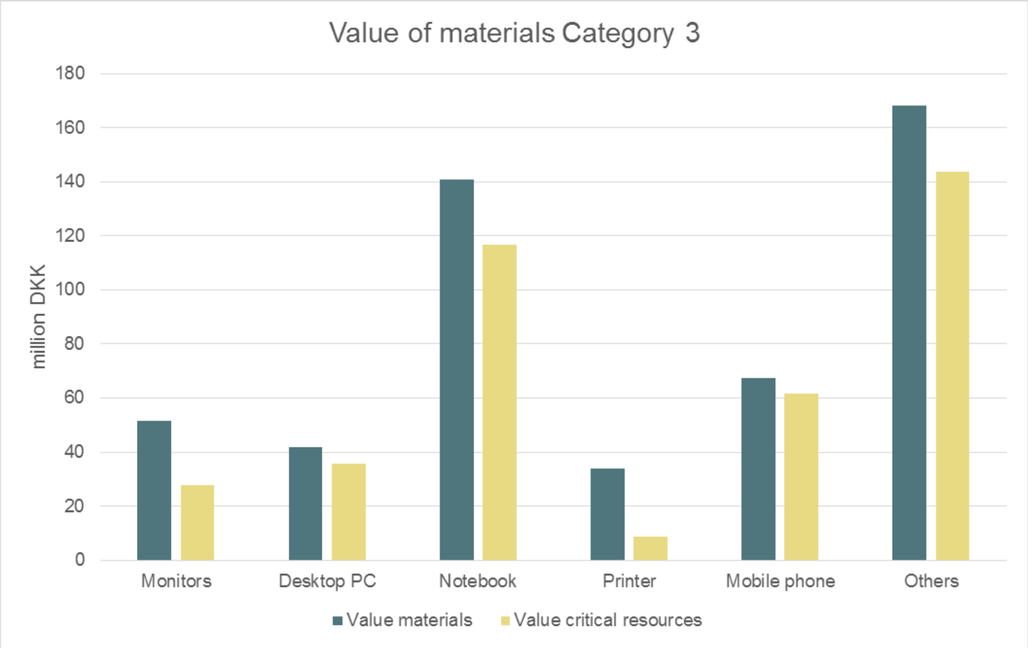
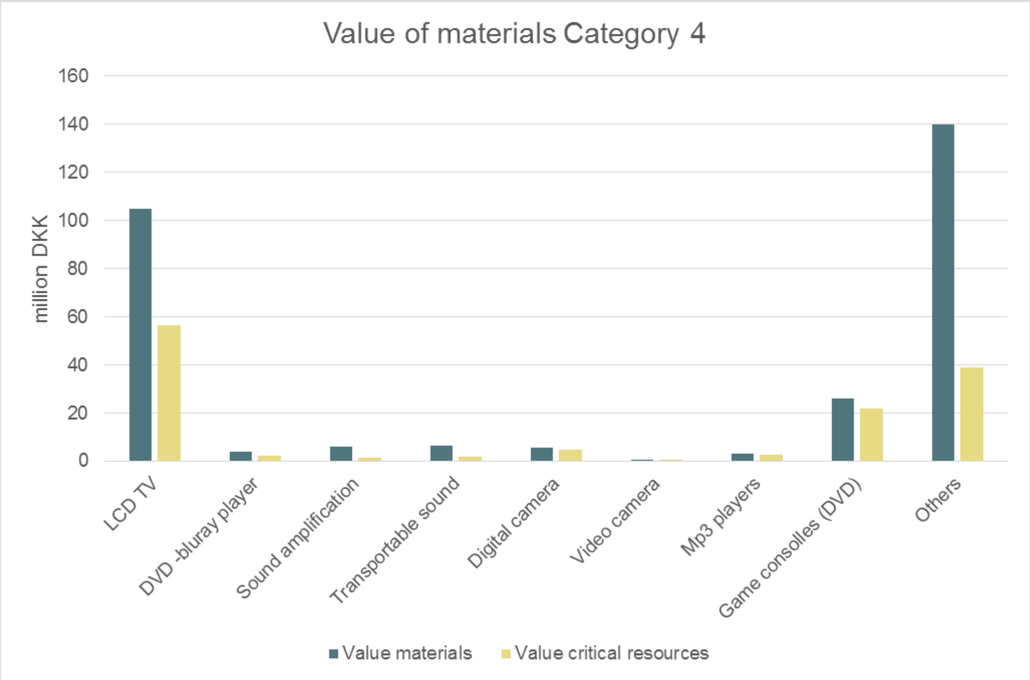


FIGURE 9 VALUE OF CRITICAL RESOURCES IN MARKETED PRODUCTS IN CATEGORY 4



The total value of critical resources in the marketed products has been estimated at approximately DKK 394m/y and DKK 131m/y for category 3 and 4, respectively. In category 3, notebooks and the category "others" constitute more than 60% of the total value (DKK 504m/y) and the critical resources constitute more than 80% of the total value. In category 4, LCD TVs and the category "others" constitutes more than 80% of the total value (DKK 297m/y) and the critical resources constitute app. 50% of the total value. The value estimations are associated with considerable uncertainty as the exact composition of almost half of the products has been estimated.

2.8 Materials lost during mechanical treatment and sorting

Throughout the recycling chain of WEEE products, material may be lost, for instance during:

- Collection
- Mechanical treatment at local Danish plants
- Sorting and refining of intermediate products from Danish plants in foreign plants

The amount of lost material throughout the recycling chain is from this point referred to as the residual material amount. The residual material amount may be reduced by introducing new treatment technologies or improving existing technologies.

The residual material amount lost during collection and mechanical treatment can be affected by the recycling mechanisms in Denmark. However, the residual material lost in foreign sorting and refining industries, e.g. copper smelters with extraction of precious metals, is not influenced by Danish initiatives.

The expected European collection efficiencies and the recovery efficiencies for mechanical treatment and final refining have previously been estimated. The studies show that there is a considerable loss of critical resources during mechanical treatment, reducing the recovery efficiency to 60% for flat screens and mobiles phones and to 72% for PCs (I.Bakas, 2013). However, other studies have reported both higher and lower efficiencies (P.Chancerel, 2010). Therefore, two scenarios with different recycling efficiencies have been used in the calculation of the economic values of materials that are currently not recovered:

- Scenario 1 (Sc1) is a scenario with high recovery and only 5% loss in the mechanical treatment. This treatment could be a situation where some of the most valuable PCBs are separated manually for separate treatment. The magnetic materials (neodymium) are assumed to be lost with the iron fraction. The values used appear in appendix 6.
- Scenario 2 (Sc2) is calculated with the recoveries shown in (I.Bakas, 2013) . The values of loss in mechanical plants are approximately 28-40% depending on product type, with the used values shown in appendix 6.

For both scenarios it is assumed that 100% is collected for recycling in Denmark, although there definitely will be some loss of e.g. small electronics from household waste treated in incineration plants and via other unknown pathways. In section 2.9, a calculation is shown based on estimated collected amounts and amounts available for recycling in Danish recycling companies.

An overview of the recovery efficiencies for all materials for both scenarios is presented in Appendix 6.

The economic value of residual material has been estimated for scenarios 1 and 2. The results are presented in Figure 10 to Figure 13 and in Appendix 7. As previously mentioned, the price of the pure materials (see Table 8) has been applied in the calculation. Whether or not materials can be obtained in a quality comparable to the pure materials is unknown. Moreover, the “unknown costs” for extracting the metals and refining must be subtracted to calculate the economy by improved recycling.

FIGURE 10 MAXIMUM ECONOMIC VALUE OF LOST RESOURCES DURING TREATMENT SCENARIO 1, CATEGORY 3

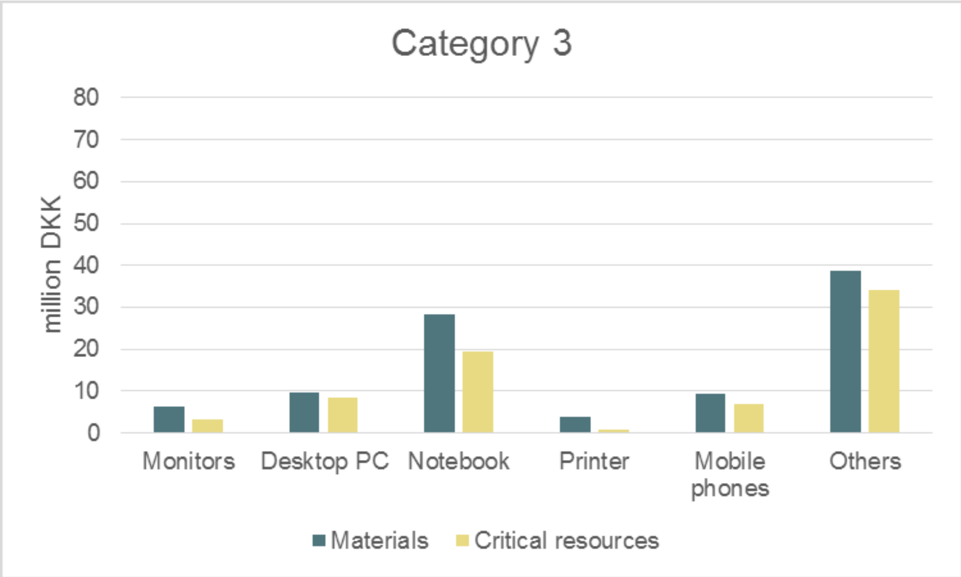


FIGURE 11 MAXIMUM ECONOMIC VALUE OF LOST RESOURCES DURING TREATMENT SCENARIO 1, CATEGORY 4

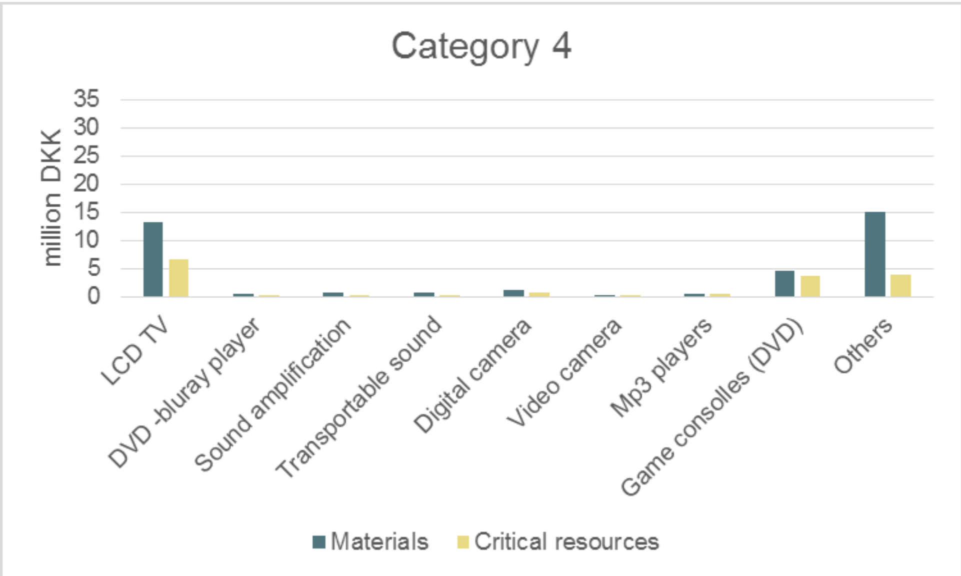


FIGURE 12 MAXIMUM ECONOMIC VALUE OF LOST RESOURCES DURING TREATMENT SCENARIO 2, CATEGORY 3

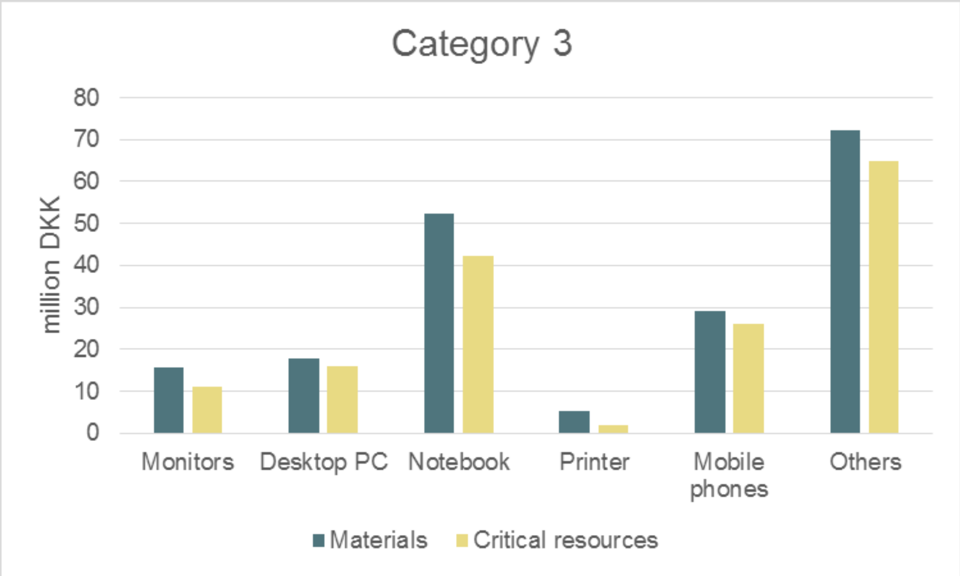
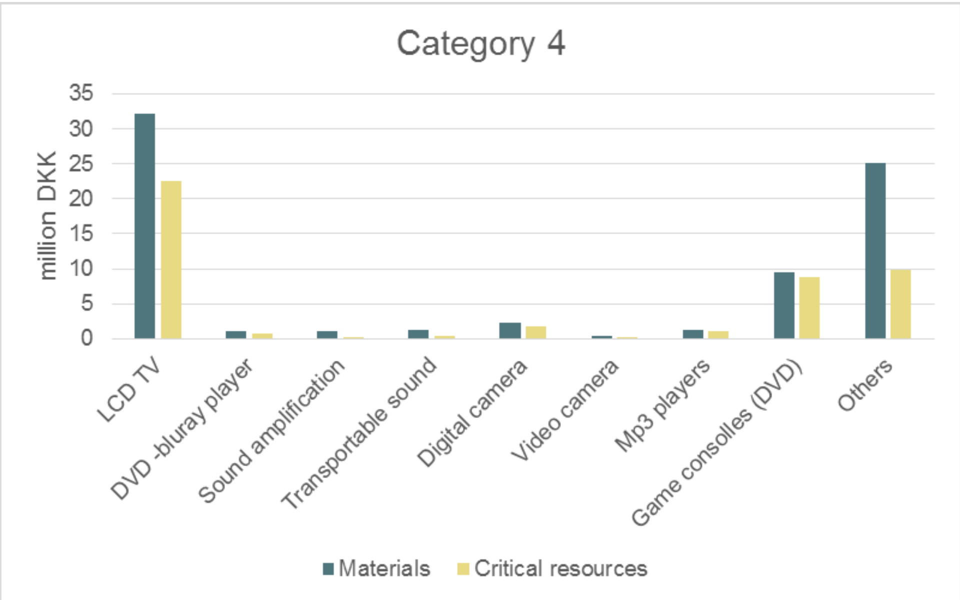


FIGURE 13 MAXIMUM ECONOMIC VALUE OF LOST RESOURCES DURING TREATMENT SCENARIO 2, CATEGORY 4



It is estimated that the residual critical resources in category 3 have a maximum value of DKK 73m for scenario 1 and DKK 162m for scenario 2 when there is no loss in the collection.

For the products in category 4, the maximum value of residual critical resources is estimated to be DKK 16m for scenario 1 and DKK 46m for scenario 2.

In the EU report (I.Bakas, 2013), a calculation was carried out on the loss of critical resources in EU of PCs, mobiles and flat screens, which corresponds to EU 1.6m or DKK 133m when downscaling. The present estimates for category 3 and 4 are based on Danish numbers for amounts and include some further estimates of amounts of these products in companies and in addition an estimate of the critical resources in other products in category 3 and 4. For the present estimate, the sum of lost critical resources for category 3 and 4 amounts to DKK 208m when using scenario 2 and assuming that there is no loss in collection.

With regard to category 9, the composition is unknown. To give an indication of the value of category 9 the value has been calculated using the values of materials in category 3 and 4 and scaling of the weight. The average weight of marketed products in 2010-2012 was 25014 tonnes for category 3, 16245 for category 4 and 2091 for category 9. Therefore, category 9 corresponds to 8.4% of the weight of category 3 and 13% of the weight of category 4.

Based on the values above, the value of the materials in category 9 can be calculated to be between DKK 38m and DKK 42m, and the value of the critical resources between DKK 17m and 33m.

Likewise, the residual value of critical resources for scenario 1 can be calculated to be between DKK 2m and DKK 6m, and for scenario 2 between DKK 6m and DKK 13 m.

In Figure 14 to Figure 17 the distribution of the economic value in lost resources is shown for the two most dominating products in category 3 and 4 (notebooks and LCD TVs). Appendix 8 shows the distribution of materials in notebooks and LCD TVs.

FIGURE 14 DISTRIBUTION OF ECONOMIC VALUE IN LOST RESOURCES DURING TREATMENT FOR NOTEBOOKS, SCENARIO 1

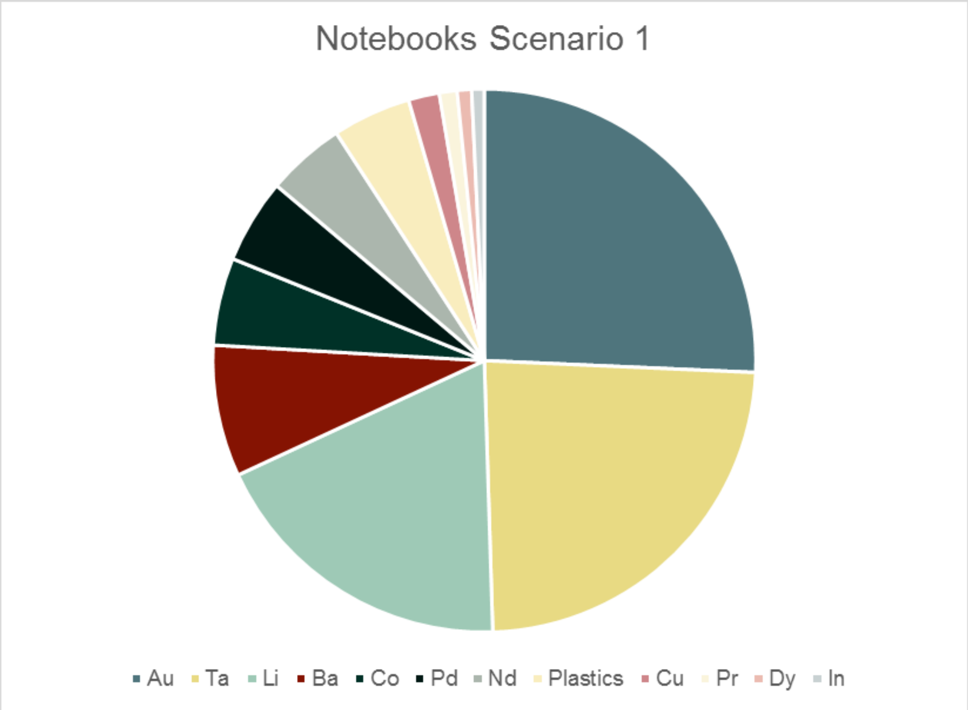


FIGURE 15 DISTRIBUTION OF ECONOMIC VALUE IN LOST RESOURCES DURING TREATMENT FOR NOTEBOOKS, SCENARIO 2

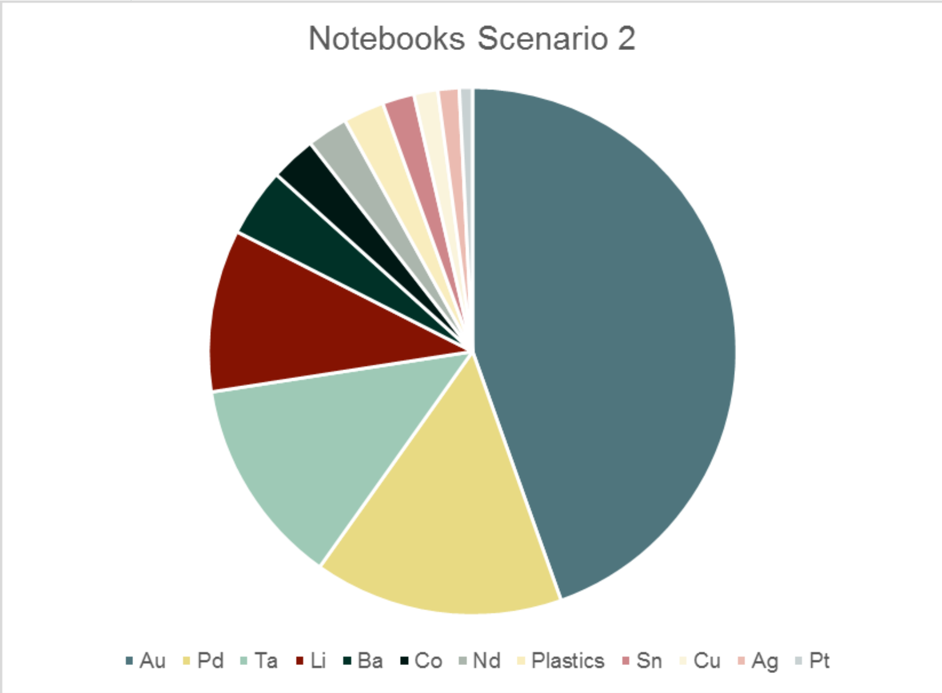


FIGURE 16 DISTRIBUTION OF ECONOMIC VALUE IN LOST RESOURCES DURING TREATMENT FOR LCD TVS, SCENARIO 1

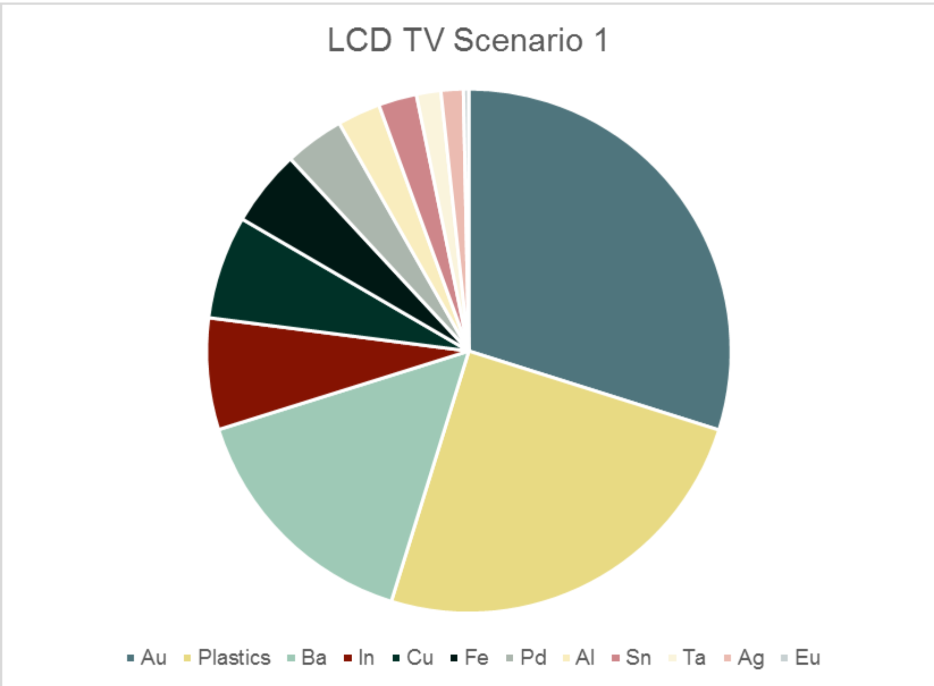
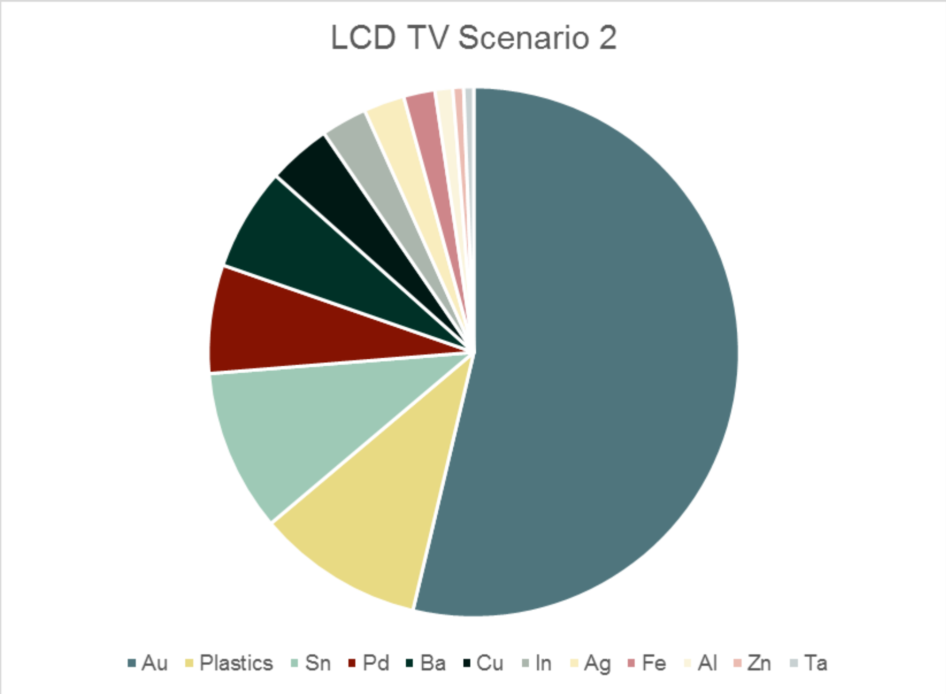


FIGURE 17 DISTRIBUTION OF ECONOMIC VALUE IN LOST RESOURCES DURING TREATMENT FOR LCD TVS, SCENARIO 2



The figures show that the major loss in economic value in scenario 2 comes from gold.

At high losses (scenario 2) the most important economic losses are:
(Critical resources marked with bold)

- Notebooks : **Gold, Palladium, Tantalum[3],** Lithium, Barium, Cobalt, **Neodymium**, Plastic, Tin, **Copper**, **Silver** and **Platinum**
- LCD TVs: **Gold**, Plastic, Tin, **Palladium,** Barium**, Copper, Indium, Silver,** Iron, Aluminium, Zink **and Tantalum**

At low losses (scenario 1) the most important economic losses are:
(Critical resources marked with bold)

- Notebooks : **Gold, Tantalum,** Lithium, Barium, Cobalt, **Palladium, Neodymium**, Plastic, **Copper**, **Praseodymium, Dysprosium** and **Indium**
- LCD TVs: **Gold**, Plastic, Barium, **Indium, Copper,** Iron, **Palladium**, Aluminium, Tin, **Tantalum, Silver, Europium** and **Yttrium**

[3] Tantalum has been reassessed as a non-critical resource in 2014

The loss of critical resources originates from the following sources:

Gold:	Components on PCBs and connectors with a gold layer
Tantalum:	Capacitors
Palladium:	Hard disk platters and some components on PCBs
Silver:	Lead-free solder in PCBs
Copper:	PCBs and wires
Europium and Yttrium:	Lighting material in flat screens
Indium:	Electrodes in flat screen panels
Neodymium:	Volume effective magnets in hard disk and compact speakers
Dysprosium:	Volume effective magnets in hard disk and compact speakers
Cobalt:	Part of Lithium batteries

Apart from those materials, there will be a loss of the construction materials iron, aluminium and plastics. For LCD TVs there is also a considerable loss of tin, which is a part of the solder material.

In addition, the critical resource niobium is used in micro-capacitors; however, no data have been found regarding content in the products. According to (R.Montero, 2012) PCBs contain approximately 36 mg Niobium /kg. The sales price of niobium is 750 DKK/kg. PCB constitutes app. 13.7% of a notebook, and therefore the value of niobium is only 0.004 DKK/kg notebook based on this reference. However, if a higher amount of tantalum-based capacitors is substituted by niobium-based capacitors then the value will increase.

The total estimated distribution of the value of materials in critical resources from category 3 and 4, and the distribution of lost resources in scenario 1 and 2, can be found in Appendix 9.

2.9 Estimation of collected amounts and amounts available for Danish recycling companies

The estimation of amount and value of critical resources in Denmark has been based on marketed product amounts. However, the materials available for recycling are the collected amounts of products.

In the following, the data for marketed amount of products in category 3, 4 and 9 are compared with the data for collected amounts from DPA for the years 2010-2012.

The table below shows that 92% of the marketed amount in category 3, 4 and 9 was registered as collected products covering a variety from 22 % for category 9 to 148 % for category 4. However, the collection rate has fluctuated over the years. Especially for category 4 the collection rate seems peculiar. This category includes i. a. television screens and an assumption is that introducing new and less heavy screen technologies has influenced the ratio between marketed products and collected products in such a way that the amount by weight of category 4 WEEE collected exceeds the marketed amount in a transitional period (Information from Danish EPA, 2014). The national statistic on collected amounts produced by the DPA does not contain data for the amounts of WEEE where the responsibility for waste treatment of electric and electronic equipment for professional use, is handed over from the producer to the end user company. Also the national statistic from DPA does not contain data for collected WEEE in the cases where companies choose to handle the WEEE themselves outside of the producer responsibility scheme. These flows should be monitored in the national Waste Data Management System, but at the moment the registration in this system is not done pr. category but as a total amount of collected WEEE. A new registration paradigm is under development. However, it is beyond the scope of this project to go into deeper details on the reasons for the registered collected amounts in the three categories.

TABLE 11 COMPARISON OF AVERAGE AMOUNT OF MARKETED AND COLLECTED PRODUCTS 2010-2012

Type	Marketed Tonne/year	Collected Tonne/year	% collected of marketed
Category 3	25014	15457	62
Category 4	16245	24013	148
Category 9	2091	466	22
SUM	43350	39935	92

SOURCE: DATA FROM DPA

Due to the uncertainties in the statistics for collection, it is so far assessed that the marketed amounts of products represent the collected amounts quite well and that the collection loss is less than 10%.

The amounts available for recycling are therefore assumed to be 90% of the marketed amounts.

However, at present (2010) only approximately 50% of the collected products in category 3 and 4 are treated in Danish sorting plants according to table 13 in (DPA, Dansk producentansvarssystem WEEE og BAT statistik 2010, 2011). Assuming the present market share for Danish treatment companies exist in the future , only 50% of the collected amount are available for recycling in Danish companies. This corresponds to 50% of 90% =45% of the marketed amount of products.

Table 12 and Table 13 show the value of materials and critical resources of marketed products and the value of products estimated to be available for recycling in Denmark using the present degree of treatment in Denmark.

TABLE 12 ESTIMATED VALUE IN DKK MILLION OF MARKETED PRODUCTS IN CATEGORY 3, 4 AND 9 IN DENMARK IN 2010 ASSUMING THAT 90% OF THE MARKETED AMOUNT IS COLLECTED FOR TREATMENT

	Selected WEEE Categories		
	Products in category 3 IT and tele equipment	Products in category 4 Consumer equipment and photovoltaic panels	Products in category 9 Monitoring and control instruments
Material value (including plastics, iron and aluminium)	504	297	38-42
Value of critical materials	394	131	17-33
Scenario 1 (low loss)			
Value of critical materials	73	16	2-6
Scenario 2 (high loss)			
Value of critical materials	162	46	6-14

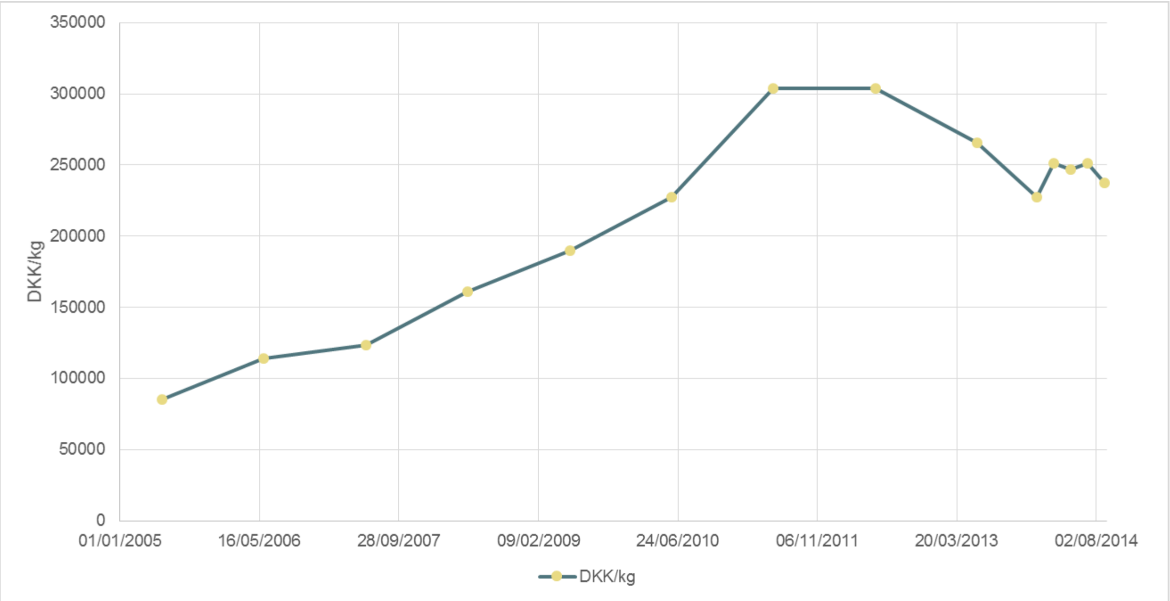
TABLE 13 ESTIMATED VALUE IN DKK MILLION OF MARKETED PRODUCTS IN CATEGORY 3, 4 AND 9 IN DENMARK IN 2010 ASSUMING THAT 45% OF THE MARKETED AMOUNT IS COLLECTED FOR TREATMENT IN DANISH SORTING PLANTS

	Selected WEEE Categories		
	Products in category 3 IT and tele equipment	Products in category 4 Consumer equipment and photovoltaic panels	Products in category 9 Monitoring and control instruments
Material value (including plastics, iron and aluminium)	227	134	17-19
Value of critical materials	177	59	8-15
Scenario 1 (low loss)			
Value of critical materials	33	7	1-3
Scenario 2 (high loss)			
Value of critical materials	73	21	3-6

2.10 Importance of price fluctuations

The value of materials typically varies significantly over time. In the present estimation, gold dominates the value of high tech products like computers, representing around 50% of the residual value of critical resources as shown earlier. Figure 18 shows that the gold price has changed from DKK 80000/kg to more than DKK 300000/kg in 2011 and it has now dropped a little again to approximately DKK 246000/kg. Therefore, the gold price is very important for a future economy in recycling of electronics. However, no one can make a price, as gold apart from use as a resource is used as an important physical money reserve, which is dependent on politics, wars and the worldwide economy.

FIGURE 18 MARKET PRICE OF GOLD FROM WWW.MONEX.COM



Other examples of price development:

> Neodymium changed from approximately DKK 850/kg in August 2012 to DKK 500/kg in the summer of 2014. Tantalum changed from approximately DKK 3000/kg in August 2012 to DKK 2400/kg in the summer of 2014.

In total, the estimated economic values of critical resources in the products in category 3, 4 and 9 are not valid for a longer period of time and will depend on the future market situation of these resources.

2.11 Future trends of importance to recycling

In the following a number of trends in the development of electronic products are shown, which should be considered when developing new technologies for increased recycling.

New digital products in the society of today are becoming increasingly compact products.

Today, the sale of TVs and monitors is based on flat screen technologies compared to the older CRT technology. Hereby the amount of CRT screens will decrease in WEEE within a number of years and technologies for treatment of CTRs will no longer be required. Regarding the flat screens for TVs and monitors, it seems that the screen size will increase for the same price, which will give a higher amount of flat screen material for recycling.

PCs have changed from desktops to laptops/notebooks and in parallel with an increasing market of screen-based computers like iPads and tablets, which in some cases just are an enlarged touchscreen mobile phone without phone capability. In 2009, the amount of laptops was larger than desktops according to (I.Bakas, 2013)

The number of sold mobile phones is rather constant according to (I.Bakas, 2013), but today they are mostly touchscreen phones with large displays compared to earlier mobile phones. Therefore, the content of resources from the flat screens in the phones is becoming more important as an economic resource. Overall, many modern products have a flat information screen including many printers, and therefore technologies for efficient recycling of materials in flat screens is an issue for further development of technologies.

The development of compact products has required the use of very small surface-mounted components where the functionality is integrated in a few specialised chips. Although PCBs are small, they have a considerable amount of critical resources including gold per weight, and it is therefore important to minimise the loss in mechanical treatment plants either by improving the technologies used in the plants or by developing techniques for separate dismantling of the most valuable PCBs.

Regarding storage technologies, the traditional hard disks, which contain neodymium, are being replaced with SSDs (solid-state drives) in new PC products and are the only storage in iPads/ tablets. However, the price per GB is still much lower (a factor 10) for a hard disk than for a SSD as mentioned in (Munce, 2012), which is why hard disks are expected to exist for some time as backup in homes and for running the Internet and business server storage facilities. Therefore, technologies for recycling materials in hard disks could still be of interest in the future, but probably more in the public and private sector than in households.

3. Danish players

3.1 Introduction

We have identified Danish players within 'the golden triangle' (DAKOFA, 2014) of players around WEEE: EEE producers, WEEE treatment companies and technology suppliers. We have identified 1,575 EEE producers, around 100 relevant technology suppliers and 5-10 WEEE treatment companies in Denmark. The technology suppliers have shown a keen interest in automation of WEEE treatment. Among the relevant technology suppliers, 83 were interested in knowing more about the strategic cooperation among players. We have not interviewed EEE producers systematically for this study, but a small proportion is expected to take an interest in the strategic cooperation.

In addition, we have identified key experts in Danish knowledge organisations. In this section, we present the different groups of players.

3.2 Danish EEE producers

The first group of players is the producers and importers of electric and electronic equipment (EEE producers). EEE producers are involved in the treatment of WEEE through the principle of extended producer responsibility [EPR], which extends the producers' responsibility for a product to the post-consumer stage of the lifecycle of the product. In Denmark, producers and importers of electrical equipment, batteries and vehicles must organise and finance take-back and waste management of the products and report information to a central producer register, the DPA-register. The DPA-register currently includes 1,575 Danish and foreign companies (DPA-Systems, 2014).

As mentioned above, EPR is mandatory within the context of WEEE in the European Union through the directives for WEEE, Batteries, and End-of-life Vehicles [ELV]. These Directives place the responsibility on the producers for the financing of collection, recycling and responsible end-of-life disposal of WEEE, batteries, accumulators and vehicles. The purpose of EPR is to encourage producers to include environmental considerations already in the design process of the product. These producer obligations may be transferred to a collective scheme, which then assumes most of the practical tasks associated with producer responsibility for its members such as registration in a producer register (DPA-System), collection of allocated household WEEE from collection sites, take-back logistics, etc.[4]

These collective schemes have been an effective instrument in organising the waste problem from WEEE. It can, however, be argued that the collective schemes form an 'iron curtain' between the waste industry and the EEE producers, thus reducing the incentive among producers and importers to engage actively in working with design for reuse, tack-back arrangements or efficient use of WEEE resources.

Individual EEE producers may benefit directly from cooperation with waste management companies. One of the most debated options for business opportunities has been the idea of designing for reuse and closed-loop or take-back arrangements. In such arrangements, selected

[4] https://www.dpa-system.dk/en/WEEE/Producers/Producer-schemes/Collective-schemes

products or product parts are identified in the WEEE and then sorted out and returned to the EEE producers for refurbishment and recirculation of the products.

Figure 19 presents the 1575 EEE producers and importers in Denmark registered in the DPA-system by category, with the producers and importers distributed by sector.

FIGURE 19: OVERVIEW OF REGISTRED EEE PRODUCERS AND IMPORTERS IN DENMARK BY SECTOR SOURCE DPA-SYSTEM (DPA-SYSTEMS, 2014) AND CALCULATIONS BY DTI

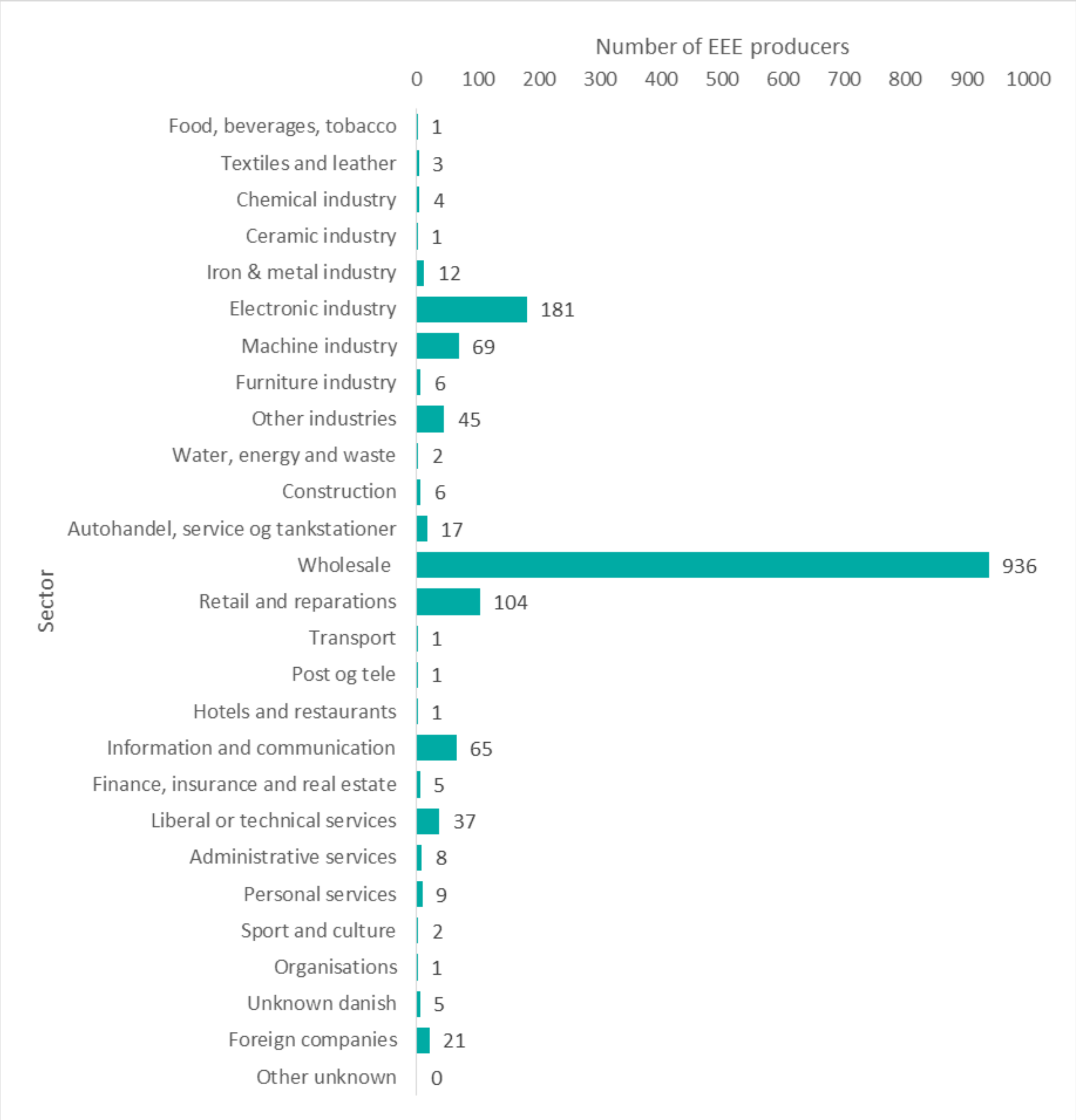


FIGURE 19 SHOWS THAT THE MAJORITY OF COMPANIES THAT DELIVER ELECTRIC AND ELECTRONIC PRODUCTS TO THE DANISH MARKET IMPORT THE PRODUCTS. OUT OF 1,575 COMPANIES IN THE REGISTER, 936 ARE ENGAGED IN WHOLESALE, WHICH MEANS THAT THE MAJORITY OF COMPANIES ARE PRIMARILY ENGAGED IN IMPORTING OR EXPORTING PRODUCTS. JUST 322 COMPANIES DEFINE THEMSELVES AS MANUFACTURING COMPANIES AND OUT OF THESE ONLY 181 ARE ACTUALLY PART OF THE ELECTRONICS INDUSTRY.

FIGURE 20: BUSINESS PRODUCTS; OVERVIEW OF NUMBER OF EEE PRODUCERS AND IMPORTERS IN DENMARK BY PRODUCT CATEGORY, SOURCE DPA-SYSTEM (DPA-SYSTEMS, 2014) AND CALCULATIONS BY DTI

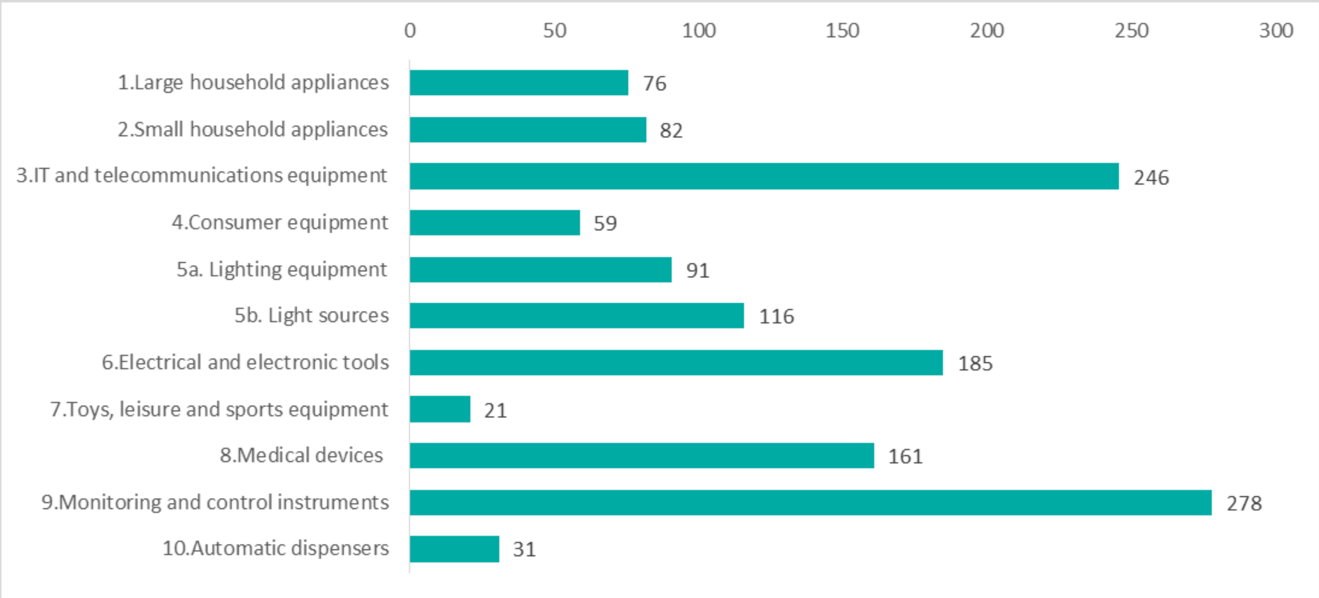


FIGURE 21: HOUSEHOLD PRODUCTS; OVERVIEW OF NUMBER OF EEE PRODUCERS AND IMPORTERS IN DENMARK BY PRODUCT CATEGORY, SOURCE DPA-SYSTEM (DPA-SYSTEMS, 2014) AND CALCULATIONS BY DTI

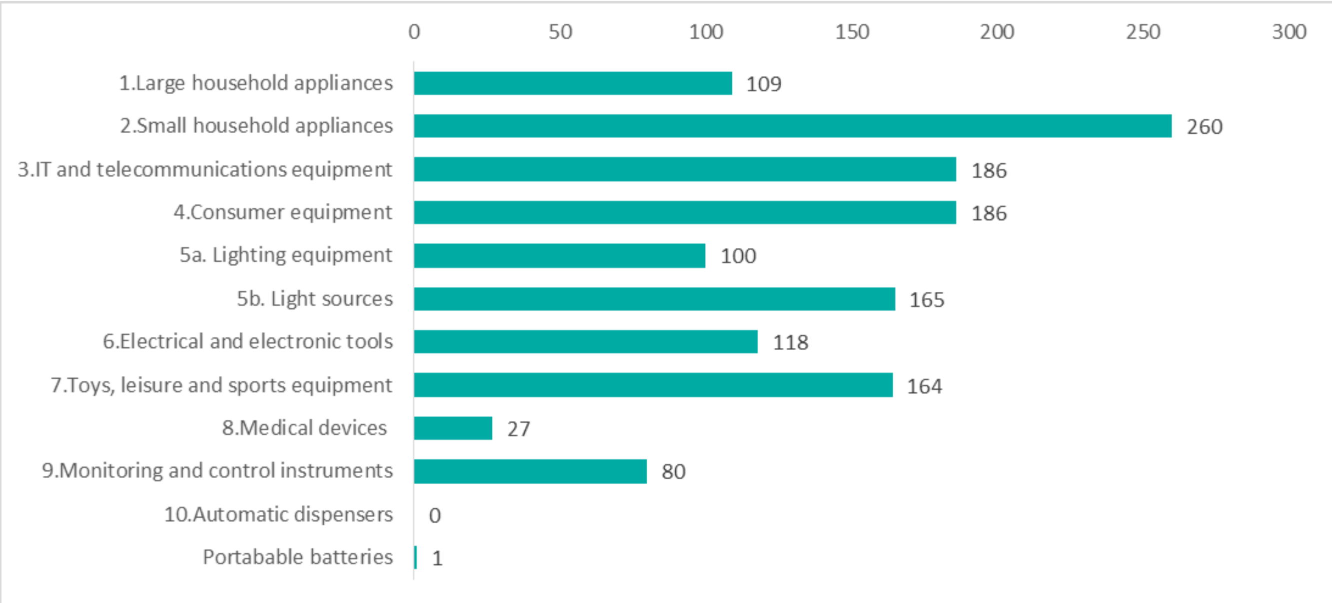


Figure 20 and Figure 21 divide the EEE producers and importers by product category and market (business and households). In the business market, the main product groups are IT and telecommunications equipment and monitoring and control instruments. For households the largest group is small household appliances and the next group is IT and telecommunications and Consumer equipment.

FIGURE 22: OVERVIEW OF EEE PRODUCERS AND IMPORTERS IN DENMARK BY CATEGORY AND SECTOR SOURCE DPA-SYSTEM (DPA-SYSTEMS, 2014) AND CALCULATIONS BY DTI

	EEE businesses											
Sectors	1.Large household appliances	2.Small household appliances	3.IT and telecommunications equipment	4.Consumer equipment	5a. Lighting equipment	5b. Light sources	6.Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	7.Toys, leisure and sports equipment	8.Medical devices (with the exception of all implanted and infected products)	9.Monitoring and control instruments	10.Automatic dispensers	Business - total
Food, beverages, tobacco	1	1	0	0	0	0	0	0	0	0	1	3
Textiles and leather	0	0	0	0	0	0	1	0	0	1	0	2
Chemical industry	0	0	0	0	0	0	0	0	2	0	1	3
Ceramic industry	0	0	0	0	0	0	1	0	0	0	0	1
Iron & metal industry	0	1	1	0	2	3	3	0	0	2	0	12
Electronic industry	3	4	29	7	19	18	8	3	10	76	1	178
Machine industry	21	4	4	1	1	2	20	0	5	16	3	77
Furniture industry	0	0	0	1	0	0	0	0	1	0	0	2
Other industries	0	0	5	1	1	1	3	2	14	16	0	43
Water, energy and waste	1	0	1	0	0	0	1	0	0	0	0	3
Construction	1	0	0	0	0	0	0	0	0	1	0	2
Autohandel, service og tankstationer	0	0	0	2	0	0	4	1	0	1	0	8
Wholesale	46	62	150	37	59	75	135	9	121	135	21	850
Retail and reparations	1	3	8	4	4	6	2	3	1	1	0	33
Transport	0	0	0	0	0	0	0	0	0	0	0	0
Post og tele	0	1	0	0	0	0	0	0	0	0	0	1
Hotels and restaurants	0	0	0	0	0	0	0	0	0	0	0	0
Information and communication	0	1	31	2	1	2	0	0	2	11	1	51
Finance, insurance and real estate	0	1	1	0	0	0	0	1	1	2	0	6
Liberal or technical services	1	1	5	1	2	3	4	0	2	8	0	27
Administrative services	0	0	0	0	0	3	0	0	0	1	2	6
Personal services	0	0	4	0	0	0	0	0	0	3	0	7
Sport and culture	0	0	0	0	0	0	0	0	0	0	1	1
Organisations	0	0	0	1	0	0	0	0	0	0	0	1
Unknown danish	0	0	1	0	1	1	0	0	0	0	0	3
Foreign companies	1	1	1	1	0	0	2	1	2	2	0	11
Other unknown	0	2	5	1	1	2	1	1	0	2	0	15
Total	76	82	246	59	91	116	185	21	161	278	31	1346

	EEE Households												
Sectors	1.Large household appliances	2.Small household appliances	3.IT and telecommunications equipment	4.Consumer equipment	5a. Lighting equipment	5b. Light sources	6.Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	7.Toys, leisure and sports equipment	8.Medical devices (with the exception of all implanted and infected products)	9.Monitoring and control instruments	10.Automatic dispensers	Portabable batteries	Households - total
Food, beverages, tobacco	1	1	0	0	0	0	0	0	0	0	0	0	2
Textiles and leather	0	1	1	1	0	0	0	1	0	0	0	0	4
Chemical industry	0	1	0	0	0	0	0	0	0	0	0	0	1
Ceramic industry	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron & metal industry	1	1	0	0	0	0	0	2	0	0	0	0	4
Electronic industry	2	10	5	14	7	11	1	1	3	9	0	0	63
Machine industry	5	1	0	0	0	0	2	1	1	6	0	0	16
Furniture industry	2	0	0	0	0	1	0	0	1	1	0	0	5
Other industries	0	1	3	1	0	0	0	3	1	2	0	0	11
Water, energy and waste	1	0	0	0	0	0	1	0	0	0	0	0	2
Construction	1	2	0	2	1	2	1	0	0	1	0	0	10
Autohandel, service og tankstationer	1	6	4	5	4	4	9	9	0	1	0	0	43
Wholesale	70	168	94	87	59	95	66	87	14	38	0	1	779
Retail and reparations	18	38	30	37	19	28	24	38	2	11	0	0	245
Transport	0	0	0	0	0	1	0	0	0	0	0	0	1
Post og tele	0	1	0	0	0	0	0	0	0	0	0	0	1
Hotels and restaurants	0	0	0	0	0	1	0	0	0	0	0	0	1
Information and communication	0	3	16	12	1	2	1	3	1	1	0	0	40
Finance, insurance and real estate	0	1	0	0	0	0	0	0	0	2	0	0	3
Liberal or technical services	2	4	9	5	3	5	4	4	0	1	0	0	37
Administrative services	0	0	2	0	0	2	0	0	0	2	0	0	6
Personal services	0	1	0	2	1	2	1	0	0	1	0	0	8
Sport and culture	0	0	0	0	0	0	0	1	0	0	0	0	1
Organisations	0	0	0	0	0	0	0	0	0	0	0	0	0
Unknown danish	1	2	2	1	2	2	0	0	0	0	0	0	10
Foreign companies	2	7	9	7	0	2	3	7	2	1	0	0	40
Other unknown	2	11	11	12	3	7	5	7	2	3	0	0	63
Total	109	260	186	186	100	165	118	164	27	80	0	1	1396

Figure 22 combines data from Figures 3-5 to show in which sectors and for which product groups the companies are active. The figure illustrates both the business market and household market and one company may appear in both markets. The figure is colour coded in red, yellow and green as a heat map to make it easier to read figure. A green cell illustrates a large number of companies, and a red cell illustrates a limited number of companies. The table shows that most manufacturing companies are in the electronics industry and primarily supply the business market. Seventy-six companies manufacture 'monitoring and control instruments'.

Figure 23 organises the EEE producers and importers from the DPA-System by sector and number of employees. The majority of companies are SMEs (small and medium-sized companies). Only 158 companies have more than 100 employees in Denmark. Most of the importing companies (found under wholesale) are rather small – even though they may import a significant amount of EEE.

FIGURE 23: DANISH EEE PRODUCERS AND IMPORTERS BY SECTOR AND SIZE SOURCE DPA-SYSTEM (DPA-SYSTEMS, 2014) AND CALCULATIONS BY DTI

Sectors	No of employees						Total no of companies
	0 or unkown	1 to 9	10 to 19	20 to 49	50 to 99	100+	
Food, beverages, tobacco	0	1	0	0	0	0	1
Textiles and leather	0	0	0	3	0	0	3
Chemical industry	0	1	0	0	1	2	4
Ceramic industry	1	0	0	0	0	0	1
Iron & metal industry	0	3	2	3	3	1	12
Electronic industry	16	69	24	32	17	23	181
Machine industry	0	21	10	13	9	16	69
Furniture industry	0	0	0	1	1	4	6
Other industries	3	23	6	4	3	6	45
Water, energy and w aste	1	0	0	0	0	1	2
Construction	0	3	3	0	0	0	6
Autohandel, service og tankstationer	1	5	5	2	2	2	17
Wholesale	65	413	171	163	61	63	936
Retail and reparations	28	41	8	3	6	18	104
Transport	0	1	0	0	0	0	1
Post og tele	1	0	0	0	0	0	1
Hotels and restaurants	0	1	0	0	0	0	1
Information and communication	10	22	5	14	3	11	65
Finance, insurance and real estate	3	0	0	0	0	2	5
Liberal or technical services	8	12	3	7	2	5	37
Administrative services	1	2	0	2	0	3	8
Personal services	3	3	1	1	1	0	9
Sport and culture	0	0	0	1	0	1	2
Organisations	1	0	0	0	0	0	1
Unknow n danish	5	0	0	0	0	0	5
	147	621	238	249	109	158	1522

The incentive for EEE companies to work directly with the waste industry on for instance take-back or design is a challenge for the following reasons:

- First, most of EEE production takes place outside Denmark and very often in multinational companies with the primary production even further back in the value chain. Multinational companies sell a large number of products in a large number of countries, and the products are constantly changing in response to demand, cost of production and distribution, technologies, competitors' products, etc. Thus, communication of needs or opportunities identified in the waste industry has a long way to travel to decision makers.
- Second, in Denmark most national EEE companies are rather small and may lack resources such as time, manpower, competences, money, technology or attention. 10 per cent have more than 100 employees. Danish EEE companies can be owned by or be a part of multinational companies – ownership is not registered.
- Third, the distance between EEE producers and the waste industry caused by the collective schemes may itself reduce the incentive.

However, a number of companies may see potential business opportunities in joining a scheme designed for recycling or cooperating/trading directly with WEEE companies. Interviews and direct contact to these companies are necessary in order to assess the true figure of relevant companies. Interviews with EEE producers have not been a part of this study, but almost 600 relevant producers[5] with more than 50 employees received an invitation to a workshop in August 2014 on possible business opportunities in the strategic cooperation as well as an invitation to join the network. The fact that only a few EEE producers attended the workshops arranged by DAKOFA illustrates the challenge.

3.3 Danish WEEE management companies

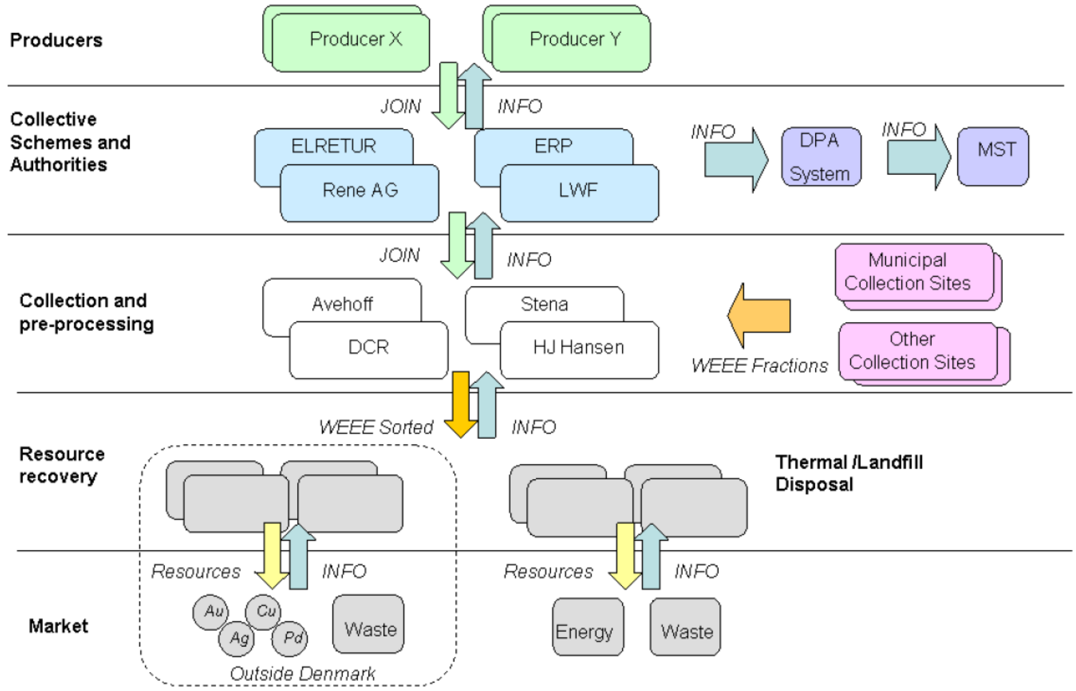
The second group of players is the WEEE management companies in Denmark. These companies collect, sort and prepare WEEE. Depending on the product or material, their business models vary.

The input material for the WEEE management companies is WEEE, and the companies sort the material and/or prepare the material for further recycling depending on their business model and place in the value chain. In some cases, WEEE management companies are paid to collect WEEE (end-of-use products and materials), and in other cases they buy WEEE (if the content of the materials is valuable).

The output from the WEEE management companies is sorted materials and/or sorted product parts. Most of the output materials are sold for further treatment, such as metals that are typically sold to smelters such as Boliden (SE), Umicore (BE) or Aurubis (DE), or for other forms of recirculation. A small fraction of WEEE is sold for energy use or disposal. The prices of treated WEEE are determined by the purity of the material fractions, their usefulness as a raw material for manufacturing companies further downstream, as well as the demand for the recycled material. A small fraction of the output may be sold to EEE producers or other manufacturing companies that require materials or parts (closed-loop). Each WEEE management company has its own business model and negotiates contracts individually with clients. There is no public insight into contract conditions or price formation. Some WEEE management companies do not treat WEEE but are primarily transport companies or waste brokers.

[5] The data in DPA-System can only be applied for statistical analysis such as the tables above and not as an address-database for contacting EEE producers and importers. Instead, we have used other sources for identifying companies (ITEK, Experian) to whom we believe cooperation with the waste sector may be profitable.

FIGURE 24: PRINCIPAL PLAYERS WITHIN THE WEEE MANAGEMENT SYSTEM INSIDE DENMARK (DANISH MINISTRY OF THE ENVIRONMENT, 2012)



As mentioned above, according to Frost & Sullivan (Frost & Sullivan, 2013), Scandinavia has the most efficient WEEE scheme in Europe with a collection rate in 2012 of 17.2 kilo per capita. In Denmark, the figure is 16.4 kilo per capita (Frost & Sullivan, 2013). The Danish WEEE collection system is explained in Environmental Project no. 1416 (Danish Ministry of the Environment, 2012). Collection of WEEE is organised by local authorities. Figure 24 provides an overview of the main WEEE players. They are ELRETUR (collection of household waste), ERP, RENE AG (Recycling Network Europe), and LWF (the light source business' WEEE association). According to Frost & Sullivan, there are almost 392 collection centres in Denmark.

Averhoff A/S and Stena are some of the main WEEE players in Denmark. They are both part of large international companies.

- Since 2010, **Kuusakoski Oy** has owned 80 per cent of Averhoff A/S. Kuusakoski Oy is a Finnish family-owned group which posted revenue of approx. EUR 842 million in 2012 and had activities in Scandinavia, Europe, the Baltic States and Eastern Europe, Russia, Asia and the USA. (Averhoffs website, 2014). Kuusakoski Oy had a share of 16% of the Scandinavian market in 2012. Kuusakoski Oy has two patents in materials sorting techniques and one in material grade classification techniques (Thomson Reuters, 2014).
- **Stena Technoworld** was the market leader in Scandinavia in 2012 with a market share on the Scandinavian market of 43.4 per cent. The company has sophisticated and innovative recycling solutions and efficient processes for precious metal separation (not in Denmark). In Denmark, the company operates under the name Stena Technoworld A/S. Stena Technoworld is owned by Stena Metall A/S. Stena technoworld A/S collects WEEE in Denmark and treat the collected WEEE in Sweden and Germany. Stena has a patent from 2011 called 'Quicksilver-containing waste product e.g. LCD, using method for use in e.g. entertainment industry, involves providing quicksilver-containing fragment larger than predetermined measurement from closed chamber'.

The third Scandinavian player is **Sims Recycling** Ltd, which had 29.7 per cent of the Scandinavian market in 2012 but was not present on the Danish market. The company has advanced technologies for non-ferrous scrap separation (Frost & Sullivan, August 2013). Sims Recycling is not a registered company name in the company register in Denmark, but it is still possible that WEEE collected in Denmark is treated at Sims recycling sites in Sweden. There is no documentation on this.
At the Scandinavian level, the remaining 11 per cent of the market share is divided among other companies (Frost & Sullivan, August 2013). In Denmark this includes companies such as DCR Miljø and the recent entry DAN WEEE Recycling A/S. Category 3, 4 and 9 WEEE is treated by Averhoff A/S, DCR Miljø and DAN WEEE Recycling A/S.

The remaining companies are primarily involved in collecting, sorting and exporting WEEE: HJ Hansen Genindvindingsindustri A/S, Jernpladsen A/S, Marius Pedersen A/S, Uniscrap A/S (owned by Scholz Holding GmbH), GP Metal A/S, Skrotpriser.dk, Ragn-Sells A/S (owned by Swedish Ragn-Sells AB), erecycling.dk (offspring of Sympia A/S) all have some WEEE sorting and preparing activities in Denmark. Altogether, Frost & Sullivan identified 110 companies in Scandinavia in 2013.

The Scandinavian WEEE recycling market's revenue amounted to $138.8 million in 2012 and the two leading participants accounted for $101.3 million (Frost & Sullivan, August 2013). Frost & Sullivan expect the three dominant players to grow due to dominance of the markets and advanced technologies. The size of the Danish market is not recorded or measured separately by Frost & Sullivan. An estimation of the Danish market can made using population proportions. About 22 % of the Scandinavians are Danes and the Danish market revenue can be estimated to a value around $30.5 million (equal to about 180 million Danish kroner[6]) – but probably a little lower since the main players are in Sweden and Finland.

This figure includes all types of WEEE. The value in Denmark may increase if waste is efficiently treated in Denmark or decrease if collected WEEE is exported to treatment plants in Sweden, Germany or Poland. The figure also illustrates that smelters consume the lion's share of the material value. The value of the treated waste can be increased by refining the fractions and by finding a more differentiated market[7].

3.4 Danish WEEE technology suppliers

The third and final group of players considered in this report is companies that can deliver automation technology for recognising, sorting, preparing and treating WEEE. The technology scope is very wide and can be everything from low-tech shredders to hi-tech X-ray recognition - often in combination with robotics.

Technological solutions are of interest, since sorting and treating WEEE to high-value fractions is labour intensive and automated solutions may be profitable. Technological solutions usually require a capital investment in the WEEE companies. This means that new technologies will only be introduced if they are considered profitable and fit the investment cycle of the company. WEEE may attract the attention of technology suppliers that until now have focused on developing technology for other highly automated sectors.

If WEEE automation technologies are developed, tested or sold commercially in Denmark, this could open up for further business opportunities involving actors in the EU or globally since WEEE is a high-interest area in most countries due to volumes and its contents of valuable or strategically important materials.

[6] Exchange-rate November 2014 – 1 DKK = $0.1673
[7] Interview with Brian Clemmensen, CEO Danweee 10-11-2014.

We have used a broad snowball method to identify relevant Danish technology suppliers. The first step was to scan relevant forums, websites and databases. We included companies that:

- were already part of the existing strategic cooperation managed by DAKOFA;
- had patents on WEEE relevant technologies - identified through searches in the Derwent World Patents Index;
- were members societies and organisations, i.e. DIRA[8] (Danish Industrial Robot Association), DAU[9] (Danish Society for Automation) and BIA[10] (Danish Sector Organisation for Industrial Automation);
- could be identified with relevant NACE codes in the Danish company database Experian; and
- by using the network at Danish Technological Institute to add more companies to the list.

During the interviews, we asked the companies to supplement the list. A total of 320 companies were identified this way as potentially relevant Danish technology suppliers. Jysk Analyse A/S attempted to contact all the companies by phone to conduct an interview. In cases where the phone number was missing or was incomplete, the correct number was found on the internet or in company databases. Jysk Analyse A/S, which carried out all the telephone interviews, made up to 15 phone calls to each company. The data collection took place over a relatively long period – from 8 May to 12 June 2014.

Out of the 320 companies, Jysk Analyse A/S managed to get in touch with 260 (81%). Forty-nine of these did not want to participate in the survey. Twenty-seven companies wanted to receive the questionnaire as an internet survey – of these, 5 companies participated wholly or partly. In total, Jysk Analyse A/S conducted 184 interviews, corresponding to just over 57 per cent. Out of these, 102 companies appear to have some relevant technology that can be adapted to the WEEE process.

The true number of relevant companies may be slightly higher. However, Jysk Analyse A/S believes that the large majority of relevant companies completed the survey, given that most technology suppliers can be assumed to have self-interest in selling their technology. The results are presented in the chapter on Danish strongholds.

3.5 Danish knowledge institutions on automation technologies

The final group is the knowledge institutions in Denmark that specialise in automation technologies. Danish Technological Institute identified 43 experts from key knowledge institutions in Denmark. Some institutions such as DTU or Danish Technological Institute have several relevant departments.

All the experts were contacted personally with an e-mail survey. Two reminders were sent in the process. The survey ran for three weeks. Nineteen (44 per cent) did not answer – corresponding to 56 per cent answered. Twenty-four answered and out of these three experts did not wish to contribute. In total, we received 21 completed questionnaires.

[8] http://www.dira.dk/
[9] http://www.dau.dk/
[10] http://www.b-i-a.dk/

TABLE 14: OVERVIEW OF KNOWLEDGE INSTITUTIONS IN DENMARK ON AUTOMATION TECHNOLOGIES

Alexandra Instituttet A/S
COWI A/S
Danish Automation Society (DAu)
Danish Robotics Network
Danish Standards
Danish Technological Institute
Danish Technological Institute, DMRI
Danish Technological Institute, Aarhus
Delta – Danish Electronics, Sound and Acoustics
DTU Elektro, Department of Electrical Engineering
DTU Informatics
DTU- Nanotech
DTU, Mechanical engineering and management
DTU-IPU
FORCE
Mercantec
Metal and machine industry
Rambøll Danmark A/S
Robot cluster
Technical University of Copenhagen
University of Copenhagen
University of Southern Denmark
University of Southern Denmark – Department of Chemistry, Bio and Environmental Technology
University of Southern Denmark – Department of Technology and Innovation
University of Southern Denmark (Mærsk McKinney Møller Institute)
Aalborg University
Aalborg University, Automation and Control
Aarhus School of Marine and Technical Engineering

We present the results of the interviews in the next chapter.

4. Danish technology WEEE treatment strongholds

4.1 Introduction

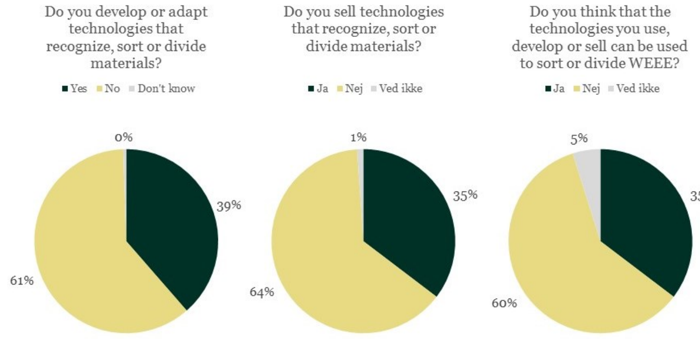
Like in most other industries with labour intensive processes, the WEEE industries are facing competition from low-wage countries. Therefore, automation technologies are attracting interest in the WEEE industry. In this chapter, we explore Danish automation technology that could be used for sorting, dismantling and preparing WEEE. We identified 320 technology suppliers of which 185 companies responded, and 102 of the interviewed companies believe that the technologies they develop or sell can be used to recognise, sort or divide materials. The technologies are applied in a wide range of sectors from pharmaceuticals to cement, food or recycling. For most companies customisation and adaption to a specific customer needs is necessary. The technologies require expert knowledge to install. The majority of the suppliers are companies that adapt technologies developed abroad or are part of multinational companies. Hence, the Danish strongholds among technology suppliers tend to the ability to adapt technologies rather than develop their own proprietary technologies. The experts in Denmark are scattered across knowledge institutions such as universities and technology service institutes. In most of the institutions, no more than a man-year is devoted to technologies for automated recognition, treatment or sorting.

4.2 Danish technology suppliers

Studies (Danish Technological Institute, Ecorys, CRI, 2013) of WEEE treatment facilities indicate that an important barrier to improving the treatment of WEEE is the quality in sorting, dismantling and preparing WEEE. Another main barrier is that we are dealing with a high-wage labour intensive process making it difficult to create a profit from the process. This challenge is similar to challenges in all other manufacturing sectors where automation vs. sourcing to low-wage countries is on the agenda. For the WEEE industry there is inspiration to find in other sectors, and relevant automation technologies for recognising, sorting and dividing materials may already have been developed in other industries.

In this section, we present the results of the survey interviews with Danish technology suppliers. As explained above, the interview company Jysk Analyse A/S contacted 320 Danish technology suppliers and from this group we successfully interviewed 184 companies. Of the 184 interviewed companies, 55 per cent develop, adapt or sell technologies that can be used to recognise, sort or divide materials. Thirty-five per cent of the interviewed companies believe that the technologies they develop or sell can be used to sort or divide WEEE.

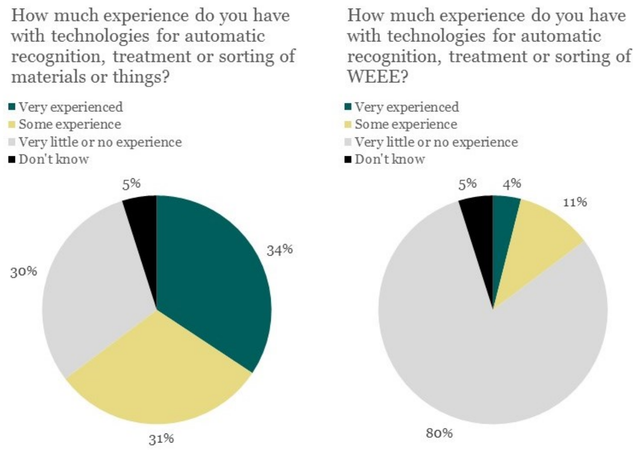
FIGURE 25: COMPANIES WITH RELEVANT TECHNOLOGIES



Source: Danish Technological Institute and Jysk Analyse. N=184

Companies that develop, adapt or sell technologies to recognise, sort or divide materials may have technologies relevant to the treatment of WEEE. Chances are that even technologies that have been developed or marketed for other purposes in other sectors may still be relevant in some way or the other for the treatment of WEEE. The first three questions as displayed in Figure 25: were used as an initial filter in the survey, and only companies that answered 'yes' to at least one of the three questions were interviewed further.

FIGURE 26: RELEVANT EXPERIENCE



Source: Danish Technological Institute and Jysk Analyse. N=102.

For some of the companies that we interviewed, automatic recognition, treatment or sorting of materials are core functions of their technology. For others, it is not at the core of their business. Among the 102 companies, about two-thirds are very experienced or have some experience with automatic recognition, treatment or sorting of materials. Only four companies believed that they were very experienced in applying the technologies to WEEE, and another eleven companies had some experience.

We asked the companies to describe the technologies they develop, adapt or sell: What type of technology do they sell? Where are the technologies currently applied? Which features of their product do they believe to be a unique selling point?

The companies emphasise vision technologies in some form or the other in combination with automation. They use sensors, cameras, scanners, X-rays, infrared light, colour recognition and so forth. The technologies are used for a very wide range of purposes:

- quality control of medical packaging;
- measuring the amount of fluids in a glass;
- removal of materials or gasses;
- automated image treatment;
- automatic recognition of objects controlled by robots;
- sorting on conveyer belts;
- quality control;
- cutting of meat;
- assembling or testing of electronics;
- cleaning of seeds;
- labelling of products;
- traceability; and
- precision work and heavy- and high-speed work.

The vision + automation technologies are typically used in the pharmaceutical industry and the cement, metal, food, recycling and high-tech sectors.

The technologies are unique in different ways, and the companies point to unique selling points such as integrated solutions, advanced robotics and environmentally friendly systems, combination of speed and precision, cloud computing, robustness in harsh or tough industrial environments, stability, adaptability, customisation by the customer, ease-of-use, service and knowhow. Other companies explain that the technology they use is standard and they sell adaption of technologies according to market demand.

The overall impression from the interviews is that for both own-developed technologies and standard technologies, customisation and adaption of the technology are necessary in most cases when applied. Automation technologies are still not off-the-shelf standard-box products. The adaption and installation of standard technologies to meet end-user needs require expert knowledge and competences. Some companies market products that feature ease-of-use and easy customisation by the customer, while others have strong support and service schemes. No companies mention low price as a unique selling point.

In the survey, the companies give a short description of the technologies they work with. In Figure 27 the descriptions are analysed by creating a “word cloud”[11] where the clouds give greater prominence to words that appear more frequently in the descriptions of technology. The descriptions were provided in Danish, but the word “VISION” stands out clearly – as well as the word genkende (recognise).

[11] See http://www.wordle.net/

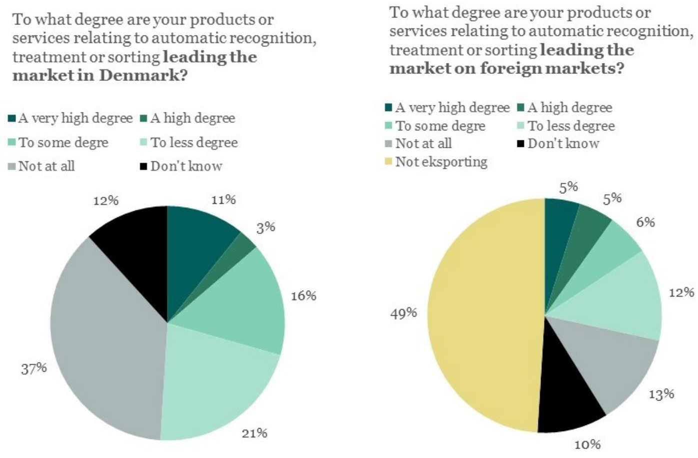
FIGURE 27: WORDLE IMAGE OF DESCRIPTIONS OF THE TECHNOLOGIES MARKETED BY THE TECHNOLOGY SUPPLIERS

Source: Danish Technological Institute and Jysk Analyse. N=66. Created with wordle.net

Application of technologies on WEEE

The companies were asked for suggestions on how their technology could be used to recognise, sort or divide waste in WEEE. Some companies already have technologies in place on the market, some had no idea, and others have suggestions based on their existing experiences. The companies point to optical sorting of metals, X-ray that could be used to identify valuable components to pick and place tasks or standard machines that could be used for sorting after the WEEE had been divided into fine parts. Some companies require waste to be labelled, coded or marked in some way before sorting is possible. One company believes that its technology would be too expensive to be profitable for WEEE.

FIGURE 28: DANISH STRONGHOLDS? MARKET LEADING COMPANIES



Source: Danish Technological Institute and Jysk Analyse.. N=102.

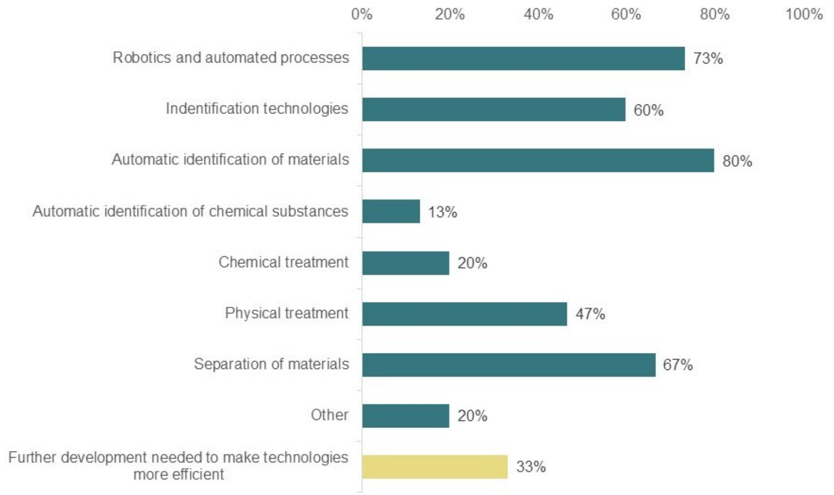
Fourteen per cent of the companies believe that they are market leaders in Denmark in connection with automatic recognition, treatment or sorting. Ten per cent believe that they are market leaders in connection with foreign markets. Below we show examples of market leaders in Denmark or internationally whose markets' automation technologies are relevant for WEEE:

- **ABB Robotics** (ABB) is a leading supplier of industrial robots, modular manufacturing systems and service. ABB has installed more than 200,000 robots worldwide. ABB is involved in almost all industries. In Sweden, ABB power and automation technologies has been helping the metal company Boliden to create the world's largest electronic scrap recycling facility that recovers copper and precious metals from electronic scrap using only a fraction of the energy required to extract metals from ore. The company has more than 150,000 employees worldwide and operates in +100 countries. In Denmark, ABB markets robots with cameras and is a market leader in connection with industrial robotics (ABB, 2014). See http://www.abb.dk/
- **DanRobotics A/S** in Middelfart in Denmark adapts and sells industrial robots from Swedish ABB. DanRobotics A/S adapts and installs the robots, trains employees and provides services. The robots are flexible and work at high speed with great precision. Dan Robotics delivers complete automated handling systems from small and simple systems to advanced handling systems (Dan Robotics, 2014). See http://www.danrobotics.dk/
- **Parameter ApS** sells camera technology that operates with visible and infrared spectrums, used to identify objects by form, colour and size. Parameter ApS works in a multitude of different market segments such as paper, wood, bio-medicine, electronics, off-shore, food, semi-conductor, traffic, robotics and manufacturing. The parent company is Swedish and its +500 customers are start-ups as well as established corporations and universities[12] (Parameter Aps, 2014). See http://www.parameter.se/
- **InnospeXion ApS** is a Danish company who manufactures and sells x-ray technologies used for quality sorting of materials in the food industry and which may be applied to screening for valuable objects within WEEE. One of its unique capabilities is making use of spectral information for the identification of specific substances and elements. (InnospeXion, 2014). See http://www.innospexion.dk
- **Rockwell Automation A/S** is part of a global automation and robotics company that markets sensors for colour recognition and other optical sensors. The sensors may be integrated into other systems. Rockwell Automation claims to be the world's largest company dedicated to industrial automation[13] and markets a wide range of automation technologies. Rockwell Automation is engaged in a wide range of sectors, but activities in the waste sector are not mentioned on its website except for waste water treatment (Rockwell Automation A/S, 2014)**.** See http://www.rockwellautomation.com/dnk/overview.page
- **Trivision A/S** markets vision technology in the form of cameras and software that can be used for sorting. Trivision cooperates with, among others, Kas-Tech (owned by Saxe) which supplies automation systems, PWR-Pack and Polymac (automation, robotics) (see http://trivision.dk/partnere). Trivison systems are used in the food industry to sort packaging, butter and cheese. According to Trivision A/S the system can be adapted to WEEE (Trivision A/S, 2014). http://trivision.dk/
- **Image House A/S** sells camera-based software systems from a wide range of global technology suppliers (Acuity, ARH, CCS, JAI, Cognex Vision, URIX software, which may also be used for WEEE (Image House A/S , 2014). See http://www.imagehouse.dk/leverandoer),

The above information is from the company websites and from direct contact with companies.

[12] http://www.parameter.se/
[13] http://www.rockwellautomation.com/rockwellautomation/about-us/company-overview.page?

FIGURE 29: COMPETENCES AMONG EXISTING SUPPLIERS OF WEEE TREATMENT TECHNOLOGY



Source: Danish Technological Institute and Jysk Analyse. N=15 – companies that has experience with WEEE treatment.

Expert level

Among the interviewed companies, 15 note that they are somewhat or highly experienced in supplying technologies to be used in the treatment of WEEE. FIGURE 29 gives a quick overview of the existing competences in these companies; automatic identification of materials, robotics and automated processes and separation of materials are among the most common. One out of three companies needs further development before existing technologies can treat WEEE even more efficiently.

International suppliers

Among the 15 expert level companies, five develop their own technology, three are wholesalers, and seven adapt technologies from suppliers and customise their own technologies to a varying degree. Eleven of the 15 companies find their main technology suppliers in Germany, a few find them in the rest of the world, i.e. Denmark (2), Sweden (4), Finland (3), Benelux (3), the USA (6) and China. None of the companies has suppliers from Japan.

Size

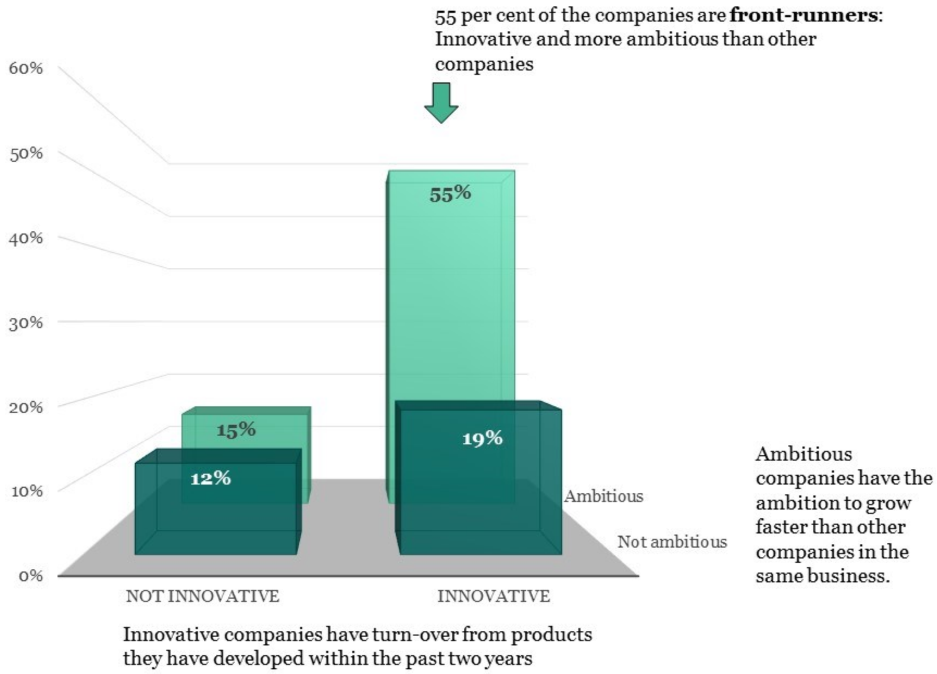
The 102 companies employ what corresponds to 1911 man-years employed with technologies for automation of recognition, treatment and sorting of materials. The largest company has 640 employees. One in four companies is an exporter and earns one in four kroner of their revenue from export activities. Nine companies have more than half their turnover from exports, and two companies export almost all their products.

International market

The most important customers for automatic recognition, treatment and sorting technologies for the 15 expert level companies are outside Denmark in Germany (4), the UK and the USA (2), Sweden (1), and other countries (4). Two companies have their main clients in Denmark.

Part of a value chain

The interviews and the examples strongly indicate that the majority of relevant Danish suppliers are companies that adapt technologies developed abroad or they are already part of multinational companies. The expertise and knowhow in the companies consist in combining existing technologies for automatic recognition, sorting and handling of materials. There is already some experience in Denmark concerning WEEE, but there appear to be a number of major international companies specialising in automation and robotics that already operate in Denmark in other sectors than WEEE.



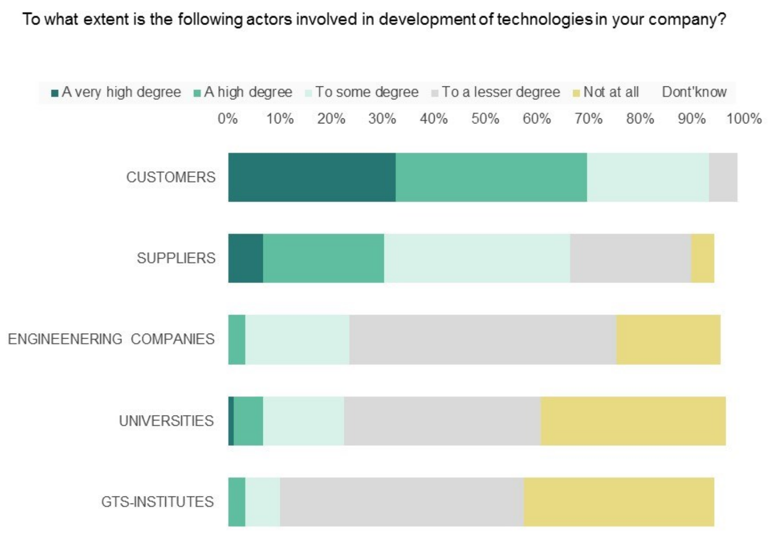
Source: Danish Technological Institute and Jysk Analyse. N=102

Figure 30 divides the companies into four groups based on their ambition to grow and their ability to develop their own products that can sell or their ability to innovate. Ambitious and innovative companies are considered front-runners. Danish Technological Institute has used the questions concerning ambition and innovation in a number of previous studies. The front-runner companies are very often[14] characterised by being more professional, knowledge-oriented and in many aspects more dynamic than non-innovative companies that present themselves as non-ambitious. Fifty-five per cent of the 102 interviewed companies fall into the front-runner category. The figure is usually around 25-40 per cent, which indicates that this WEEE supplier 'sector' and potential WEEE suppliers are very ambitious and innovative companies.

Figure 31 gives an insight into the organisation of the innovation process in the companies. "Companies" in this section refers to the 102 interviewed technology suppliers. The figure illustrates how almost all companies involve their customers in the development process to some or a high degree. This is largely a matter of the companies adapting and customising solutions for their customers. The companies have no standard off-the-shelf solutions that their customers can simply buy and install. In addition, suppliers to the companies play an important role for the companies. The suppliers that supply the original technology will often be selling parts and components, so close contact and sparring with suppliers make sense. This illustrates how the innovation process has its own value chain from OEM manufactures via suppliers to the companies who, in close contact with their customers, adapt or modify the parts and components into solutions. External to this value chain is technology advice and services. Traditional technology advice and services from experts in engineering companies, research at universities, or technology advisers in the GTS-system[15] are not as common for the companies as cooperation with customers and suppliers.

[14] Danish Technological Institute has used the indicators on innovation and ambitions in surveys since 2008. Among them panel studies and individual studies – in total the questions have been asked well over 50,000 times to Danish companies. In these studies the category of 'front-runners' are consistently characterised by being more professional, knowledge-oriented and in many aspects more dynamic than non-innovative companies that present themselves as non-ambitious.
15 GTS – Advanced Technology Group is a network consisting of nine independent Danish research and technology organisations.

FIGURE 31: TO WHAT EXTENT DO YOU INVOLVE THE FOLLOWING PLAYERS IN DEVELOPING TECHNOLOGIES?



Source: Danish Technological Institute and Jysk Analyse. N=102

4.3 Danish knowledge institutions on WEEE technologies

We received 21 responses from knowledge institutions. Twelve of them have some or much experience with automation technologies for recognition or sorting materials or objects. Just one institution works with technologies that can be used directly for automated WEEE treatment (again recognition, sorting or handling), and nine institutions work with technologies that can be applied to WEEE after some development and adaption. In a sense, this mirrors the situation for the companies, i.e. there are relevant technologies that can be used for WEEE, but in most situations the technology will need adaption.

The technologies mirror the technologies that exist in the companies as well, i.e. recognition combined with robotics, vision systems, infrared vision, multispectral analysis, Prompt Gamma Neutron Activation Analysis (PGNAA), X-rays or detection via electro-chemical or mechanical methods.

Just a few institutions have WEEE as their primary focus. Among the interviewed knowledge institutions, two institutions have published in international scientific literature on automation in recognition, sorting or handling of WEEE. Three are working with private companies on automation in recognition, sorting or handling of WEEE.

Commercial technologies

Four of the institutions are commercially active in developing, adapting and selling technologies to private companies that can be used for automatic treatment of WEEE. Three technologies have been mentioned above, i.e. automatic detection of chemical elements in the material by PGNAA, vision technologies applied to conveyer belts to detect objects that deviate from the norm, and a combination of a variety of sensors. All of the mentioned technologies still need further development before they are ready to be marketed as an efficient way to recognise and sort WEEE. Three of the institutions rely primarily on their own technologies and one combines its own technologies with supplier technologies. The suppliers of technologies come from Denmark, Sweden, Germany, the UK, the USA and a few other European countries. There are no Japanese or Chinese suppliers.

Size
In most of the institutions (10) not more than one man-year is devoted to technologies for automated recognition, treatment or sorting. Three institutions have allocated three man-years. In the interviewed institutions altogether 19 man-years are used. Three institutions have an annual turnover of DKK 3 million from their work with automated recognition, treatment or sorting. Two have an annual turnover of DKK 2 million and one has a turnover of DKK 1 million. The total turnover in this field for the interviewed institutions was DKK 6 million. Two of the institutions have an ambition of a higher growth than other players in the 'industry'.

Market
One institution of the four commercially active institutions believes that their technology is market-leading in Denmark; none of them believe that they are an international market leader. Their primary market is Denmark, a little is sold in Sweden, and one institution has sold a commercially insignificant amount in the USA. It is worth noting that the four institutions are innovative and have a turnover from technologies they have developed within the past 2 years. In one institution, the entire turnover stems from new products.

Cooperation
The four commercially active institutions work with external experts to some degree. Two work with engineering companies, three with universities, and all of them with GTS – Advanced Technology Group institutions (GTS-institutions) in Denmark.

Turning from the companies relevant for and interested in WEEE in Denmark and their technologies to the available e-waste technologies in Europe and rest of the world, we will in the following investigate the latest technological developments.

5. E-waste technologies

5.1 Introduction

The latest developments in e-waste technologies set the scene for its commercial potential in Denmark. If companies are to succeed, it is important to be aware of the existing technology landscape but also the latest technological trends. Which technologies are already out on the market? And what are the most important technological developments? This chapter highlights the technological developments, using patent data and bibliometric analysis to identify the technology trends in e-waste technologies.

Electronic and electric products are continuously getting smaller and more complex. This results in an increased need for efficient and accurate dismantling processes in the waste processes. Critical or valuable materials in WEEE are not recovered through mechanical processes such as shredding. This is a loss to both the individual WEEE company and to society as a whole.

Material recovery is a major theme in e-waste technologies; especially material recovery of rare earth minerals is a technological focus area with the strongest annual growth from 2006 to 2010 in the population of WEEE patents analysed.

The number of technological developments in e-waste is increasing, both in terms of new unique high-tech products (patents) and in terms of academic knowledge (publications). A patent analysis shows that the number of e-waste patents is increasing due to a dramatic increase in China. A bibliometric analysis shows that publication activity has increased significantly every year since 2002, and the yearly activity is now 10 times as high as in 2002.

Overall, separation (dismantling) is the field with the most patent activity. This can be an indicator of the technological challenges involved in separating valuable materials from e-waste. There is also some technological volume in treatment and extraction, while collection and sorting are less technology intensive and therefore less patent-active. Separation and extraction technologies seem to be the most influential technologies with an increased level of new activity. Separation technologies have increased dramatically since 2005 and extraction technologies since 2010.

There are many technologies for dismantling, processing and treating WEEE with rare earth metals and precious metals, but not in a cost-efficient manner. Focus should therefore be on how this could be changed.

5.2 Methodology

5.2.1 Patent analyses

We analysed the global strongholds in e-waste using a patent analysis. The analysis was based on patents granted within the relevant technologies. Patents give the assignee a legal protection of the invention that the patent describes, so that other firms or individuals cannot use this technology. A patent office will grant the patent if the invention described in the application is truly unique (WIPO, 2013).

Patent analysis provides insight into countries and regions' unique strengths in specific technologies and development. Who contributes to innovation and technological development? A way to quantify global strongholds in a technology field is as the number of patenting organisations or the total number of patents. Since patents are only granted for unique inventions, adaptations of existing technologies do not count. In other words, the patent analysis maps the unique technologies in a country while adjustments are not included.

TEXT BOX 5-1: DATA FOR THE PATENT ANALYSIS

The patent database Derwent World Patents Index is the world's most comprehensive database of patents. Experts at Thomson Reuters who know a given technology field translate and improve the original patent data. They edit, analyse, sum up and index all patent information manually. This means that the database provides the most complete picture in the world of developments in new technologies. The database has a global reach in English – and it includes most data from Asia. This is important at a time when Asian research and development are really beginning to stir. The data editing, coding, indexing are consistent across the world patent offices. The large amount of data means that you can find inventions and developments that you could otherwise easily overlook. The patents are divided into more than 20 million patent families covering nearly 50 million patent applications.

SOURCE: DANISH TECHNOLOGICAL INSTITUTE (WWW.TECH-OUTLOOK.DK)

It is essential to retrieve the right patents that relate to e-waste terminology. Otherwise, the search might include patents not related to e-waste and thereby render the result unreliable. Another methodological error in the technology search is to have too narrow search criteria, whereby the results may be biased. In other words, it is crucial to use the right search criteria that find all the relevant patents without including non-relevant patens. Therefore, we have used a search string from WIPO with all the relevant technology codes.

Patents technologies are grouped according to the International Patent Classification (IPC). This official patent classification system is used in over 100 countries to ensure consistent classification of technologies. The IPC technology codes are hierarchical, consisting of 8 sections, 129 classes, 639 subclasses, 7,314 main groups and 61,397 subgroups. In other words, the IPC codes classify technologies in patents to an extremely detailed level, using more than 60,000 specific technology codes. This makes it possible to search for specific technologies within the otherwise overwhelming total number of 93 million patents.

Some technology codes are clearly e-waste technologies. Others technology codes are more ambiguous and can include patents with e-waste technology and patents not containing e-waste technology. Therefore, we only include patents with these ambiguous technology codes when e-waste terminology is used in the patent.

TEXT BOX 5-2: TECHNOLOGIES FOR HANDLING OF E-WASTE

IPC-codes

A62D0101*	Harmful chemical substances made harmless, or less harmful, by effecting chemical change
B03B000906	General arrangement of separating plant; specially adapted for refuse
B03C0001*	Magnetic separation techniques
B09B0003*	Disposal of solid waste
B29B0017*	Recovery of plastics or other constituents of waste material containing plastics
B29B001702	Separating plastics from other materials
C08J0011*	Recovery or working-up of waste materials
C09K001101	Recovery of luminescent materials
C22B*	Production and Refining of Metals
H01B0015*	Apparatus or processes specially adapted for salvaging materials from cables
H01J000952	Recovery of material from discharge tubes or lamps
H01M000652	Reclaiming serviceable parts of waste cells or batteries
H01M001054	Reclaiming serviceable parts of waste accumulators

* Only included when e-waste terminology is used in the patent.

TEXT BOX 5-3: PATENTS AND PATENT FAMILIES

Throughout this section we focus on patent families and not individual patents. The same invention can be patented in more than one country, so a single invention may result in several patent applications for multiple countries. Patents families relate to the unique invention and collect all patents that derive from the same invention in one patent family. The European Patent Office defines a patent family as follows:

'*A patent family is a set of either patent applications or publications taken in multiple countries to protect a single invention by a common inventor(s) and then patented in more than one country. A first application is made in one country – the priority – and is then extended to other offices.*' (European Patent Office, 2014)

We use patent families instead of the overall number of patents since it is a more direct measure for technological innovation. Patent families relate to the number of new unique inventions, while the overall number of patents is partly a result of the inventors' patenting strategy.

SOURCE: DANISH TECHNOLOGICAL INSTITUTE (WWW.TECH-OUTLOOK.DK)

5.2.2 Bibliometric analysis

We carried out a bibliometric analysis of research publications from companies and research institutions concerning e-waste. The analysis of research publications is based on two types of publications, i.e. peer-reviewed articles in academic journals and publications presented at international conferences.

Thomson Reuters indexes both publication types in its premier database of bibliometric data, Web of Science. Using this data, we identify individual players and groups of players that generate research output in various disciplines concerning e-waste. By analysing the content of these publications, we can also see how the disciplines have developed over time and thus identify trends in the pattern of development of the individual disciplines.

TEXT BOX 5-4: SEARCH STRING FOR BIBLIOMETIC ANALYSIS OF E-WASTE PUBLICATIONS

We performed a keyword search in all fields in the Web of Science database. We searched for different ways that e-waste is described. The keywords were 'e-waste', 'electronic waste', or 'WEEE'. Another search criterion was publication years in the period from 1990 to 2014.

5.3 General technology trends

A general trend in the technological development is that the development of the products and the product design determine what the end processors receive from the dismantling companies. There is a clear trend that electronic products in general (with exceptions such as flat screens) are getting smaller and more complex, which can make the dismantling process more difficult and result in loss of WEEE.[16] However, in the demolition process, there is often the expectation that recyclers can extract all WEEE in a closed loop. Recycling is increasingly costly and it is challenging to find technologies to separate WEEE, and some electronics cannot be separated at all using current technologies. For instance, if a lithium-ion battery is to be dismantled from a smartphone, many other metals are lost in the process using current technologies. In addition, a very precise automatic process (perhaps robotics) is needed to distinguish the materials from each other.[17]

In addition, it should be noted that certain mechanical processes such as shredding can reduce the amount of WEEE and thereby contribute to losing part of the recovered material (Frost & Sullivan, August 2013). For instance, the recovery of gold in desktop PCs is between 80-97 per cent when using manual recovery methods, but ranges from 26 to 70 per cent when using mechanical processes. Another example focuses on the pre-processing efficiencies for critical metals in TVs and flat screen monitors, where manual processes in many cases recover 60 per cent of the critical material, whereas mechanical processes (involving shredding) recover 0 per cent. This is, for instance, true for lithium and beryllium (Bakas, Fisher, Harding, & et.al., 2013). These findings are supported by interviews. Clearly, some companies may have found a business model that makes manual handling cost-effective, but for most Danish companies, manual sorting processes are too expensive. Thus, automation, for instance in the form of robotics, can be a solution for improved dismantling of WEEE.

5.4 The patent landscape

The global patent portfolio forms a technology landscape of different technologies used to handle e-waste.

Figure 32 shows the patent landscape for e-waste technologies. WIPO made this theme-scape based on the most commonly occurring concepts and phrases in the e-waste patent collection (WIPO, 2013). The figure gives a holistic view of the different themes in e-waste technologies. As the outcome of the underlying text mining analysis is presented as a topographical map, it is easy to see which items share related text. If several patents share related text items, these text items will appear as mountains on the map: The more related the items are, the higher the mountain (WIPO, 2013).

[16] Interview with EERA Recyclers
[17] Interview with EERA Recyclers

WIPO divides the e-waste patent collection into three key concepts:

- materials that are recovered and recycled from e-waste streams, items such as plastics and metals;
- sources of e-waste and the processing of these sources, such as batteries, displays, cabling and printed circuit boards; and
- the processes and logistics involved in e-waste treatment or recycling, such as magnetic sorting, IT-related management of recycling systems and similar items (WIPO, 2013).

The figure below indicates that material recovery is a major overall theme in e-waste technologies. Several patents have shared text concerning Rare Earth Metals, Noble Metals, etc. In other words, material recovery is a central theme in e-waste patents.

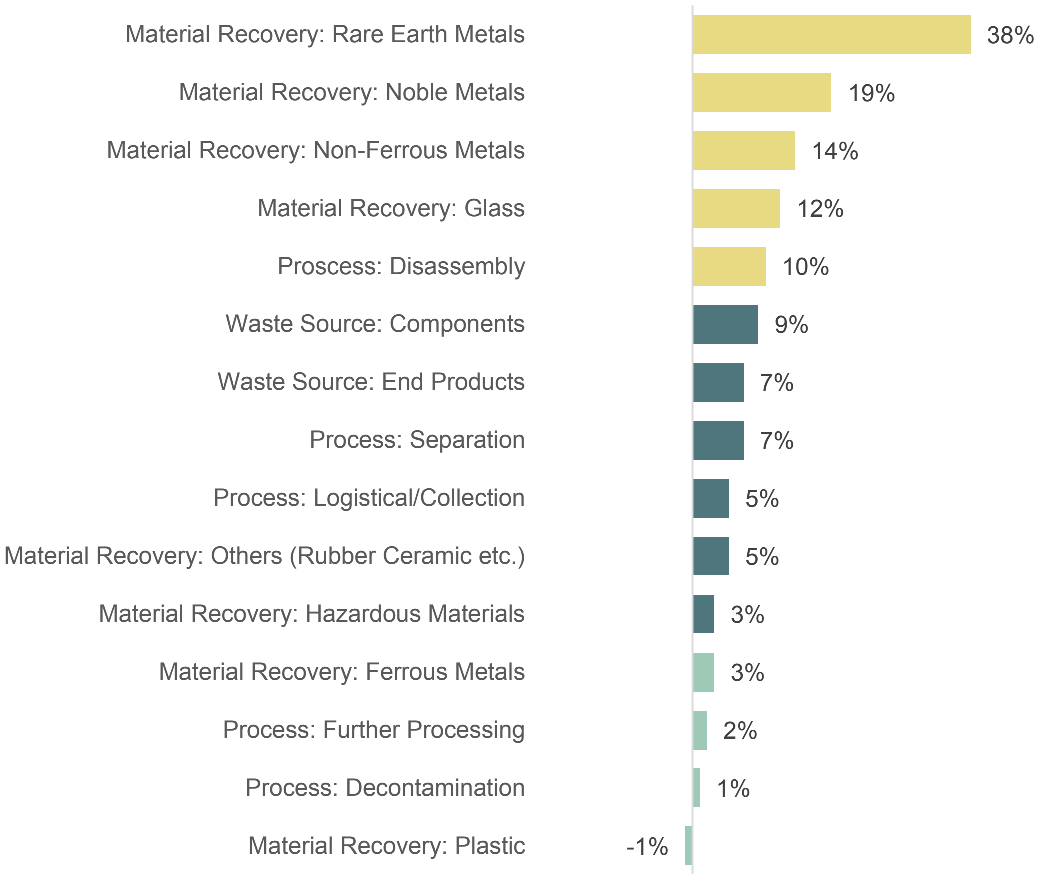
FIGURE 32: PATENT LANDSCAPE FOR E-WASTE TECHNOLOGIES

SOURCE: WIPO'S 'E-WASTE PATENT LANDSCAPING' (WIPO, 2013).

It is worth noticing that material recovery is a theme with a substantial annual growth. In other words, the patent activity concerning material recovery themes is generally increasing.

Figure 33 shows the annual growth or decline in different e-waste themes. The figure shows the development in activity level but not the absolute level of activity. In other words, it highlights e-waste themes on the rise. Four themes concerning material recovery stand out as the themes with the most increasing patent activity. The level of activity for rare earth metals is not as high as other areas of interest, but is by far the area with the highest *increase* in activity; the patent activity has seen an annual growth of 38% from 2006 to 2010.

FIGURE 33: ANNUAL GROWTH OR DECLINE OF RECENT PATENT ACTIVITY TRENDS, 2006 TO 2010



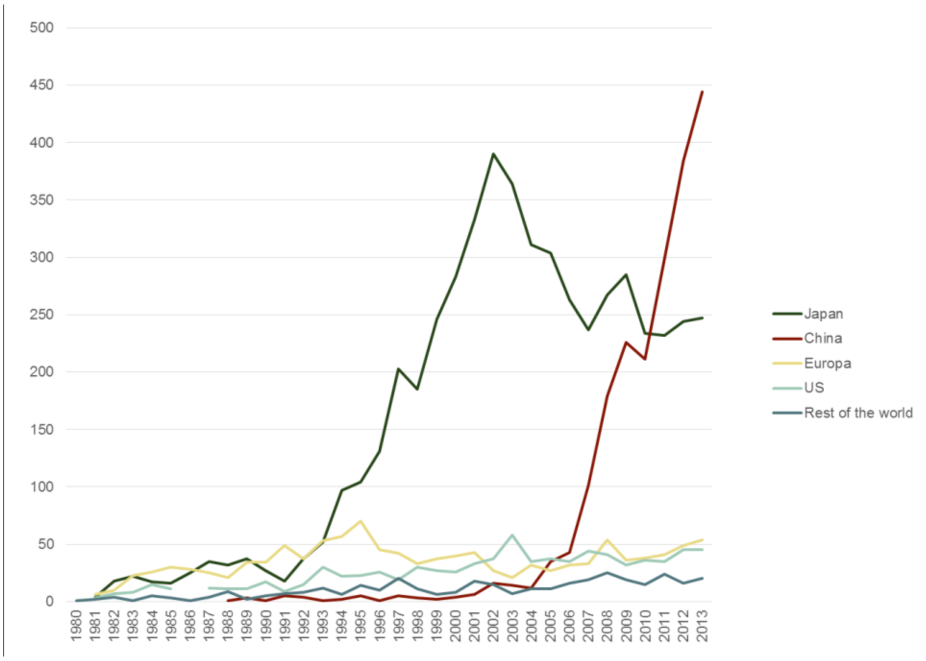
SOURCE: WIPO'S 'E-WASTE PATENT LANDSCAPING' (WIPO, 2013)

5.5 Development in technological activity

The historical development in e-waste patent activities is quite remarkable. Until the mid-1990's, Europe held a global stronghold in e-waste patents with almost the same patent activity as Japan. However, in the following years the patent activity in Japan increased dramatically until it peaked in 2002. In 2002, the number of granted patents in Japan was ten times as high as in Europe, while the patent activity in Japan and Europe were at the same level ten years before. The patent activity in Japan has decreased since its peak in 2002, but the activity level is still greater than Europe's. Currently, Japan introduces five times as many patents a year as Europe.

China appears to be on its way to gain a dominant global stronghold. Japan still holds the largest number of aggregate patents, but China clearly has the largest number of new e-waste patents per year. This is due to a dramatic increase in China's e-waste patent activity since 2004. In 2006, China passed the activity level of Europe and the USA. By 2011, it passed Japan as well in terms of granted patents per year, and the increase in China's innovative level has continued since then.

FIGURE 34: DEVELOPMENT IN THE NUMBER OF NEW E-WASTE PATENTS PER YEAR

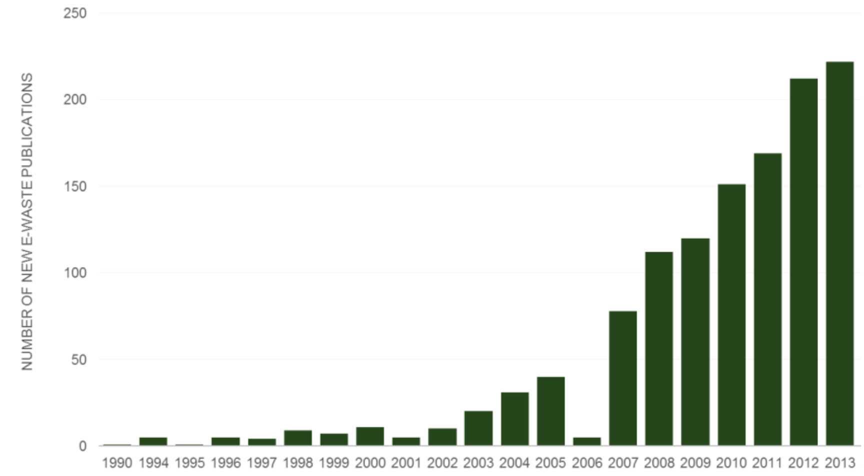


SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

E-waste is an academic area on the rise. Since the millennium, the number of new e-waste publications has increased substantially. The overall increase is due to increases in all the important regions. However, China stands out as a global leader with an increasing academic activity. China accounts for 32 per cent of all e-waste publications from 1990 to 2014.

Figure 35 shows how the number of new e-waste publications increased from 20 in 2003 to 222 in 2013. In other words, the academic activity is 10 times as high as ten years ago.

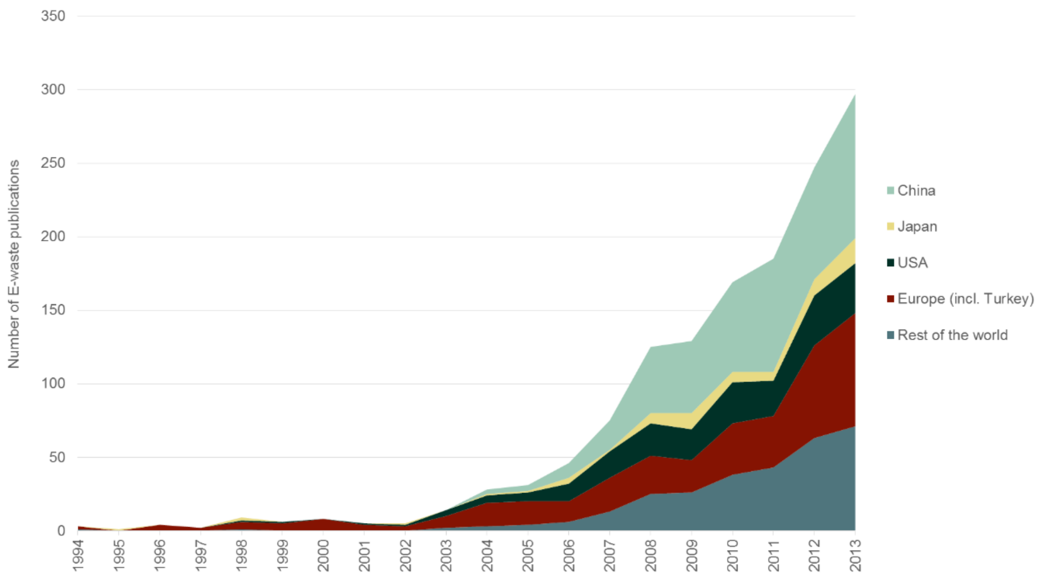
FIGURE 35: DEVELOPMENT IN THE NUMBER OF E-WASTE PUBLICATIONS, 1990-2013



SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION. 2014 IS INCOMPLETE (DATA FROM SPRING 2014, SO THE YEAR IS NOT FULLY REGISTERED)

The increase in academic activity is due to an increased academic level across several regions. China seems to have gained a leading role measured in number of new e-waste publications. The academic activity level in Europe and the rest of the world has increased as well.

FIGURE 36: DEVELOPMENT IN THE NUMBER OF E-WASTE PUBLICATIONS, BY REGION



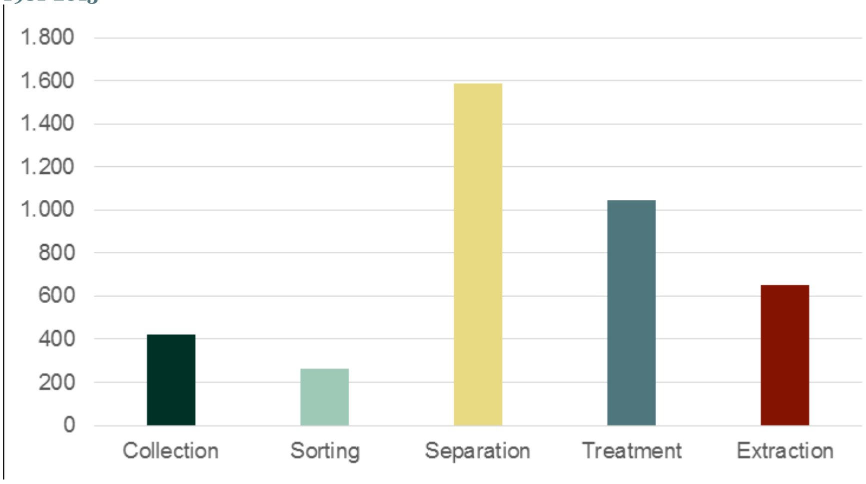
SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION. A PUBLICATION CAN BE REGISTERED IN SEVERAL COUNTRIES, SO THE TOTAL NUMBER IS NOT COMPARABLE WITH FIGURE 35.

With 1,586 patents, separation (dismantling) is the largest technological field in terms of patent volume. The next largest field is treatment (pre-processing) with 1,047 patents. Extraction (end processing) has 654. At the other end of the supply chain, collection and sorting have 423 and 264 patents respectively.

Overall, separation (dismantling) is the field with the highest patent activity. This indicates that there is a great technological challenge in dismantling valuable materials from e-waste or that the currently available technologies can be improved with advantage. Literature and interviews showed that mechanical processes such as shredding could reduce the amount of WEEE and/or mix it with other waste streams such as glass or plastics. This can lead to lower quality of recycled materials (Frost & Sullivan, August 2013). The patents in this phase may therefore be used for other dismantling techniques to increase the quality of the recycled materials.

There is also some technological volume in treatment (pre-processing) and extraction (end-processing), while collection and sorting naturally are less developed in terms of technology.

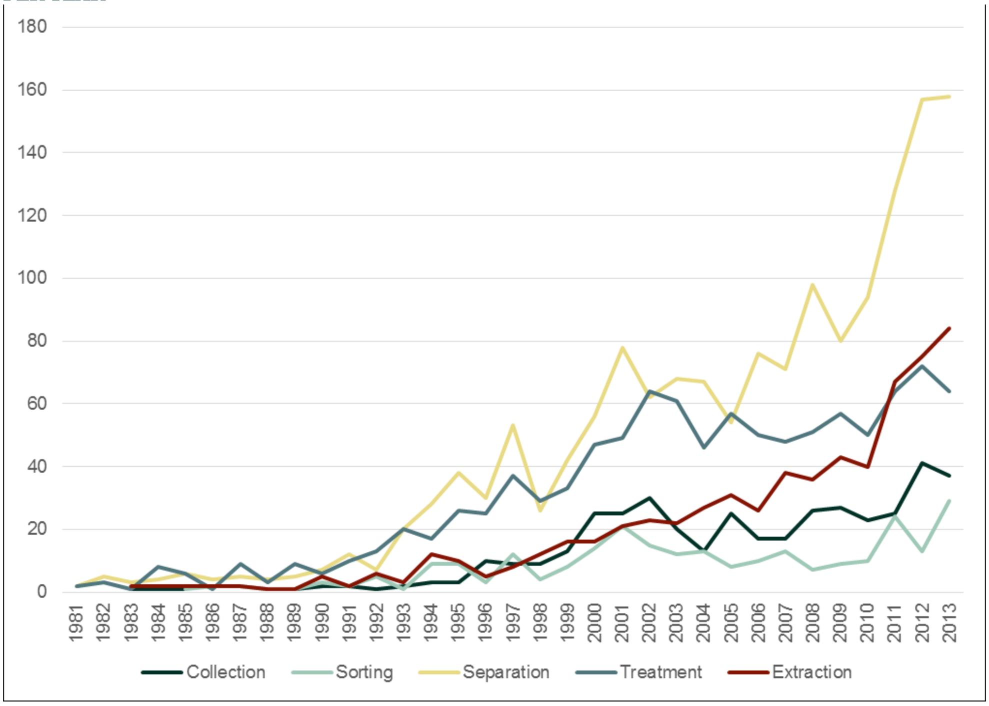
FIGURE 37: NUMBER OF PATENTS FOR TECHNOLOGIES USED IN THE DIFFERENT E-WASTE PHASES, 1981-2013



SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

Technological developments in the different phases are quite remarkable. Until 2005, technological developments in separation and treatment were at quite similar levels. Since 2005, technological developments in separation technologies have increased dramatically. Separation technologies now account for the largest number of new patents per year. There seems to be a technological trend in extraction (end processing) technologies, since the patent activities for these technologies have increased drastically since 2010. Extraction technologies have surpassed treatment technologies as the second most patented technology of these five technology fields, Extraction technologies seem to continue to rise, while development of treatment technologies seems to have stagnated.

FIGURE 38: DEVELOPMENT IN TECHNOLOGIES USED IN DIFFERENT E-WASTE PHASES, NEW PATENTS PER YEAR



SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

There is an interesting global pattern in regional technological activity. China, the USA, Europe and the rest of the world focus primarily on dismantling and secondarily on pre-processing technologies. Japan stands out in three ways: First, Japan is almost as active in pre-processing as in dismantling. Second, Japan has by far the highest patent activity in collection technologies. Third, Japan holds the strongest patent activity within all different e-waste phases.

China is relatively strong on end-processing technologies, where they are almost at the same level as Japan. Europe's technological focus is similar to the USA and rest of the world. However, Europe holds a stronghold in pre-processing technologies where it is the second-most active region.

FIGURE 39: TECHNOLOGIES USED IN DIFFERENT E-WASTE PHASES, BY REGION

	China	Japan	US	Europe	Rest of the world
Collection	26	309	33	18	42
Sorting	65	107	13	62	19
Dismantling	391	569	173	247	225
Pre-processing	169	509	88	189	112
End-processing	191	218	56	82	111

SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

5.6 Specific e-waste technologies

The different emerging e-waste technologies are introduced in an interactive presentation at the web-site Tech-Outlook.dk.[18] The interactive graph shows the latest emerging technologies. Patents introduced in the last 3 years are presented according to technology group. We have identified when the different technologies were introduced in a given area. This can give an indication of emerging technologies. The technologies are grouped according to their function.

In the sections below we will focus on specific technologies.

5.6.1 Visual recognition

The DTI-survey of the Danish technology strongholds highlights that some Danish technology deliverers consider themselves to be market leaders in Denmark or on foreign markets with products or services relating to automatic recognition, treatment or sorting. Visual recognition appears to be a stronghold in Denmark. Therefore, this section looks further into the patent activity in visual recognition technologies.

FIGURE 40: THE MOST COMMONLY USED KEYWORDS IN PATENTS CONTAINING TECHNOLOGIES FOR VISUAL RECOGNITION

[18] full link: http://tech-outlook.dk/index.php?option=com_content&view=article&id=33:e-waste-technologies&catid=16&Itemid=126&lang=en

SOURCE: DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION AND THE VISUALISATION INSTRUMENT WORDLE.NET.

One hundred and forty-four international e-waste patents contain keywords that relate to visual recognition technologies. Some of these technologies use visualisation either to sort WEEE or to automate the separation of WEEE.

TEXT BOX 5-5: SEARCH STRATEGY FOR VISUAL RECOGNITION TECHNOLOGIES

The search for visual recognition technologies took place in the previously defined data set for e-waste technologies. We did a keyword search for 'visual', 'camera' and 'recognition' in the patent field 'DWPI – Independent Claims'. This field has a detailed description of what the patented technology can be used for.

TEXT BOX 5-6: GLOBAL VISUAL AND AUTOMATION TECHNOLOGIES

Examples of relevant Visual and Automation Technologies
Apparatus for processing e.g. electric light bulbs has a sensor or camera that recognises forms of fluorescent tube or electric light bulb type lighting fixture by sensing or image discrimination and determines two cutting positions.
An automatic and precise alignment and assembly system for printed circuit board and its method
An automatic production line laser wire stripping device has positioning clamps arranged on a recycle operation conveying mechanism, where positioning lines of positioning clamps strip wires by lasers emitted from upper and lower laser heads.
An automatic separation system for separating plastic fragments and impurities has an electronic valve installed between air compressor and nozzle, where the electronic valve and camera are connected to a computer
A method for classification of e.g. recyclable plastic material in home appliance involves sliding down recyclable plastics material from a flat plate by difference in friction coefficient of materials, so that unnecessary material is separated.
A method for disassembling storage batteries, e.g. manganese cell, involves taking out electrode elements from the container by moving the container while the electrode element is gripped, so that the element and container separate from each other
A hyperspectral waste sorter for sorting residue from e.g. refrigerator shredding includes a hyperspectral camera for image objects in the waste stream.
Identifying and sorting used equipment batteries for evaluation involves storing images detected by camera for each battery, transforming it into a simplified pattern or parameter set characterising the battery and comparing it with a stored pattern or parameter set using a computer
An inspection system for individual inspection of a continuous stream of e.g. blueberries in the food industry has a control unit configuring exposure time and scan time and synchronising scanning of a focused light beam with the exposure time of the camera.

SOURCE: PATENT DATA FROM THOMSON INNOVATION.

5.6.2 Technologies to extract gold

A recent report from the European Environment Agency (EEA) shows that there is a large economic potential in extracting gold and lithium from electronic waste (Bakas, Fisher, Harding, & et.al., 2013). Consequently, it is relevant to identify who has technologies to extract these rare materials. In this section we focus on gold. The project undertaken by EEA estimates the socio-economic impact of Waste of Electrical and Electronic Equipment (WEEE). The largest economic potential is in the extraction of gold. This is also shown in chapter 2. In Europe, gold losses from WEEE (here mobile phones, desktop and laptop computers, flat screens and rechargeable batteries) amount to 24.5 tonnes. This represents a value of EUR 1,010 million based on 2011 commodity prices.

TEXT BOX 5-7: SEARCH STRATEGY FOR TECHNOLOGIES TO EXTRACT GOLD

The search for technologies to extract gold took place in the previously defined data set for e-waste technologies. We did a keyword search for 'AU' and 'gold' in the patent field 'DWPI – Independent Claims'. This field has a detailed description of what the patented technology can be used for.

The search for technologies to extract gold resulted in 81 patents within this area. Most of these belong to Japanese or Chinese firms. However, the European firm Siemens AG appears as well, but only with a single patent related to gold. This search of patent technologies indicates that technologies used to extract gold from electronic waste exist.

FIGURE 41: FIRMS WITH PATENTS TO EXTRACT GOLD, 1990-2014

Firm	Number of Gold patent families
Taiyo Holdings Co.	6
DOWA Mining Co.	4
University of Donghua	3
Tanaka Kikinzoku Group	3
Korean Institute of Geoscience and Mineral Resources	3
Mitsubishi	2
Sumitomo Metal Mining Co.	2
Nippon Mining & Metals Co.	2
Oriya Co.	2

SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION. WE ONLY SHOW FIRMS WITH MORE THAN ONE PATENT.

5.6.3 Technologies to extract lithium

There is a substantial economic potential in being able to extract lithium from electronic waste. According to the study undertaken by EEA, the quantity of lithium losses from WEEE (here mobile phones, desktop and laptop computers, flat screens and rechargeable batteries) amounts to 117 tonnes. This represents a value of EUR 411 million based on 2011 commodity prices.

A patent search for technologies used to extract lithium resulted in 263 patents. Japanese firms hold most of these. The dominant players are Sumitimo Metal Mining Co, Toyota, DOWA Ecosystem KK (partly initiated by Sumitimo) and Nippan. The French *Centre national de la recherche scientifique* (French National Centre for Scientific Research) holds one patent.

TEXT BOX 5-8: SEARCH STRATEGY FOR TECHNOLOGIES TO EXTRACT LITHIUM

The search for technologies to extract Lithium took place in the previously defined data set for e-waste technologies. We did a keyword search for 'Li' and 'lithium' in the patent field 'DWPI – Independent Claims'. This field has a detailed description of what the patented technology is used for.

FIGURE 42: FIRMS WITH PATENTS TO EXTRACT LITHIUM, 1990-2014

Firm	Number of Lithium patent families
Sumitomo Mining Company	17
Toyota	15
DOWA Eco-System	13
Nippon Mining & Metals Co.	8
Foshan Brunp Cycling Technology	6
State Grid Corp. China	6
Hitachi	5
Korean Institute of Geoscience and Mineral Resources	5
Korea Institute of Science and Technology	5

SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION. WE ONLY SHOW FIRMS WITH AT LEAST FIVE PATENTS.

5.6.4 Technologies to extract tantalum

A patent search for technologies used to extract tantalum resulted in 143 patents. The dominant players are Starck GmbH, Capot Corporation and Nippon. There was just one tantalum relevant patent in Europe.

TEXT BOX 5-9: SEARCH STRATEGY FOR TECHNOLOGIES TO EXTRACT TANTALUM

The search for technologies to extract Tantalum took place in the previously defined data set for e-waste technologies. We did a keyword search for 'Ta' and 'tantalum' in the patent field 'DWPI – Independent Claims'. This field has a detailed description of what the patented technology is used for.

FIGURE 43: FIRMS WITH PATENTS TO EXTRACT TANTALUM, 1990-2014

Firm	Number of Tatanum patent families
H.C. STARCK GMBH	15
CABOT CORP	11
NIPPON MINING&METALS CO LTD	9
MITSUI MINING & SMELTING CO LTD	6
SHOWA CABOT SUPER METAL KK	6
CABOT SUPERMETALS KK	5
GLOBAL ADVANCED METALS USA INC	4
NIKKO GOLD FOIL CO LTD	4
KOBE STEEL LTD	3
GFE GES ELEKTROMETA	3
SUMITOMO METAL MINING CO	3
NINGXIA ORIENT TANTALUM IND CO LTD	3

SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

5.6.5 Examples of new interesting technologies for sorting, separation and treatment

This section will show a selection of interesting e-waste technologies related to sorting, separation and treatment, which are the most relevant phases for Danish WEEE-companies.

Sorting - most cited invention published after 2004

UNIV BEIJING AERONAUTICS&ASTRONAUTICS
Utilization method of non-metallic materials in waste printed circuit board.

Novelty: This invention discloses a method for recovering non-metallic material from waste printed circuit board, which comprises the following steps: a) sorting non-metallic powder through bolting or air current grading device; it can be divided different grain size section according to different requirement, and can adjust the range from 10 order to 400 order; b) surface modifying treating the non-metallic powder through the particle surface modifying project; c) filling the non-metallic powder into the high molecular material and architectural materials, and getting high molecular compound material or architectural material product, meanwhile, it improves the property of basis materials. Said method has versatility.

SHENZHEN GREEN MATERIALS HI TECH CO LTD
Process and system for sorting and dismantling waste cell[19].

Novelty: The invention discloses a sorting detaching technology and system of waste battery, which comprises the following steps: sorting materials in the waste battery according to size; loading the sorted material on the same carrying band; adopting battery lossless detector to detect battery inner structure; transmitting different waste batteries in different material bins; arranging uniformly to output; proceeding automate case-breaking disposal for waste battery; separating the broken battery in the corresponding storage groove; disposing electrode in each storage groove separately. The invention improves the recycling efficiency for waste battery, which modifies second pollution.

[19] "Cell" is probably a translation problem. Read "Battery" and it makes sense in relation to the invention.

Sorting - most cited invention published after 2004

Univ China Mining
Dry physical recovery process for recovering valuable components from waste electronic board card.

Novelty: The present invention relates to a dry physical process for recovering valuable components from electronic discarded board and card. Its whole technological process adopts mechanical and dry physical sorting method, and uses the machines of double-geared roller shearing machine, high-effective impact breaker, magnetic separator, sorting sieve, eddy current separator, damping pneumatic separator, drum static separator, friction separator and successively adopts the steps of shearing, breaking, sieving and separation so as to obtain the valuable metals of aluminium and copper, etc. and other materials.

Univ Hokkaido
Wet gravity concentration machine for sorting particles of e.g. plastic according to specific gravity of particles for recycling, produces upward flow speed equivalent to fluidization start speed in water of heaviest quality of composition.

Novelty: The machine classifies a mixing plastic particle (1) by the difference of a climbing speed in water or a lowering speed, due to the specific gravity of the particles being separated, when the water is pulsated up and down. The upward flow speed equivalent to fluidization start speed in the underwater of the heaviest quality of a composition of specific gravity in mixing plastic particle is produced, when classifying the mixing plastic particle in the raise process of water.
Use: Wet gravity concentration machine for use in sorting/classifying waste material such as granules of e.g. plastic, for recycling, in accordance with the specific gravity of the particles and their motion when placed in water pulsated up and down
Advantage: The waste materials are recycled and utilized efficiently, as the material of fresh stock.

QINETIQ LTD
Hyperspectral waste sorter for sorting residue from e.g. fridge shredding, includes hyperspectral camera to image objects in waste stream.

Novelty: The sorter comprises a hyperspectral camera (102) to pick-up the image of objects on the conveyor belt (112) that moves objects in the waste stream. The processor (108) classifies the objects in the waste stream, based on the output signals from the hyperspectral camera.
Use: For sorting organic objects such as fruits, vegetables or compostable waste and residue like steel, aluminium, glasses and plastics, glass, composite material like Tetra Pak containers from fridge shredding and car shredding, residue like paper and card and waste of different grades like plastic from domestic electrical equipment in material reclamation facilities (MRFs).
Advantage: The cost of hyperspectral camera with the required spatial resolution capability is relatively modest and standard.

NIC KK, NK Kankyo KK, Power Kogyo KK
Apparatus for processing waste fluorescent tube, has tube edge alignment mechanism and cutting mechanism provided at both sides of waste fluorescent tube conveyor.

Novelty: A conveyor (2) conveys straight tube form waste fluorescent tubes (K) of different length and diameter at random without sorting. A first edge alignment mechanism aligns one edge of the tubes. A first cutting mechanism (3) cuts the cap portion of the tubes at the aligned end. A second edge alignment mechanism aligns the other edge of the tubes. A second cutting mechanism (4) cuts the cap portion of the tubes at the second aligned end. A scavenging air blower (5) blows air in the caps removed glass tube.
Use: Apparatus for processing waste fluorescent tube for separating metal, glass, mercury, etc., separately.
Advantage: Separate disposal of a lot of waste fluorescent tubes having different tube length, diameter, etc., is enabled efficiently, thus enabling to raise the collection efficiency of different components of the waste fluorescent tube.

Sorting - most cited invention published after 2004

Sharp KK
Specific gravity sorting apparatus for manufacturing plastics raw material used for producing plastics molding of e.g. TV, has sedimentation unit with rotary body having shaft positioned parallel to liquid level in bath.

Novelty: An injection unit supplies the crushing material of a mixture comprised plastic waste materials with different specific gravities in a bath (1) that accommodates a gravity separation liquid. A sedimentation unit (4) precipitates the mixture in the gravity separation liquid, and having rotary body with a shaft positioned parallel to the liquid level in the bath. An extraction opening (6) for floating component and an ejection opening for sedimentation component are formed at the bath.
Use: For manufacturing plastics raw material used for producing plastics molding of domestic electrical appliance such as air-conditioning unit, TV, refrigerator and washing machine.
Advantage: Ensures efficient and inexpensive recycling by decreasing the plastic waste material by which thermal recycling is carried out.

Dongguan Tiantu Environment Protection
Waste circuit board recycling resources processing device, has pulse bag-type dust removing device and exhausting device arranged together, and high voltage static sorting device connected with efficient winnowing.

Novelty: The device has a pulse bag-type dust removing device and an exhausting device arranged together. A high voltage static sorting device is connected with an efficient winnowing. An inner-air separating device comprises an air pipe and formed with a material cavity. The material cavity is equipped with an axis between a feeding opening and a discharging opening. A positive pressure pipe is located in the material cavity of a selecting air pipe. An end of positive pressure pipe is provided with an air hole and selected to the material cavity.
Use: Waste circuit board recycling resources processing device.
Advantage: The device can avoid secondary pollution, and has special production, high production efficiency, better recycling effect, low energy consumption and prolonged service life. The device can realize an environment-friendly, economic and efficient treatment.

Separation - most cited invention published after 2004

Metalchemical Co. LTD., Korea
Apparatus comprising a crushing machine including a hopper, pinch rolls, a driving motor and a spray for recovering cobalt powder from used lithium secondary batteries and method therefore using the same.

Novelty: An apparatus and a method for efficiently recovering cobalt powder from metal cases, current collectors, electrolytes, carbon and cobalt compounds composing used lithium secondary batteries in a safe and eco-friendly manner are provided.

SUMITOMO METAL MINING CO
Valuable metal collection method from used lithium ion battery of motor vehicle, computer, involves leaching positive electrode active material with acidic solution in presence of activated carbon.

Novelty: The lithium ion battery is dismantled and cleaned with alcohol or water, to remove electrolyte liquid. The dismantled battery is immersed in sulphuric-acid aqueous solution of pH 0-3.0, to separate positive electrode material that is leached with acidic solution in presence of carbon containing material such as activated carbon. The aluminium and copper are separated by neutralization from resulting chemical exudates. The nickel and cobalt are separated after neutralization. The solid of lithium is separated after concentrating lithium in remaining aqueous solution.
Use: For collecting valuable metal such as lithium, nickel and cobalt from used lithium ion battery of motor vehicle, computer and word processor, and household appliances, in recycling process.
Advantage: The valuable metal can be separated and recovered efficiently from the used lithium ion battery, without performing dry processing such as heating/incineration.

Separation - most cited invention published after 2004

TANABE SANGYO KK
Method for separating glass plate joined to sheet body of glass panel, involves introducing glass panel into heat processing apparatus and raising temperature of glass panel atmosphere to maximum temperature according to bonding material.

Novelty: The method involves introducing a glass panel (1) into a heat processing apparatus (10). The glass panel within the heat processing apparatus is heated and a sheet body and a glass plate are separated. A temperature of the atmosphere around the glass panel is raised gradually to a maximum temperature that is set according to a bonding material. The glass plate is joined to a surface of the glass panel through the bonding material. The temperature of the atmosphere is lowered gradually in comparison to the maximum temperature.
Use: Method for separating a glass plate joined to a sheet body, particularly a photovoltaic cell of a glass panel, particularly a photovoltaic power generation panel (Claimed).
Advantage: The temperature of the atmosphere around the glass panel is raised gradually to a maximum temperature that is set according to the bonding material, through which the glass plate is joined to a surface of the glass panel, and thus ensures a favourable removal of the bonding material and efficient separation that carries out the recycling of the sheet body and the glass plate.

IND TECHNOLOGY RES INST
Recovery of valuable metals from waste secondary batteries comprising lithium ion by dissolving ash with sulfuric acid aqueous solution, and using aqueous layer rich in nickel and cobalt ions as electrolysis solution, at specific voltage.

Novelty: Valuable metals from waste secondary batteries are recovered by: dissolving an ash with 2-6 N sulfuric acid aqueous solution; using an aqueous layer rich in nickel and cobalt ions as an electrolysis solution, and using a voltage of 1.5-4.0 V to perform an electrolysis, thus forming by reduction a nickel and a cobalt metal on a cathode in the electrolysis, respectively.
Use: For recovery of valuable metals from waste secondary batteries comprising Li ion batteries, Ni-H batteries, and Ni-Cd batteries (claimed) used as power source for electric cars. It is useful for mixed waste secondary batteries of different types.
Advantage: Recovery and purity of the metals recovered are enhanced. The invention achieves the possibility to economically separate the recycled mixed waste secondary batteries into different types of waste secondary batteries without an error.

MBA POLYMERS INC, ALLEN L E, RIISE B L
Separation of polymer mixture for use in polymeric products, involves using charging media containing functional additive selected for compatibility with recovery process.

Novelty: A particulate media is added to mixture of polymeric components for selectively mediating a triboelectric charging. The mixture is then triboelectrically charged with the media. Two or more components of the mixture are separated according to the charge, and portion(s) of the media is recovered. The media contains a polymeric material and functional additive selected for compatibility with recovery process.
Use: For separating polymer mixture from used automobiles, appliances, and electronic equipment.
Advantage: The separation method recovers a fairly pure stream of plastic particles from a mixture of plastics, such as mixture obtained from recycled plastic feed. The media is added to the mixture to charge the particles and ensure consistent charging within each grade and type of plastics. Recovering media before or after the separation, reduces the expense associated with preparing or acquiring media, and leads to isolation of more pure products from triboelectric separation. The incorporation of additive into charging media improves the recoverability of the media. The incorporation of conductive or ferromagnetic material into the media can reduce charge build-up on the media and provides more control over the charge the media applies to the mixture.

Matsushita KK
Dehumidifier system, e.g. for use in drying machine, has moisture absorber to absorb moisture from supplied air so as to dehumidify cool air which is obtained by cooling humidified air using coolant in heat absorption device.

Novelty: A moisture absorber (115) absorbs moisture from supplied air. The dehumidified target air is heated by heat radiation of coolant (106) in a heat radiator (102) and heated air is humidified by moisture released from a moisture absorption/releasing unit (110). The humidified air is cooled by heat absorption of the coolant in a heat absorption device (104). The cooled air is dehumidified by the absorbed moisture.
Use: For use in dehumidifier, drying machine, air conditioning machine, solvent-recovery apparatus.
Advantage: The novel system increases the difference between the relative humidity of the air supplied to the moisture absorption and release region. Hence, the dehumidification efficiency is enhanced.

Separation - most cited invention published after 2004

Nickel H
Pre-processed and partial demounted material compound e.g. electro and electronic unit, disintegrating and separating method, involves crushing material into one or two staged processes and freeing material from damages and anionic trashes.

Novelty: The method involves crushing a pre-processed and partially demounted material to be treated into one or two staged processes and freeing the material from damages and anionic trashes in a treatment course. Ferromagnetic components and light materials are removed from the material flow. The material flow is divided into two flows. Metals and plastics are removed selectively from the coarse material by using specific sensors.
Use: Used for disintegrating and separating pre-processed and partial demounted material compound e.g. electro and electronic unit.
Advantage: The method provides selective removal of pollutants or polluted products, effective disintegration of compounds, complete separation of ferrous and non-ferrous metals, extraction of plastics with reliable separation and high material yield and reduction of non-recyclable material components to minimum residual volume. The method provides extensively fully automatic operation, includes lows specific power requirement and maintenance free and wear-resistant operation and avoids high protection materials, expensive safety measures.

University of South China
Recovery and treatment of waste lithium ion cell by crushing cell, separating cobalt by ammonium oxalate deposition, and extracting cobalt and copper by solvent extraction.

Novelty: The method for recycling and processing worn-out lithium ion battery includes:(1) taking out pack of worn-out battery;(2) using crushing facilities to open up case of battery and segregation through magnetic method;(3) dissolving waste of pole core of battery by using acid and separating out most of cobalt through ammonium oxalate depositing method; and(4) extracting cobalt and copper deposited in residual liquid through solvent extraction method. Adding sodium carbonate generates deposition to retrieve lithium.
Advantage: Simple technique on solving pollution of worn-out batteries and reclaiming resources at same time.

5.7 Business opportunities

The technological developments in separating technologies indicate that this is the most technologically developed field in the e-waste process. The large number of patents in this field points to the fact that this is the most researched task and perhaps the most complicated for which to find solutions. There are technologies to collect and sort e-waste but separation seems to be the most challenging.

As mentioned above, technologies to separate to a certain degree already exist. It is possible to do it manually (Bakas, Fisher, Harding, & et.al., 2013) or by using automation processes such as robots (Interview with EERA Recyclers), but the main challenge is to cost-optimise the separation process. To invest in automation processes, companies need a certain scale of production to justify the heavy investments that are often associated with these technologies.[20]

Thus, this challenge is one that needs to be addressed. Another issue that emerged from this analysis and the workshop on 4 June 2014 is closer cooperation in the value chain. Taking inspiration from the Japanese eco-system discussion, it should perhaps be considered if WEEE companies in Europe could be linked more closely and thereby contribute to driving each other's innovation. For instance, the demands from specific end processing companies could help dismantling companies develop new ways of separating the waste better with reduced loss of WEEE material. The international players, their way of working, and possible inspiration for new business opportunities will be the main focus points of the next chapter.

[20] Interview with EERA Technologies

6. International players

6.1 Introduction

When it comes to patenting activities, Japan, China, USA, Germany and South Korea are the leading countries in e-waste technology. However, the literature shows that Europe is an important market and much development takes place here too. Europe is a leading region with technically advanced recycling companies. The forecast from 2012 to 2020 is for the European WEEE market to have an annual growth rate of 4.1%. This growth rate is particularly predominant in Germany, Central and Eastern Europe, the Iberian Peninsula, and France. Between 2013 and 2020 these countries and regions are expected to grow considerably due to a significant increase in the volume of waste collected and technological developments. Scandinavia leads the European market in terms of collection and recycling levels of waste (Frost & Sullivan, August 2013).

Furthermore, the analysis shows that although there is a global tendency for WEEE companies to become involved in several aspects of the value chain from collection to dismantling, pre-processing and end-processing, this is not so much the case in Europe, where the large companies Umicore, Boliden and Aurubis continue to have their primary focus on end-processing. Finally, although most companies in the dismantling phase use mechanical processes, some focus on automatic solutions in terms of robotics or optical solutions, which could serve as inspiration for Danish companies.

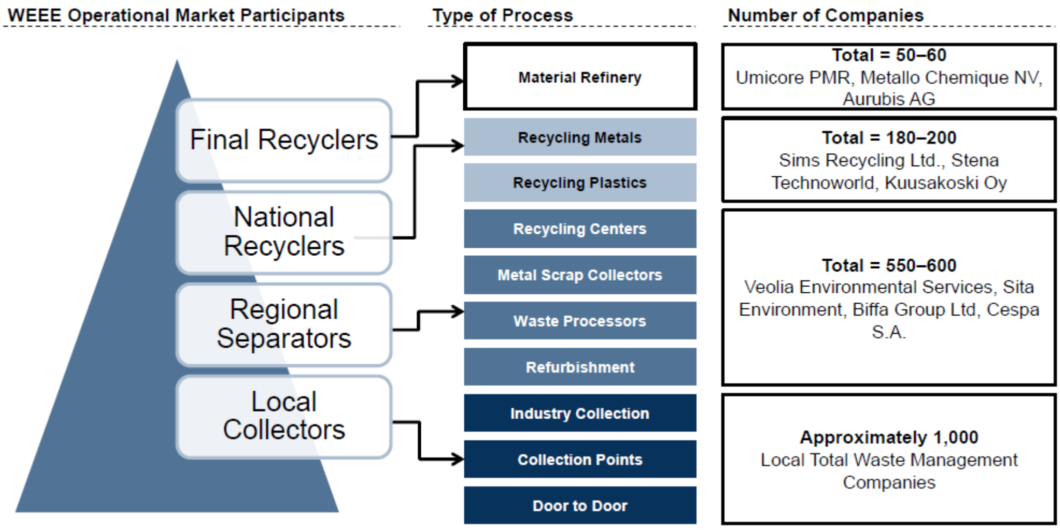
This chapter sets out to investigate the international competition within sorting, dismantling, pre-processing and end-processing of WEEE. The aim is to gain a better understanding of the international environment of which Danish companies are a part to better identify the challenges and opportunities they face.

The chapter starts with a presentation of the structure of the European WEEE market and a growth forecast for the European WEEE market. After that, we present the WEEE technology providers and WEEE companies that we have identified through desk research and input from experts at Danish Technological Institute (DTI) and interviews. Next, we discuss global and Danish patenting activities using the Thomson and Derwent World Patent databases. Finally, we conduct an analysis of the international playing field.

6.2 Structure of the European WEEE market

WEEE collection takes place at local or regional level with tens of thousands of collection points. Dismantling and pre-processing typically takes place at a regional or national level at various facilities all over the EU-27. There are thousands of dismantling companies all over Europe while pre-processors are measured in their hundreds (Hagelüken, 2012) (see Figure 44).

FIGURE 44: WEEE RECYCLING MARKET: MARKET PARTICIPANTS, EUROPE, 2012



SOURCE: FROST & SULLIVAN 2013

Umicore has created a similar overview where the figures look a bit different (Hagelüken, 2012). Notably, the number of final recyclers/end processors is much smaller than Frost & Sullivan note whereas the collection and dismantling area has more players in the Umicore figure. It is clear that there are different ways of seeing the market and that Umicore may understand the market more narrowly as it is focusing on its direct competitors and not on other companies that are able to carry out part of the end-processing.

All pre-processing begins with the removal of certain hazardous components. Afterwards the different WEEE components are separated. Today, the technique applied at this step largely depends on labour costs in the country in question (Chancerel, 2010). Studies and interviews have shown that manual dismantling processes are more effective in recovering critical metals than mechanical processes. For instance, the percentage of gold recovered from notebook PCs ranges from 80% to 97% when using manual processes, and from 26% to 70% when using mechanical processes (Bakas, Fisher, Harding, & et.al., 2013). This obviously has a major influence on the further separation steps and thus on metal recovery efficiency (Chancerel, 2010). However, increased automation, for instance in the form of robotics or vision technologies, may reduce the importance of labour costs.

After pre-processing, a range of different technologies for automatic size reduction is available on the market. These include cutting systems, rotor shredders, rotor impact mills, and hammer mills. Following size reduction, different fractions of materials (ferrous metals, non-ferrous metals - among these critical metals - and plastics) are separated using mechanical and manual procedures. The shredding residues are often used for energy recovery where critical metal parts are lost for further recovery (Bakas, Fisher, Harding, & et.al., 2013) and (Frost & Sullivan, August 2013). As mentioned above, interviews and literature revealed that mechanical processes such as shredding can both reduce the size of the WEEE (meaning that a part of the recovered material is lost) and mix it with other waste streams such as glass or plastics. This can lead to a lower quality of recycled materials. In addition, the fatigue, tensile, and impact strengths of separated and processed metals are also lower than that of primary materials and they need to be mixed (Frost & Sullivan, August 2013).

End-processing takes the dismantled components produced in the pre-processing step and recovers metals and other materials that can be used as secondary raw materials in the production of new

EEE or in other industries. WEEE end-processing facilities are very expensive to build and need large amounts of pre-processed WEEE to yield an acceptable ROI. Therefore, there are relatively few players in Europe and worldwide. Neither in Europe nor globally is it economically feasible for many different recyclers to recover the same material. There is a certain need for economies of scale.[21] The main player in this field is Belgian Umicore, which recovers precious metals (silver, gold, platinum, palladium, rhodium, iridium, ruthenium) and special metals (indium, selenium, tellurium) in an integrated smelter. In 2012, Umicore employed 14,438 persons.[22] Two other players are the Aurubis Group in Germany and Boliden in Sweden, which both use copper smelters for recovery of precious metals. The Aurubis Group employs 6,400 persons[23] (not all of them in the EU) and Boliden employs 4,500 persons in Sweden and Finland.[24]

The end-processing part does not seem to be an area of business opportunities for Danish companies for several reasons. There are no WEEE smelting companies in Denmark and consequently a lack of metallurgical knowledge. The entry costs in terms of investments in technologies and infrastructure (buildings) are too high. Finally, a few very strong players already dominate the market with the power to influence the price mechanisms – and a technological advantage. Thus, the entry barriers for establishing a company focusing on end-processing are simply too high.

Consequently, Danish companies may gain a competitive edge particularly within separation and sorting, dismantling and pre-processing processes.

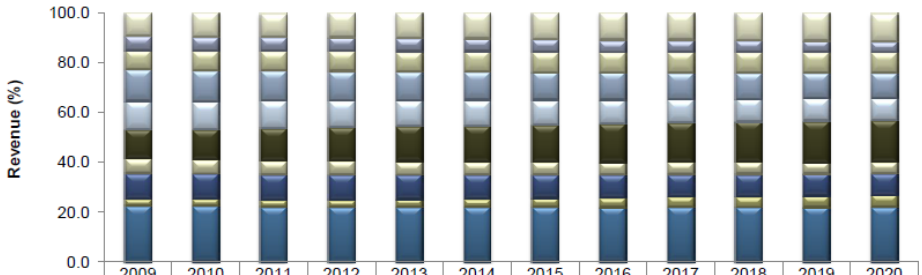
In a global value chain perspective, a strong position in these technological areas may imply that Danish companies can improve the quality of the materials coming out of the dismantling and pre-processing processes to create the best possible input for the smelting companies and thereby the highest profit. In other words, the aim for the Danish suppliers is to create as much value for their clients as possible, thereby becoming a trusted and perhaps strategic supplier.

6.3 Growth forecast of the European market

At present, EEE account for the fastest growing volume of waste generated. The European WEEE recycling market is forecast to post an annual growth rate of 4.1% from 2012 to 2020. This amounts to a revenue increase from $1,300 million to approx. $1,800 million. Especially France and Poland are driving this development, while Scandinavia is expected to experience a small drop in revenue. The same applies to Germany, although it continues to be by far the leading country/region in terms of revenue (see Figure 45).

[21] Interview with the WEEE Forum
[22] Source: http://www.umicore.com/en/
[23] Source: http://aurubis.com
[24] Source: http://boliden.com

FIGURE 45: TOTAL WEEE RECYCLING MARKET: PER CENT REVENUE FORECAST BY REGION – EUROPE, 2009-2020



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CEE	9.2	9.7	9.6	10.0	10.2	10.4	10.6	10.8	10.9	11.1	11.3	11.4
Benelux	5.8	5.7	5.6	5.4	5.3	5.1	5.0	4.8	4.7	4.6	4.5	4.4
Iberia	7.8	7.9	8.0	8.0	8.1	8.2	8.2	8.3	8.3	8.4	8.3	8.3
Italy	12.6	12.4	12.1	11.9	11.6	11.4	11.1	10.9	10.7	10.5	10.4	10.2
Scandinavia	11.5	11.1	10.9	10.7	10.4	10.2	9.9	9.7	9.4	9.2	9.1	8.9
France	11.5	12.1	13.0	13.6	14.1	14.6	15.0	15.4	15.8	16.2	16.5	16.8
Alpine States	5.8	5.8	5.6	5.5	5.4	5.2	5.1	5.0	4.9	4.7	4.6	4.5
The United Kingdom	10.4	10.2	10.3	10.0	9.8	9.6	9.5	9.3	9.1	9.0	8.8	8.7
Poland	2.7	2.7	2.7	2.8	3.0	3.3	3.5	3.8	4.1	4.4	4.7	4.9
Germany	22.7	22.6	22.2	22.2	22.1	22.1	22.0	21.9	22.1	21.9	21.8	21.9

Year

SOURCE: FROST & SULLIVAN, 2013.

NOTE: FIGURES ARE ROUNDED, BASE YEAR IS 2012

As mentioned above, from 2013–2020 Germany is expected to be the most attractive market for WEEE recycling. The reason is Germany's particularly effective collection schemes and innovative technologies for recycling. The markets in Central and Eastern Europe, the Iberian Peninsula, and France are also expected to grow in the same period, particularly because of significant waste volume collection and technological developments (Frost & Sullivan, August 2013) (see Figure 46).

FIGURE 46: TOTAL WEEE RECYCLING MARKET: EUROPE, 2012

Market Overview

MEASUREMENT NAME	MEASUREMENT	TREND
Market Stage	Growth	—
Market Revenue (2012)	$1,300.1 M	▲
Average Recycling Price Per Ton (2012)	$325.8	▼
Market Size for Last Year of Study Period—Frost & Sullivan Scenario (2020)	$1,793.7 M	▲
Base Year Market Growth Rate	4.0%	▲
Compound Annual Growth Rate—Frost & Sullivan Scenario (CAGR, 2012–2020)	4.1%	—
Customer Price Sensitivity (scale of 1 to 10, Low to High)	9	●
Degree of Technical Change (scale of 1 to 10, Low to High)	7	●
Market Concentration (% of base year market controlled by top three competitors)	32.4%	▼

TREND	Decreasing	Stable	Increasing
	▼	●	▲

SOURCE: FROST & SULLIVAN 2012. NOTE: ALL FIGURES ARE ROUNDED, BASE YEAR IS 2012

6.4 Drivers and restraints in the WEEE market

In Europe, Frost & Sullivan (2013) sees both drivers and restraints in the WEEE market.

The most important driver expected by Frost & Sullivan is a continued driver to set up more WEEE treatment plants. This is driven by legislation and limited landfill opportunities. The same trend can probably not be expected for Denmark, but WEEE treatment plants represent an expanding market and illustrate the business opportunities for technology suppliers with cost-effective automation solutions. If cost-effective automation technologies can be assembled and demonstrated in Denmark, other new WEEE treatment plants in Europe might become an interesting market.

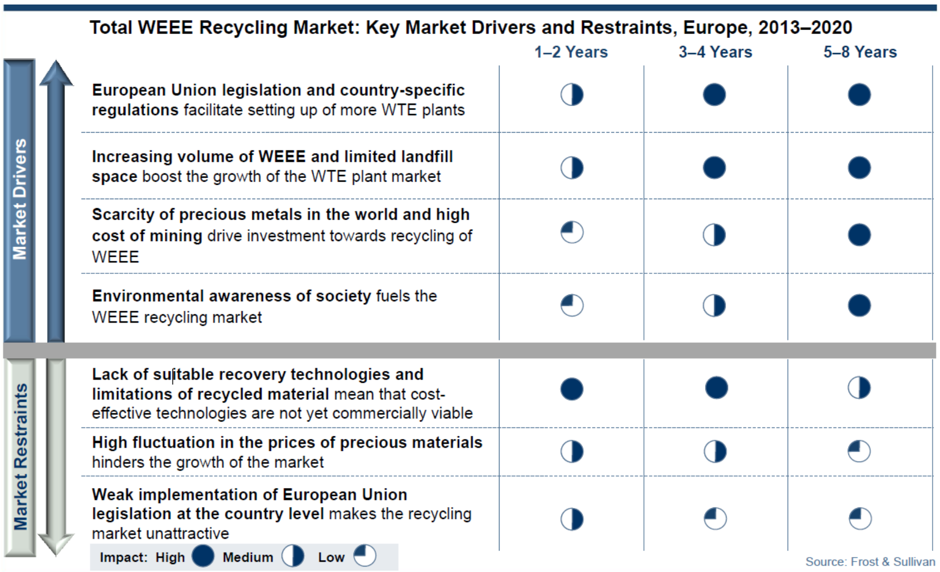
Another important driver is the scarcity of virgin raw material; the cost of virgin materials is expected to increase in the next 6–9 years as the environmental, energy, and civil work costs associated with mining are likely to rise. Consequently, the WEEE recycling market is expected to grow as a result of the increased cost of mining. Finally, Frost & Sullivan mentions increased environmental consciousness.

The most important restraint identified by Frost & Sullivan is the lack of suitable recovery technologies: '*Quality and level of purification of material are important considerations for final recyclers. Mechanical processes, such as shredding and precious material recovery systems, reduce the size of WEEE and mix it with other stream of waste (e.g. glass). This can lead to lower quality of recycled materials. The level of purification that can be achieved during final recycling is also limited by time, energy, and processing cost. Nevertheless, the separation of metals and plastics in the WEEE recycling market is expected to improve, in future.*' (Frost & Sullivan, 2013).

This illustrates that the situation in the rest of Europe is similar to that in Denmark. There are a number of promising technologies for automatic recognition, sorting, and dismantling of WEEE, but these technologies still need further testing and adjustments to work.

Again, for technology suppliers there will be business opportunities and probably especially for first movers since Frost & Sullivan expects the technology restraint to diminish in a 5-8 year perspective. Price fluctuations of precious metals are a restraint since the unstable value of the products from WEEE treatments hinders investment in new technology, infrastructure and innovation. Frost & Sullivan writes about the price fluctuations: '*The economic slowdown in Europe is likely to have a negative effect on the WEEE recycling market, as prices of recycled metals and plastics decline. The price of copper declined by nearly $2,680 per tonne (according to London Metal Exchange Stock) between 2010 and 2013. The price of recycled materials also depends on its quality and purity, where inclusions, such as sand, plastics, and other materials, negatively impact prices. Prices of precious materials are expected to stabilize over the next nine years.*' (Frost & Sullivan, 2013).

FIGURE 47: TOTAL WEEE RECYCLING MARKET – KEY DRIVERS AND RESTRAINTS



SOURCE: FROST & SULLIVAN, 2013

6.5 The global WEEE companies

In identifying the global WEEE companies we have constructed the tables below based on different sources:

- desk research, literature and websites;
- companies participating in relevant conferences;
- input from interviews; and
- input from own experts.

Next, we visited the websites of all the companies and assessed the companies' key activities. It is not a complete list of all players, neither in terms of WEEE companies nor in terms of technology providers. In comparison, the Frost & Sullivan report lists 1,500 companies active in the field of WEEE – from collection and sorting to dismantling, pre-processing and end-processing (Frost & Sullivan, August 2013). However, the present list includes the most active and important players. Moreover, we do not think that the list has to be complete to get a good overview of the potential international partners for and international competitors to Danish companies. Thus, the aim of the list is to assess whether there are special Danish strengths - but also to be an inspiration for new collaborations in connection with WEEE with foreign companies.

6.5.1 WEEE technology providers

Table 15 illustrates the global WEEE technology providers that produce the technologies used for collecting, sorting, separating, treating and/or extracting WEEE. The companies sometimes both produce the equipment and use it themselves.

TABLE 15: GLOBAL WEEE TECHNOLOGY PROVIDERS

Company	Country	Markets	Advanced	Technology: Collection	Sorting	Dismantling	Pre-processing	End processing
A.S.A. Group	Austria	Central- og Eastern Europe	▮▮▯▯	◔			●	
ABB	Sweden	Europa	▮▮▮▮					
Adelmann Umwelt GMBH	Germay	Germany, rest of Europe	▮▮▯▯					
Alba R - plus GmbH.	Germany	Global	▮▮▮▮					
Albert Hoffmann GmbH	Germay	Germany	▮▮▯▯	●	●	●		
ALR Innovations	Eireland	Global	▮▮▮▯					
ANDRITZ MeWa GmbH	Austria	Global	▮▮▮▮				◑	
ATM Recyclingsystems GmbH	Austria	Japan	▮▯▯▯		●	●	●	●
Aurubis AG	Germay	Europa	▮▮▮▮			●	●	●
Balkan	UK	UK, (South America)	▮▮▯▯					
Batrec	Schweiz	Global	▮▮▮▮					
BHS	Germay	Global	▮▮▯▯			●	●	
BHS-Sonthofen GmbH	Germay	Europa - Worldwide	▮▮▯▯					
BIANATT WEEE Recycling	Greece	Primarily Greece	▮▮▮▮			◑	●	
BluBox Trading AG	Schweiz	Global	▮▮▮▯					
Boliden	Sweden	Europa	▮▮▮▮					
Bronneberg	Netherlands	Global	▮▮▯▯					
BT - Wolfgang Binder GmbH	Austria	Global	▮▮▮▯		●	●	●	
Coolrec	Netherlands	Worldwide	▮▮▮▮					
Cory Environmental	UK							
CP Manufacturing	US	Global	▮▮▯▯					
Creative Recycling Systems	US	US	▮▮▮▯					
Dataserv GmbH	Germay	Global	▮▮▮▮					
Dela GmbH	Germay	Europa	▮▯▯▯					
DOWA Group	Japan	Global	▮▮▯▯				◑	◑
Eldan Recycling	Denmark	Global	▮▮▯▯					
Electro Optimal Components Inc.	California, US	US	▮▮▮▯		◑	●	◔	
Electronic Recyclers International (ERI)	California, US	Primarily US	▮▮▮▮		◑	◑	◑	
Enviroserv	South Africa	South Africa	▯▯▯▯					
Erdwich	Germay	Global	▮▮▯▯	◑	◑			
EREMA	Austria	Global	▮▮▮▯					
Eriez	US	Global	▮▯▯▯					
E-Waste systems	US	Global	▮▮▯▯					
EWC	UK	UK	▮▯▯▯					
FCC Recycling Ltd.	UK	UK	▮▮▯▯					
Fercell	US	Global	▯▯▯▯			◔	◔	
Forrec	Italy	Global	▮▯▯▯			●	●	
Genco	Pennsylvania, US	US / Global	▮▮▯▯	●		●	●	
Geordis Logistics	Germay	Germany	▮▯▯▯					
Granutech	Texas, US	American customerbase	▮▮▯▯			●	◑	
GRAZIOLI-REMAC	Italy	Italy, Sydeuropa	▮▮▯▯					
Hamos	Germay	Global	▮▮▮▮					
Hera Gruppo	Italy	Italy	▮▯▯▯					
Herbold	Germay	Global	▮▮▮▯					
IFE Bulk	Austria	Europa	▮▮▮▯			●	●	●
Immark	Schweiz	Europa	▮▮▯▯					
Imro Machinenbau GMBH	Germay	Europa	▮▮▮▮					
Indumental Recycling S.A.	Spain	Spain, Germany	▮▮▯▯			●	●	●
IPI	Singapore	Singapore	▮▮▮▯				◑	◑
Jacomij Electronics Recycling	Netherlands	Benelux	▮▮▯▯	◑	●	●	●	●
KGHM Ecoren	Poland	Poland, Eastern Europe	▮▮▮▮					
KM	Germay	Europa	▮▮▮▯					
KMK Recycling Ltd.	Eireland	Irland	▮▮▯▯					
Krause Manuffacturing	UK	Global	▮▮▯▯					
KUKA Nordic Norway	Norway		▮▯▯▯	◑		◑		
KuUSkoski Recycling	Finland	Global	▮▮▯▯					
Kühne	Germay	Germany, Central Europe	▯▯▯▯					
Liquisort	Netherlands	Global	▮▮▮▯					
Magpie	France	Europa	▮▮▮▯					
MaiRec	Germay	Europa	▮▮▯▯		◑	●	●	
MBA Polymers	UK	Global	▮▮▮▯					

Metallo	Belgium	Europa					
MGG Recycling	Austria	Central- og Eastern Europe					
Montanwerke-Brixlegg	Austria	Europa					
MRT System	Sweden	Global			◑	◑	
MSS, Inc.	Tennessee, US	North America		●	●	●	◑
MTB	France	Global					
Nadin	Bulgaria	Bulgaria, Eastern Europe			◔	●	●
NGR Recycling Machines	Austria	Austria, US, Malaysia				●	
NOEX AG	Germay	Germany, Europa					
NRT	Tennessee, US	Primarily US	◑				
Oran Environmental Solutions Limited	UK	UK			●	●	◑
OUSEI KANKYOSHOJI Co.,LTD	Japan	Japan		◑	◑	●	
Paggiola	Italy	Italy		●	●	◑	
Pallmann	Germay	Europa		●	●	●	
Paprec Group	France	Frankrig					
Pöttinger	Austria	Global		◑	◑		
Ragn-Sells Group	Denmark	Norden og Baltikum					
Recifemetal	Portugal	Iberia.			●	●	
Recilec	Spain			◑	◑	◑	
Recy Systems AG	Germay	Global					
Recydur BV	Netherlands	Netherlands					
Refind	Sweden	Global	◔	◑	●	●	●
Remondis	Germay	Global					
Ges.m.b.H.	Austria	Primarily Austria	◑	◔	●	●	●
Satake Australia	Australia	Global			◑	●	●
Satake Group	Japan	Global		◔	●	●	●
Saubermacher AG	Germay	Austria, US, Malaysia			◑	●	●
Séché Environnement	France	Global			◑		
Sens eRecycling	Schweiz	Schweiz					
SESOTEC (S+S)	Germay	Global					
SGM S.p.A.	Italy	Global			◑	●	◑
Sheerbrooke	Canada	North America		◑	◑	◑	◑
SIKOPLAST	Germay	countries					
Sims Metal Management	Australia	Global					
Sims recycling solutions	UK	Global				●	●
SITA Environment	UK	UK		◑	●	●	◑
Spaleck	Germay	border-countries		◑	●	●	
SSI	Oregon, US	Global		●	●	●	
Steinert	US	Global	◔	◔	◔	◔	◔
Stena Technoworld	Sweden	Europa			●	●	
STF Group	Germay	Global			●	●	
Sumitomo	Japan	Global		◑	●	●	
Sunnking	US	US			●	●	
SwissRTEC	Schweiz	Global					
Synergy Recycling	US	US			●	●	●
Tegos	Germay	Europa			●	●	
The Galloo Group	Netherlands	Benelux / UK					
Titech	Norway	Global		●	●		
Tomra Sorting	Norway	Global					
Umicore Precious Metals Refining	Belgium	Global			◔	◔	
Universal Recycling Technologies LLC (URT)	Wisconsin, US	US					
UNTHA Recycling Technology (URT)	Germay	Europe				◑	
URBASER	Spain	Spain,					
Vacoplan	Germay	Global		●	●	●	
Van Gansewinkel Group	Netherlands	Europa		◑	◑	◑	
Vans Chemistry	Singapore	Singapore, (China)			●	●	
Vecoplan AG	Germay	Global				●	●
Venti-Olde	Germay	Europe				●	●
Veolia Environmental Services	US	Global					
VES	UK						
Viridor	UK				●	●	◔
Wincanton Recycling	UK	Global					
ZEN Robotics	Finland						

SOURCE: DANISH TECHNOLOGICAL INSTITUTE, 2014

Legend: ◔ means that the process is a peripheral activity, ◑ means that the activity is a sub process in the company, and ● means that the activity is a core activity.

Table 15 shows that the global technology providers are especially active in the areas of dismantling and pre-processing. As mentioned above, these are the areas where Danish companies may gain a competitive edge too. Looking closer at the companies that are active in these fields, many of them focus on traditional shredding, rotor and hammer mills. However, some companies have developed other techniques (see Text box 6-1).

TEXT BOX 6-1 : EXAMPLES OF COMPANIES THAT FOCUS ON OPTIC VISION

The Finnish company *ZenRobotics* has developed robot-controlled technology. This advanced control system utilises multiple sensor inputs in real time, reacts to changes and learns from its mistakes. The sensors include various camera types (visible light and spectrometric cameras such as NIR), 3D scanners, haptics, metal detectors, etc. With enough sensors, ZenRobotics Brain can form a more comprehensive view of the waste stream than has been possible so far. Using enormous amounts of sensor data, ZenRobotics Recycler can identify the desired items and raw materials from the waste stream and reclaim them for recycling.[25]

Satake Australia has developed optical sensor-based machines for sorting. These are, among other things, used to sort plastics and metal parts from waste.[26]

The American company *NRT* has developed sorting equipment using optical X-ray technology. At present, the company's machines are primarily used for treatment of valuable waste. These optical sensor-based machines can effectively scale and separate the waste.[27]

It is clear from the database that relatively few companies focus on optic vision technologies/robotics. Combined with the fact that the literature shows that mechanical processes often cannot separate the waste well enough, meaning that critical materials are lost, it might be valuable for Danish companies to gain inspiration from these types of companies. Moreover, the companies represent some of the technologies that the Danish companies in the survey highlight as being their key competences (optical sensors, vision, etc.).

However, a problem with the optic vision technologies is that they primarily distinguish between colours, not materials. Hence, these technologies may need to be combined with other technologies or manual sorting if they are to be successful. DTI's own experts have highlighted other technologies suitable for the dismantling of WEEE. Below we present a number of other techniques that can distinguish between different types of materials.

TEXT BOX 6-2: EXAMPLES OF TECHNIQUES THAT CAN DISTINGUISH DIFFERENT TYPES OF MATERIALS

Kongskilde Industries

Kongskilde Industries is a subsidiary of DLG Amba. For many years, the company has developed and produced machinery for use in the primary industry (farming and forestry), and the company is a leading developer of machines for cleaning up grain and seed crops by removing foreign bodies such as stones, chaff and straw material from the main product. In recent years, Kongskilde has adapted its technologies to the problem of sorting waste material, e.g. plastics according to density.

The technology: The technology for this is based on letting the material to be sorted fall freely in a strong upward air current. This results in the less dense materials being slowed in their fall or directly being carried off by the flow of air, thus separating the materials according to density. The systems from Kongskilde are renowned for being capable of operating at high capacities.

[25] http://www.zenrobotics.com/product/
[26] http://www.satake.com.au/
[27] http://www.nrtsorters.com/

Adapting the technology for sorting electronics components: This technology could be adapted as a robust means of performing an initial sorting of electronics components that have been crushed in a coarse milling process. Many less dense plastic materials could easily be removed from the core metallic parts of the electronics waste.

Cimbria Group

Cimbria A/S is one of the world leading companies in manufacturing machinery for processing, handling and storage of crops in bulk quantity. The company has solid experience with producing equipment for removing foreign bodies from grains and seeds. Many of the company's products can be adapted to become a useful part in a system for extracting valuable materials from electronic waste.

The Technology: Cimbria is experienced in using camera systems for automatic visual identification of waste materials, e.g. colour sorting of plastics, in bulk quantities. The company has a wide range of conveyor systems for transporting granular products and sorting according to size and density. Cimbria also has a range of small-scale laboratory equipment for testing concepts prior to up-scaling a process.

Adapting the technology for sorting electronics components: Many of Cimbria's products can be implemented as basic equipment in an automated sorting complex for waste electronics. Currently, standard cameras are used for sorting plastics waste according to colour. The equipment should be supplemented by adding appropriate sensors/detectors that are capable of identifying useful materials in the waste that cannot be identified using standard vision systems.

ELDAN Recycling

ELDAN was started as dedicated recycling company. ELDAN manufactures and sells equipment globally for shredding, rasping and cable stripping for various waste products. The company's main focus is on recovering copper, aluminium, magnesium, ferrous materials and WEEE recycling (for subsequent extracting of gold from electronics).

The Technology: ELDAN currently manufactures machines for upgrading waste into fractions enriched with specific metals and non-metals. Technologies include magnetic separation, eddy current separators and water separation systems for separating ferrous, non-ferrous and non-metallic fractions of the waste.

Adapting the technology for sorting electronics components: The ELDAN systems are already in place and are well adapted to solving most of the WEEE issues. The systems can be further developed but most of the outstanding issues can be resolved in the refinery steps that follow the fractionating of the waste. Individual metal components can be extracted chemically from the non-ferrous and non-metallic; the latter may contain costly elements in the form of oxides.

Danish Technological Institute

Danish Technological Institute (DTI) is a government approved technological service partner for industry. DTI collects new and innovative concepts and helps make them applicable for industry on a commercial basis. A number of knowledge centres within the DTI organisation have extensive experience with the development of measuring systems that can assess the value of the various fractions that result from existing WEEE sorting systems.

The need for assessing the value of waste: In Denmark and abroad, systems for retrieving valuable elements from electronic and electrical waste are constantly being improved. The task of utilising the waste is divided into three steps, namely collecting the waste, mechanical separation of the various components within the waste, and finally chemical extraction and refining of the individual metals. An incentive for waste management companies to improve their mechanical separation technology is for them to have measuring equipment capable of determining the value of each waste fraction by specifying the content of individual precious/rare-earth elements. On-line or at-line measurement systems suitable for this task can be developed for the recycling industry based on readily available measuring principles that only need modification.

The map in Figure 48 shows the locations of European competitors.

FIGURE 48: EUROPEAN WEEE COMPANIES – TECHNOLOGY PROVIDERS

SOURCE: DTI

Figure 48 shows that the majority of technology providers are located in Germany, Belgium, the Netherlands and Austria. This is not surprising given the prevalence of the WEEE industry in general in these countries.

6.5.2 WEEE companies

When looking at the WEEE companies (i.e. the ones carrying out the actual collection, sorting, separating, treatment, and extraction), the global landscape is depicted in the tables on the following pages.

TABLE 16: GLOBAL WEEE COMPANIES

Company	Country	Markets	Advanced	Collection	Sorting	Dismantling	Pre-processing	End processing
				WEEE treater				
.A.S.A. Group	Austria	Europe	2/4					
ABB	Sweden	Europa	4/4	●	●	●	◑	
Adelmann Umwelt GMBH	Germay	Germany, rest of Europe	2/4			◔	◑	◑
Alba R - plus GmbH.	Germany	Global	4/4			◑	●	●
Albert Hoffmann GmbH	Germay	Germany	2/4	●	●	●	●	
ALR Innovations	Eireland	Global	3/4	●	●	●	●	●
ANDRITZ MeWa GmbH	Austria	Global	4/4					
ATM Recyclingsystems GmbH	Austria	and Japan	1/4					
Aurubis AG	Germay	Europa	4/4					
Averhoff	Denmark						●	
Balkan	UK	UK, (South America)	2/4	◔	◑	●	●	
Batrec	Schweiz	Global	4/4					
BHS	Germay	Global	2/4				●	●
BHS-Sonthofen GmbH	Germay	Europa - Worldwide	2/4			◑	●	
BIANATT WEEE Recycling	Greece	Primarily Greece	4/4					
BluBox Trading AG	Schweiz	Global	3/4	●	●	◑		
Boliden	Sweden	Europa	4/4	◑	●	●	●	●
Bronneberg	Netherlands	Global	2/4					
BT - Wolfgang Binder GmbH	Austria	Global	3/4		◔	●	●	●
Coolrec	Netherlands	Worldwide	4/4	●	●	●	●	◑
Cory Environmental	UK					◑	●	●
CP Manufacturing	US	Global	2/4	◑		●	●	●
Creative Recycling Systems	US	US	3/4	●	●	●	●	◑
DanWEEE	Denmark						●	
Dataserv GmbH	Germay	Global	4/4					
Dela GmbH	Germay	Europa	1/4	●	●	●	●	
DOWA Group	Japan	Global	2/4					
Eldan Recycling	Denmark	Global	2/4					
Electro Optimal Components Inc.	California, US	US	3/4	◑	◑	●		
Electronic Recyclers International (ERI)	California, US	Primarily US	4/4					
Enviroserv	South Africa	South Africa	0/4					
Erdwich	Germay	Global	2/4	●	◑	●	●	◑
EREMA	Austria	Global	3/4	●	◔			◑
Eriez	US	Global	1/4					
E-Waste systems	US	Global	2/4	●	●	●	●	●
EWC	UK	UK	1/4					
FCC Recycling Ltd.	UK	UK	2/4					
Fercell	US	Global	0/4					
Forrec	Italy	Global	1/4	●	●	●	●	◑
Genco	US	US / Global	2/4					
Geordis Logistics	Germay	Germany	1/4	●	●	●	◑	
Granutech	Texas, US	American customerbase	2/4			●	●	●
GRAZIOLI-REMAC	Italy	Italy, Sydeuropa	2/4	●	●	●	●	●
Hamos	Germay	Global	4/4			●	●	●
Hera Gruppo	Italy	Italy	1/4					
Herbold	Germay	Global	3/4	●	●	●	◔	
IFE Bulk	Austria	Europa	3/4	●	◔			
Immark	Schweiz	Europa	2/4					
Imro Machinenbau GMBH	Germay	Europa	4/4					
Indumental Recycling S.A.	Spain	Spain, Germany	2/4					
IPI	Singapore	Singapore	3/4	●	●	●	●	◑
Jacomij Electronics Recycling	Netherlands	Benelux	2/4					
KGHM Ecoren	Poland	Poland, Eastern Europe	4/4	●	●	●		
KM	Germay	Europa	3/4					
KMK Recycling Ltd.	Eireland	Irland	2/4					
Krause Manuffacturing	UK	Global	2/4	●	●	●	◑	
KUKA Nordic Norway	Norway		1/4	●	●	●	●	
KuUSkoski Recycling	Finland	Global	2/4	●	●	●	●	
Kühne	Germay	Germany, Central Europe	0/4	●	●			
Liquisort	Netherlands	Global	3/4					
Magpie	France	Europa	3/4			●	●	●
MaiRec	Germay	Europa	2/4	●	●	●	●	●
MBA Polymers	UK	Global	3/4	●	●	◑		

Metallo	Belgium	Europa					
MGG Recycling	Austria	Europe			◐	◐	
Montanwerke-Brixlegg	Austria	Europa					
MRT System	Sweden	Global		◔	◔	●	●
MSS, Inc.	Tennessee, US	North America					
MTB	France	Global					
Nadin	Bulgaria	Bulgaria, Eastern Europe	●	●	●	●	
NGR Recycling Machines	Austria	Austria, US, Malaysia	●	●	●		
NOEX AG	Germay	Germany, Europa					
NRT	Tennessee, US	Primarily US					
Oran Environmental Solutions Limited	UK	UK					
OUSEI KANKYOSHOJI Co.,LTD	Japan	Japan					
Paggiola	Italy	Italy	●	◔	●	●	
Pallmann	Germay	Europa					
Paprec Group	France	Frankrig					●
Pöttinger	Austria	Global					
Ragn-Sells Group	Denmark	Norden og Baltikum					
Recifemetal	Portugal	Iberia.	◐	◐	◐	◐	◐
Recilec	Spain				●	●	
Recy Systems AG	Germay	Global					
Recydur BV	Netherlands	Netherlands	●	●	●		
Refind	Sweden	Global					
Remondis	Germay	Global					
Ges.m.b.H.	Austria	Primarily Austria					
Satake Australia	Australia	Global					
Satake Group	Japan	Global					
Saubermacher AG	Germay	Austria, US, Malaysia			●	●	●
Séché Environnement	France	Global	◐		●	●	
Sens eRecycling	Schweiz	Schweiz					
SESOTEC (S+S)	Germay	Global					
SGM S.p.A.	Italy	Global	●	●	●	●	●
Sheerbrooke	Canada	North America	●	●	◔		
SIKOPLAST	Germay	countries					
Sims Metal Management	Australia	Global					
Sims recycling solutions	UK	Global					
SITA Environment	UK	UK			●	●	
Spaleck	Germay	border-countries					
SSI	Oregon, US	Global					
Steinert	US	Global					
Stena Technoworld	Sweden	Europa					
STF Group	Germay	Global					
Sumitomo	Japan	Global	●	●	●	●	●
Sunnking	US	US					
SwissRTEC	Schweiz	Global			◔	◔	
Synergy Recycling	US	US	◐		●	●	●
Tegos	Germay	Europa					
The Galloo Group	Netherlands	Benelux / UK	●		●	●	●
Titech	Norway	Global					
Tomra Sorting	Norway	Global			●	●	
Umicore Precious Metals Refining	Belgium	Global	●	●	●	●	
Uniscrap	Denmark						
(URT)	Wisconsin, US	US					
UNTHA Recycling Technology (URT)	Germay	Europe					
URBASER	Spain	Spain,					
Vacoplan	Germay	Global					
Van Gansewinkel Group	Netherlands	Europa					
Vans Chemistry	Singapore	Singapore, (China)	●	●	●		
Vecoplan AG	Germay	Global				●	●
Venti-Olde	Germay	of Europe					
Veolia Environmental Services	US	Global					
VES	UK		●	●	●	●	
Viridor	UK						
Wincanton Recycling	UK	Global					
ZEN Robotics	Finland						

SOURCE: DANISH TECHNOLOGICAL INSTITUTE, 2014

Legend: ◔ means that the process is a peripheral activity, ◐ means that the activity is a sub process in the company, and ● means that the activity is a core activity.

An important player within the field of pre-processing is the Swedish *Stena Technoworld*. In 2012, the company accounted for approx. 40% of the total Scandinavian market revenue. This is largely because the company has made significant progress in developing efficient metal separation and recovery systems (Frost & Sullivan, August 2013). In particular, the company focuses on precious and semi-precious metals such as gold, silver, copper and palladium, and uses manual sorting as well as water and heating mechanisms.[28] Other leading companies include the French *Veolia Environmental Services*, the Italian *Sita Environment*, the UK-based *Biffa Group Ltd.* and the *Spanish Cespa S.A.*

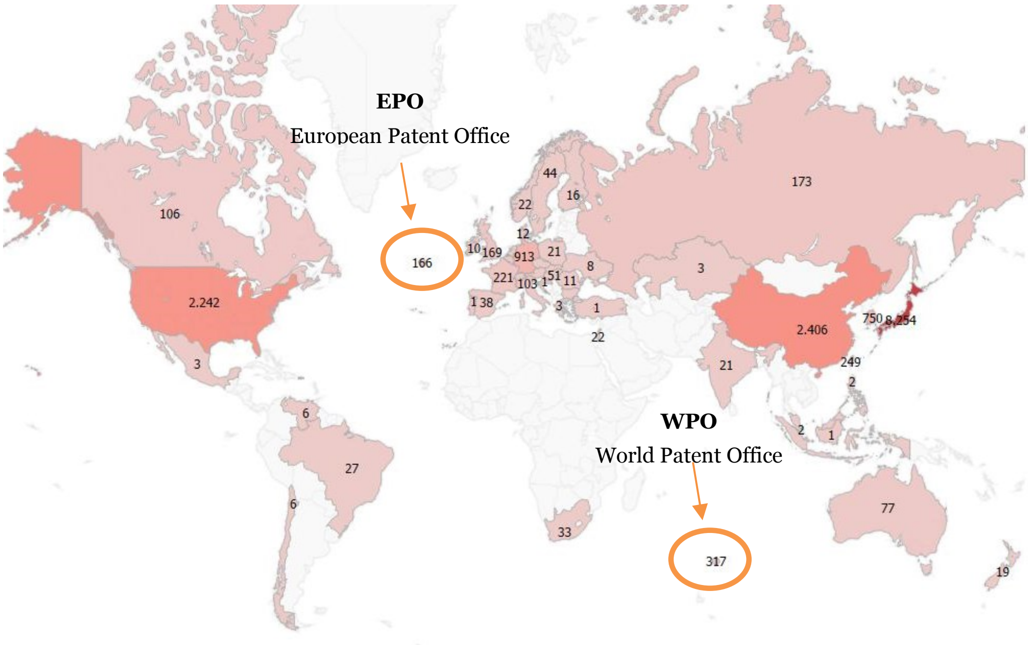
Table 16 shows that a large number of companies are active in more than one area, and that the majority of companies are active in three or more areas. This indicates that the companies are increasingly integrating the supply chain from collection to dismantling, pre-processing and end-processing. This is true for both the European companies and companies from the rest of the world. Many of the large Japanese companies such as Panasonic and Mitsubishi have established their own take-back systems, where a full extraction of the WEEE is performed in a closed value chain. This strategy goes hand in hand with the traditional Keiretsu 'spider web' of a Japanese enterprise, where the large company has an ecosystem of suppliers, knowledge institutions, etc., closely linked to its core activities (WIPO, 2013). However, the large European players Umicore, Aurubis and Boliden still focus on the high-value end of the value chain (especially end-processing, but to some extent also pre-processing), thus indicating that the focus of building an eco-system around the companies or focusing on the entire value chain is still a relatively new concept in Europe. Instead, focus is largely on price. In Scandinavia, the price of recycled material is expected to decrease by $43.1 per tonne between 2012 and 2020, as competition in the market is expected to favour companies that offer low service costs and high performance (Frost & Sullivan, August 2013).

6.6 Global patenting activities

Turning from the overview of the international players to a patent analysis of e-waste technologies, this analysis sets out to identify WEEE players and gain a better understanding of which players work together and where they are located. This is to give inspiration to future cooperation possibilities for Danish companies. The patent analysis finds that Japan has the most patent activity in this field. This is due to a number of major Japanese players in this field, such as Matsushita, Hitachi, Mitsubishi, Sharp and Sony. However, China has had a dramatic increase in its e-waste patent activities, and it is now the most active country measured in number of patents per year (see Figure 49).

28

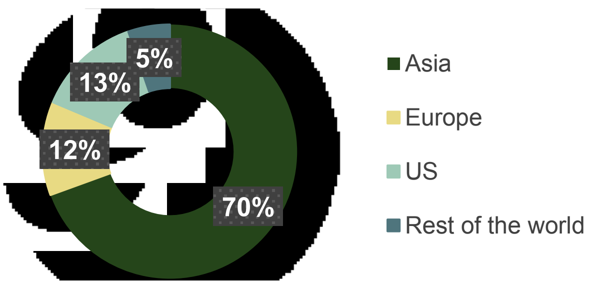
FIGURE 49: MAP OF E-WASTE PATENTS, 1980-2014



SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

Asia holds a global technological stronghold in the handling of e-waste (see Figure 50) with 70% of all patents in technologies for handling e-waste, indicating that Asia dominates the technological development in this area. Europe and the USA hold 12% and 13% respectively. The prominent Asian technology stronghold is especially due to Japan's technological capacity. Japan is clearly the most important player globally with 8,254 patents, followed by China with 2,406 patents.

FIGURE 50: GLOBAL PATENT DISTRIBUTION



SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

The major global players in e-waste technologies are Japanese firms. Mitsubishi is the firm with most e-waste patents with 373 patents totally for all Mitsubishi entities (Mitsubishi Jukogyo KK, Mitsubishi Electric Corp, Mitsubishi Electric Corp and Mitsubishi Electric Corp). The Top 10 patenting firms are not specialised in e-waste technologies, they are major conglomerate corporations that also focus on e-waste technologies as part of a production ecosystem with several electronic materials (see Figure 51).

FIGURE 51: TOP-10 - MAJOR GLOBAL PATENT ASSIGNEES, 1990-2014

	Firm	Total number of patent families
1	Mitsubishi	373
2	Panasonic (Matushita Denki Sangyo KK)	247
3	Hitachi	216
4	Toshiba	186
5	Sharp	145
6	Sumitomo Mining Company	123
7	Sony	111
8	Nippon Mining & Metals Co.	106
9	Toyota	86
10	DOWA Mining Co.	77

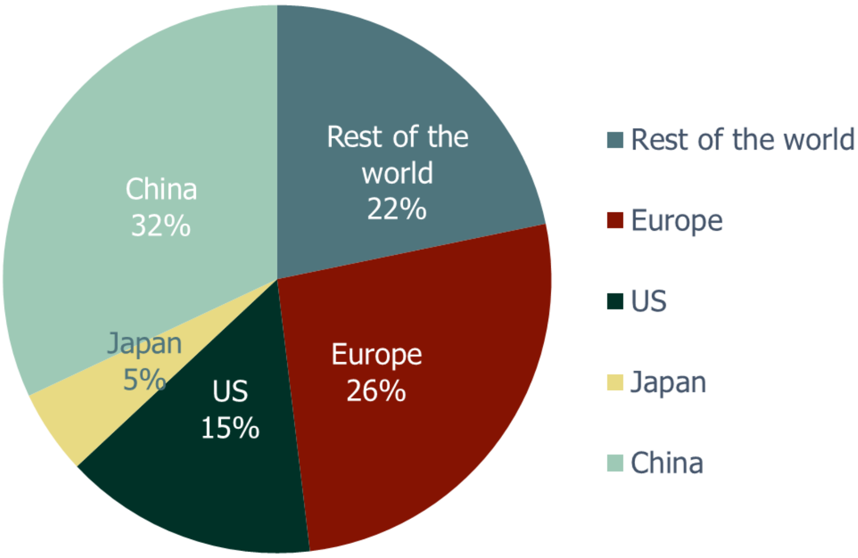
SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

China has the largest share of e-waste publications in the period 1990-2014 (see Figure 52). Overall, China accounts for almost a third of all e-waste publications in the period from 1990 to 2014. As a collective entity, Europe accounts for a quarter of all e-waste publications. This is a more prominent position than in patents. In other words, Europe appears to have a stronger global stronghold in academia than in terms of high-tech products.

FIGURE 52: SHARE OF E-WASTE PUBLICATIONS, 1990-2014

Japan's global stronghold in terms of patents is not reflected in the country's publication activities, since Japan only accounts for 5 per cent of the e-waste publications. In comparison, the USA accounts for three times as many publications and China for six times as many publications.

FIGURE 53: REGIONAL SHARE OF E-WASTE PUBLICATIONS 1994-2014



SOURCE: CALCULATIONS BY DANISH TECHNOLOGICAL INSTITUTE BASED ON PATENT DATA FROM THOMSON INNOVATION.

That being said, the literature strongly indicates that Europe is a leading WEEE region with technically advanced recycling companies, among these Umicore, Boliden and Aurubis, but also Kuusakoski (Frost & Sullivan, August 2013) that is also active in Denmark. Thus, the patent data do not reflect the development that takes place in these companies based on existing patents.

6.7 Danish patents

The patent analysis of technologies for electronic waste management shows that there are only a limited number of Danish companies with a unique technology within WEEE. This indicates that Denmark does not (yet) hold a global position relative to high-tech solutions for WEEE-processing. Possible Danish positions of strength will more likely be in the adaptation of technologies.

The identification of Danish players is based on the database Derwent World Patent Index. The database contains more than 20 million patents from around the world. There were two phases in the identification of Danish patents in electronic waste management.

- First, we identified all patents dealing with technologies for electronic waste. We used a technology classification prepared by the World Intellectual Property Organisation in a recent report on e-waste (WIPO, 2013).
- Second, we searched for the Danish patents available from this total group of patents on electronic waste.

We identified the following Danish players with patents within electronic waste:

- NKT Research Center A/S (the former Nordiske Kabel- og Traadfabrikker A/S)
- Råstof og Genanvendelsesselskabet af 1990 (RGS 90 A/S)
- Jan Prodica (now CEO of RGS 90)
- H.J. Hansen Elektronikmiljø A/S

- Ers Miljøteknik v/Peter Kafton
- E.L.M. Faaborg A/S (patent from 1985)
- Paul Bergsoe & Sons A/S (patent from 1983)

Danish companies do not appear to have unique technologies for the management of electronic waste. Only a limited number of companies hold patents in the area, and several of these patents are relatively old. This indicates that Denmark may not have a global position in high-tech solutions for e-waste (yet). However, the potential for adapting existing high-tech solutions such as optic/vision solutions, robotics, etc., may place Danish companies in a strong position in the dismantling/pre-processing phases, since, as mentioned above, the literature has shown that many mechanical processes cannot dismantle the waste properly.

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Appendix 1: Marketed products DPA

The following table shows the amounts of marketed products from DPA statistics.

MARKETED PRODUCTS IN TONNES, 2010 (DPA, DANSK PRODUCENTANSVARSSYSTEM WEEE OG BAT STATISTIK 2010, 2011)

Category	Households	Business	Total
3 (IT/Tele equipment)	11930	14968	26899
4 (consumer equipment)	20860	865	21725
9 (monitoring and control equipment)	105	478	583

For category 7, the amount from households in 2010 was 4570 tonnes and from business 114 tonnes

MARKETED PRODUCTS IN TONNES, 2011 (DPA, DANSK PRODUCENTANSVARSSYSTEM WEEE OG BAT STATISTIK 2011, 2012)

Category	Households	Business	Total
3 (IT/Tele equipment)	15621	9608	25229
4 (consumer equipment)	15465	745	16210
9 (monitoring and control equipment)	235	2255	2491

MARKETED PRODUCTS IN TONNES, 2012 (DPA, DANSK PRODUCENTANSVARSSYSTEM WEEE, BAT OG ELV STATISTIK 2012, 2013)

Category	Households	Business	Total
3 (IT/Tele equipment)	14968	7681	22649
4 (consumer equipment)	13633	1132	14765
9 (monitoring and control equipment)	232	2116	2348

Appendix 2: Product types in categories 3, 4, 7 and 9 (Directive, 2012)

Products in category 3

- Centralised data processing
- Mainframes
- Mini computers
- Printer units
- Personal computing
- Personal computers (CPU, mouse, screen and keyboard included)
- Laptop computers (CPU, mouse, screen and keyboard included)
- Notebook computers
- Notepad computers
- Printers
- Copying equipment
- Electrical and electronic typewriters
- Pocket and desk calculators and other products and equipment for the collection, storage, processing, presentation or communication of information by electronic means
- User terminals and systems
- Facsimile machine (fax)
- Telex
- Telephones
- Pay telephones
- Cordless telephones
- Cellular telephones
- Answering systems and other products or equipment of transmitting sound, images or other information by telecommunications

Products in category 4

- Radio sets
- Television sets
- Video cameras
- Video recorders
- Hi-fi recorders
- Audio amplifiers
- Musical instruments and other products or equipment for the purpose of recording or reproducing sound or images, including signals or other technologies for the distribution of sound and image than by telecommunications
- Photovoltaic panels

Products in category 7

- Electric trains or car racing sets
- Hand-held video game consoles
- Video games
- Computers for biking, diving, running, rowing, etc.
- Sports equipment with electric or electronic components
- Coin slot machines

Products in category 9

- Smoke detector
- Heating regulators
- Thermostats
- Measuring, weighing or adjusting appliances for household or as laboratory equipment
- Other monitoring and control instruments used in industrial installations (e.g. in control panels)

Appendix 3: Material distribution in WEEE products

The table below shows the composition of a number of product types in mg/kg

Type	LCD TV	Desktop PC	Notebook	VCR	DVD player	Stereo system	Radio cassette rec.
Plastic	318000	28000	258000	241000	153000	189000	469000
Fe	435684	473222	200069	532004	626540	415332	357032
Al	45308	1692	26466	50530	7560	20219	11344
Pb	1972	2162	1343	3160	1680	2109	1768
Sn	3364	1692	2192	2844	3080	2442	2496
Zn	2320	254	2192	2528	3640	1554	1144
Ba	348	179	767	190	602	155	146
Bi	0	5	16	0	12	0	24
Sr	35	36	52	4	56	2	12
Li	0	0	4000	0	0	0	0
Cu	28880	27800	36030	45280	66800	33650	46560
Ag	70	54	151	33	99	6	18
Au	23	23	86	4	21	1	3
Pd	5	14	27	8	3	0	4
Co	0	5	23061	7	15	0	1
Ga	0	1	1	1	1	0	1
Ta	12	545	795	4	11	0	1
Nd	0	500	745	0	0	0	0
Pr	0	64	96	0	0	0	0
Dy	0	14	21	0	0	0	0
In	30	0	14	0	0	0	0
Pt	0	0	1	0	0	0	0
Y	13	0	1	0	0	0	0
Gd	0	0	0	0	0	0	0
Ce	1	0	0	0	0	0	0
Eu	1	0	0	0	0	0	0
La	1	0	0	0	0	0	0
Tb	0	0	0	0	0	0	0
Te	0	0	0	0	0	0	0
W	0	20	19	0	0	0	0
Be	0	0	7	0	0	0	0
Ru	0	1	3	0	0	0	0

Continued

Type	Printer	Cell phone	Digital camera	Cam-corder	Port CD player	Port MD player	Video game
Plastic	458000	376000	318000	290000	723000	263000	478000
Fe	356258	13454	58060	57965	12646	168065	214862
Al	15320	4545	47848	5133	6868	69239	31240
Pb	740	3939	3434	5310	1212	1460	2678
Sn	1184	10605	7878	6726	5050	7536	5356
Zn	311	1515	1778	2301	2020	1727	2472
Ba	222	5757	3232	3186	869	2983	1051
Bi	1	133	46	42	111	104	54
Sr	13	130	89	108	23	53	82
Li	0	0	0	0	0	0	0
Cu	42360	102990	57540	66170	24200	81810	55140
Ag	5	1151	646	885	374	534	152
Au	3	455	158	94	37	148	47
Pd	2	91	40	172	1	86	9
Co	3	85	28	32	8	24	21
Ga	0	42	3	9	0	0	3
Ta	0	788	1596	1416	68	1507	17
Nd	0	0	0	0	0	0	0
Pr	0	0	0	0	0	0	0
Dy	0	0	0	0	0	0	0
In	0	0	0	0	0	0	0
Pt	0	0	0	0	0	0	0
Y	0	0	0	0	0	0	0
Gd	0	0	0	0	0	0	0
Ce	0	0	0	0	0	0	0
Eu	0	0	0	0	0	0	0
La	0	0	0	0	0	0	0
Tb	0	0	0	0	0	0	0
Te	0	50	0	0	0	0	0
W	0	1469	0	0	0	0	0
Be	0	11	0	0	0	0	0
Ru	0	0	0	0	0	0	0

* the 22 substances marked with **bold** are critical resources
LCD TVs, monitors, DVD Blu-ray, mobile phones and cameras are expected to contain neodymium (compact speakers); however, no data supporting this have been found in the literature.

Appendix 4: Composition of notebook and value of materials

The table below shows the composition of material in a notebook and the price per kg notebook.
The full names of the elements are stated in chapter 2 of this report, table 7.

Material	mg material/kg notebook	DKK/kg notebook
Plastics	258000.0	3.870
Fe	200069.0	0.413
Cu	36030.0	1.522
Al	26466.0	0.297
Co	23060.6	4.205
Li	4000.0	1.500
Sn	2192.0	0.295
Zn	2192.0	0.028
Pb	1342.6	0.017
Ta	794.6	1.922
Ba	767.2	0.633
Nd	744.7	0.378
Ag	150.7	0.572
Pr	95.7	0.086
Au	86.3	21.284
Sr	52.1	0.002
Pd	27.4	4.158
Dy	21.3	0.069
W	18.6	0.005
Bi	16.4	0.002
In	14.2	0.060
Be	7.4	0.046
Ru	2.8	0.044
Pt	1.4	0.383
Ga	1.4	0.002
Y	0.6	0.0002
Eu	0.05	0.0003

Appendix 5: Value of materials in category 3 and 4

The tables below show the estimated value of all materials, and also the critical resources of all marketed products in category 3 and 4 in Denmark. The values are given in million DKK

VALUE OF RESOURCES CATEGORY 3 IN MARKETED PRODUCTS (IN MILL DKK), DENMARK, 2010

	Monitors	Desktop PC	Notebook	Printer	Mobile phones	Others	Sum
Value materials	51.4	41.7	140.8	33.9	67.3	168.4	503.5
Value critical resources	27.6	35.6	116.7	8.5	61.6	143.8	394.0

VALUE OF RESOURCES CATEGORY 4 IN MARKETED PRODUCTS (IN MILL DKK), DENMARK, 2010

	LCD TV	DVD/ Blu-ray	Sound ampli-fication 1)	Trans-portable sound 2)	Digital camera	Video cam-era	Mp3 player s	Game consoles 3)	Others	SUM
Value materials	104.9	3.8	6.0	6.6	5.6	0.7	3.0	26.0	140.1	296.8
Value critical resources	56.3	2.5	1.6	1.8	4.7	0.7	2.6	22.0	39.0	131.2

1) Sound amplification comprises: Receivers/amplifiers/home cinema
2) Transportable sound includes products like boom boxes and DAB radios
3) Game consoles are incl. DVD or Blu-ray drive

Appendix 6: Loss by mechanical recycling of materials

The table below shows the losses assumed for mechanical recycling in Scenario 1 and 2

	SC 1 (% loss)	SC 2 LCD % loss	SC2 PC % loss	SC 2 mob % loss
Plastics	5	5	5	5
Fe	5	5	5	5
Al	5	5	5	5
Pb	5	40	28	39
Sn	5	40	28	39
Zn	5	40	28	39
Ba	5	40	28	51
Bi	5	40	28	51
Sr	5	40	28	51
Li	0	0	0	0
Cu	5	10	10	10
Ag	5	40	31	39
Au	5	40	28	39
Pd	5	40	53	39
Co	0	0	0	0
Ga	5	40	28	51
Ta	5	40	28	51
Nd	100	100	100	100
Pr	100	100	100	100
Dy	100	100	100	100
In	5	40	28	51
Pt	5	40	28	39
Y	5	40	28	51
Gd	5	40	28	51
Ce	5	40	28	51
Eu	5	40	28	51
La	5	40	28	51
Tb	5	40	28	51
W	5	40	28	51
Be	5	40	28	51
Ru	5	40	28	51

LOSS BY MECHANICAL RECYCLING

Scenario 1 (SC1) is a scenario with low loss and Scenario 2 (SC2) is a scenario with a higher loss corresponding to values in (Bakas, Fisher, Harding, & et.al., 2013)

It has been assumed that all Li batteries are removed before recycling, and that magnetic materials (neodymium) are lost with iron fractions.

“SC1 (% loss)” is the loss assumed for all products in scenario 1.

“SC2 LCD % loss” is the loss assumed for LCD TVs and monitors based on partly modified data from (I.Bakas, 2013)

SC2 PC % loss” is the loss assumed for desktops, laptops and other products such as game consoles, again based partly on the data in (I.Bakas, 2013).

Loss for mobile phones “SC2 Mob % loss” is based on data in (I.Bakas, 2013).

For the elements iron and aluminium a low loss of 5% has been assumed as this is typically for shredder plants and because a major part of iron and aluminium exist as larger and easily extractable parts from cabinet cooling plates etc. However, the loss might be higher depending on plant design.

For copper a loss of 10% has been assumed, which requires recovery of wires and of course the major part of all PCBs. Again, this efficiency may vary from plant to plant.

For a number of other elements not included in (Bakas, Fisher, Harding, & et.al., 2013), the loss is assumed to be the same as for indium and gallium.

The losses in refineries appear in the next table. It has been assumed that 10% of cobalt is lost when refining lithium batteries and that no lithium is recovered in the refining process, in agreement with (I.Bakas, 2013)

The table below shows the loss by refining in melting processes

	SC 1 and 2 (% loss)
Plastics	5
Fe	5
Al	5
Pb	100
Sn	100
Zn	100
Ba	100
Bi	100
Sr	100
Li	100
Cu	5
Ag	5
Au	5
Pd	5
Co	10
Ga	100
Ta	100
Nd	100
Pr	100
Dy	100
In	100
Pt	5
Y	100
Gd	100
Ce	100
Eu	100
La	100
Tb	100
W	100
Be	100
Ru	5

LOSS BY REFINING IN MELTING OVENS WITH CURRENT TECHNOLOGY

Appendix 7: Value of residual material amount (loss materials)

The table below shows the calculated values in million DKK of the amount of residual materials as well as residual critical resources. Values are given for scenario 1 and 2 in category 3 and 4 and are based on the marketed amount of products in 2010 in Denmark.

ESTIMATED RESIDUAL VALUE OF RESOURCES INCL. LOSS IN METAL REFINING STEPS SCENARIO 1 CATEGORY 3, DENMARK

	Monitors/ DKK m	Desktop PC/ DKK m	Notebook/ DKK m	Printer/ DKK m	Mobile phones/ DKK m	Others/ DKK m	Sum
Value materials	6.4	9.5	28.2	3.8	9.5	38.6	96.1
Value critical resources	3.2	8.5	19.4	0.8	7.0	34.1	73.1

ESTIMATED RESIDUAL VALUE INCL. LOSS IN METAL REFINING STEPS SCENARIO 1 CATEGORY 4

	LCD TV/ DKK m	DVD/ Blu-ray/ DKK m	Sound ampli-fication 1) DKK m	Trans-portable sound 2) DKK m	Digital camera DKK m	Video cam-era/ DKK m	Mp3 player s/ DKK m	Game consoles 3) DKK m	Others DKK m	SUM
Value materials	13.1	0.5	0.7	0.7	1.1	0.1	0.5	4.6	15.1	36.4
Value critical resources	6.6	0.2	0.2	0.2	0.8	0.1	0.4	3.7	3.9	16.0

ESTIMATED RESIDUAL VALUE OF RESOURCES INCL. LOSS IN METAL REFINING STEPS SCENARIO 2 CATEGORY 3, DENMARK

	Monitors/ DKK m	Desktop PC/ DKK m	Notebook/ DKK m	Printer/ DKK m	Mobile telephones/ DKK m	Others/ DKK m	Sum
Value materials	15.8	17.9	52.2	5.4	29.2	72.2	192.7
Value critical resources	11.0	16.1	42.4	1.9	26.1	64.8	162.3

ESTIMATED RESIDUAL VALUE INCL. LOSS IN METAL REFINING STEPS SCENARIO 2 CATEGORY 4

M. DKK	LCD TV/ DKK m	DVD/ Blu-ray DKK m	Sound ampli-fication 1) DKK m	Trans-portable sound 2) DKK m	Digital camera DKK m	Video cam-era DKK m	Mp3 player s DKK m	Game consoles 3) DKK m	Others DKK m	SUM
Value materials	32.2	1.1	1.2	1.2	2.2	0.3	1.2	9.5	25.1	74.0
Value critical resources	22.5	0.7	0.3	0.5	1.8	0.3	1.0	8.8	9.9	45.7

1) Sound amplification comprises receivers/amplifiers/home cinema
2) Transportable sound includes products like boom boxes and DAB radios
3) Game consoles are incl. DVD or Blu-ray drive

Appendix 8: Distribution of economic value in notebooks and LCD TVs

The table below shows the estimated value of materials and the value of the residual material amount for individual materials in notebooks in DKK/kg.

Material	Product value DKK/kg	Scenario 1 DKK/kg	Scenario 2 DKK/kg
Au	21.28	2.08	6.73
Ta	1.92	1.92	1.92
Li	1.50	1.50	1.50
Ba	0.63	0.63	0.63
Co	4.20	0.42	0.42
Pd	4.16	0.41	2.30
Nd	0.38	0.38	0.38
Plastics	3.87	0.38	0.38
Cu	1.52	0.15	0.22
Pr	0.09	0.09	0.09
Dy	0.07	0.07	0.07
In	0.06	0.06	0.06
Ag	0.57	0.06	0.20
Be	0.05	0.05	0.05
Ru	0.04	0.04	0.01
Fe	0.41	0.04	0.04
Pt	0.38	0.04	0.12
Al	0.30	0.03	0.03
Sn	0.29	0.03	0.29
W	0.005	0.00	0.00
Zn	0.028	0.00	0.03
Bi	0.002	0.00	0.00
Ga	0.002	0.00	0.00
Sr	0.002	0.00	0.00
Pb	0.017	0.00	0.02
Eu	0.0003	0.0003	0.0003
Y	0.0002	0.0002	0.0002
Tb	0.0001	0.0001	0.0001

RESIDUAL VALUE INCL. LOSS IN METAL REFINING STEPS SCENARIO 1 AND 2 NOTEBOOKS

The table below shows the estimated values of materials and the value of the residual material amounts for individual materials in LCD TVs in DKK/kg.

Material	Product value DKK/kg	Scenario 1 DKK/kg	Scenario 2 DKK/kg
Au	5.721	0.558	2.460
Plastics	4.770	0.465	0.465
Ba	0.287	0.287	0.287
In	0.128	0.128	0.128
Cu	1.220	0.119	0.177
Fe	0.900	0.088	0.088
Pd	0.704	0.069	0.303
Al	0.508	0.050	0.050
Sn	0.453	0.044	0.453
Ta	0.028	0.028	0.028
Ag	0.264	0.026	0.114
Eu	0.006	0.006	0.006
Y	0.005	0.005	0.005
Zn	0.030	0.003	0.030
Pb	0.026	0.002	0.026
Tb	0.0014	0.0014	0.0014
Sr	0.0012	0.0012	0.0012
La	0.00005	0.00005	0.00005
Ce	0.00004	0.00004	0.00004

RESIDUAL VALUE INCL. LOSS IN METAL REFINING STEPS SCENARIO 1 AND 2 LCDTVS

There will be an additional content of Nd, Pr, and Dy in LCD TVs as some have compact speakers with these magnets (waste analysis results from Danish Technological Institute), but the content has not been quantified.

Appendix 9: Distribution of economic value in materials in WEEE from category 3 and 4 in Denmark

The table below shows the estimated value of materials and the value of the residual material amount for all marketed products in category 3 and 4 in 2010 for individual materials.
The material prices are based on 2013/2014 values.

Material	Material value DKK/kg	Value in Products M DKK	Value loss Scenario 1 M DKK	Value loss Scenario 2 M DKK
Au	246600	306.9	29.9	109.0
Plastics	15	189.2	18.4	18.2
Pd	151754	75.0	7.3	39.8
Cu	42	73.0	7.1	10.6
Fe	2	40.0	3.9	3.9
Ta	2419	31.4	31.4	31.4
Sn	135	15.6	1.5	15.6
Co	182	14.2	1.4	1.4
Ba	150	12.9	12.9	12.9
Ag	3794	11.8	1.2	4.5
Al	11	9.30	0.91	0.89
Nd	507	5.73	5.73	5.73
Li	375	5.05	5.05	5.05
Pt	270312	3.02	0.29	0.96
In	4248	1.54	1.54	1.54
Pr	897	1.30	1.30	1.30
Pb	13	1.18	0.12	1.18
Dy	3245	1.05	1.05	1.05
Zn	825	0.73	0.07	0.73
Ru	15674	0.46	0.46	0.15
W	254	0.27	0.27	0.27
Be	6263	0.21	0.21	0.21
Ga	1564	0.09	0.09	0.09
Bi	34	0.08	0.08	0.08
Eu	6490	0.06	0.06	0.06
Sr	13	0.05	0.05	0.05
Y	354	0.05	0.05	0.05
Te	767	0.02	0.02	0.00
Tb	5310	0.02	0.02	0.02
Sum	246600	800	132	267

The Danish WEEE market

This report concerns recycling of waste from electrical and electronic equipment. Electrical and electronic equipment is a very heterogeneous group of products ranging from large household appliances to small mobile devices. Some are incredibly complex – others more simple. Critical metals and rare earths are necessary to produce electrical and electronic equipment. In many cases, however, there are no natural sources for these raw materials in Europe. Consequently, the materials are imported from competing economies, notably China. This has put "urban mining" and recovery of critical metals and rare earths on the agenda.

With this analysis, we set out to gain a better understanding of the playing field for the actors involved in what is labelled "the golden triangle": EEE producers, technology suppliers and WEEE treatment companies. What are the values to be gained from material recycling? who are the players in the golden triangle? who are their competitors? and which technologies can be used in recovery of the values? This understanding is necessary for all involved actors to better identify potential business opportunities in an enhanced exploitation of the resource potential in WEEE.

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