Improving on the open-loop reverse supply chain for data centre servers

The environmental and financial aspects of data centre server disposal

Master's Thesis - Sustainable Business and Innovation

Author
Casper van Hoorn
c.vanhoorn2@students.uu.nl / c.vanhoorn@nl.evoswitch.com

Thesis supervisor
dr. ir. Alexander Peine
a.peine@uu.nl

Internship supervisor
Eric Lisica
e.lisica@global.evoswitch.com

Utrecht University

evoswitch NEXT GENERATION DATACENTERS

“As you set out for Ithaka
hope the voyage is a long one,
full of adventure, full of knowledge.”

C.P. Cavafy

Summary

Recovery of value and materials present in waste electrical and electronic equipment (WEEE) is critical to prevent environmental damage, prevent depletion of resources and use energy efficiently. In returning the materials back to a forward supply chain, often a closed-loop supply chain is preferred over an open-loop supply chain. In a closed-loop supply chain new production is substituted with recovery of old equipment, recovering maximum economic and environmental value. For data centre servers however, this is not possible as servers have very short lifecycles and become technologically obsolete quickly.

This thesis investigates how to improve on the current open-loop reverse supply chain for data centre servers, to come to a more environmentally friendly, resource efficient and economically viable reverse supply chain for data centre servers. To perform the study, literature on business to business (B2B) WEEE, open-loop supply chains and green IT was used to create a conceptual framework. The supply chain from production, use, through to disposal was considered. A qualitative case study was performed, collecting qualitative data by doing eighteen different interviews with actors in the Amsterdam Metropolitan Area representing all relevant actors. Data was coded and analysed using the theoretical concepts to create categories for qualitative content analysis.

In the disposing of data centre servers four relevant scenarios can be identified. Dismantling of servers is preferred over shredding of servers, before materials are sorted and brought to shredding actors. In the reuse spectrum the crux is whether the servers are reused regionally or exported for reuse. With exporting for reuse valuable materials leave the region, while it cannot be made sure these resources can be recovered at the end of their next lifecycle. Regional reuse on the other hand is more environmentally friendly, but is very difficult to accomplish, as servers can be freely traded. It is common that multiple brokers have had ownership over the server before it ends up at the next end-user, making it impossible to retain control over the materials.

By informing actors on the possibilities of data destruction without losing value, servers users could be motivated through the financial incentive to dismantle servers instead of shredding them. For reusing servers, a new business model is needed which guarantees servers stay in the region and are recycled at the end of their second life. To be able to assess whether a server should be recycled or reused, more research is needed.

Table of Contents

Introduction

One of the major challenges in the 21st century is resource efficiency. Increased resource scarcity is caused by population growth, the rise in consumption of materials and the growth in waste production (Cramer, 2014). Systemically designing out material leakage and disposal through moving to the circular economy, is an opportunity to manage waste and at the same time generate economic, environmental, and social benefit. A major waste stream is formed by redundant electrical and electronic equipment (Georgiadis & Besiou, 2010). Moreover, it is the fastest growing solid waste stream (Elliot, 2007; Toffel, 2003). For the production of electrical and electronic equipment (EEE) several metal values are used, such as iron, copper, aluminium, cobalt, nickel, tin and zinc, but precious metals such as gold, silver and palladium as well (Alsheyab, 2014). Among these elements in EEE are also toxic substances, like mercury, cadmium, lead and other rare earth elements, that can leak into the environment through disposal in landfills or can form dangerous compounds through burning in incinerators (Elliot, 2007; Forge, 2007; Hanselman & Pegah, 2007; Vanner et al., 2014). Additionally, these metals and substances are not recovered when the waste electrical and electronic equipment (WEEE) is landfilled or incinerated (Georgiadis & Besiou, 2010). Proper disposal through recycling or reuse is necessary, as EEE is responsible for 10-20% of natural resources depletion (Georgiadis & Besiou, 2010).

The provision of the materials present in EEE is seen is a critical issue (Graedel, 2010). Recovery of materials from WEEE is thus a welcome second source of supply. This is especially true for high-grade WEEE, which includes the waste categories IT, Telecommunications and consumer equipment (Alsheyab, 2014). Because of the materials in EEE, it can be a valuable commodity for recovery. High-grade WEEE especially is valuable as this has the richest portion of precious metals (Bigum, Brogaard, & Christensen, 2012). In computing the waste problem is accelerated through Moore's Law, the fact that new technologies continually make faster processors possible for the same price (D'Amico & White, 2012). This is also what motivates owners of data centre servers to keep lifecycles of servers short. Lifecycles for servers are generally three to five years (Peagam, McIntyre, Basson, & France, 2013; Whitehead, Andrews, Shah, & Maidment, 2015), and can be as short as a year (Whitehead, Andrews, & Shah, 2015). The demand for data centres is growing (Harmon, Demirkan, & Raffo, 2012), making recovery of materials from their servers necessary to prevent further depletion of resources (Walther, Steinborn, Spengler, Luger, & Herrmann, 2010).

Data centres are the backbone of the modern IT network structure, but at the same time high energy consumers (Whitehead, Andrews, Shah, & Maidment, 2014). According to research by the 'Dutch Datacenter Association' in May 2016, 28% of all company firm server racks were located in data centres, and for 2020 it is predicted 50% of all server racks will be located in data centres (Vermeulen & Patel, 2016). In sustainability in data centres the main consideration has been the energy consumption footprint. The power consumption of ICT in general is growing even faster than the global power consumption (Vereecken et al., 2012), this is as the consumption of ICT increases with 20% a year (Pazowski, 2015). Data centres are responsible for one sixth of the involved footprint (Vereecken et al., 2012). This is why becoming more sustainable for these data centres has in recent years mainly concerned reducing energy use (Dao, Langella, & Carbo, 2011; Daoud, 2008). Reducing energy consumption in data centres is cost driven and a 'low-hanging fruit' in becoming more environmentally friendly (Daoud, 2008; Whitehead et al., 2014). The environmental implications of manufacturing, design, distribution, and disposal of materials, have only recently started to be considered in the data centre industry (Daoud, 2008; Deshpande & Kuware, 2015). When data centres dispose their servers, IT asset disposition services are sought in order to manage this disposal cost effectively (Brannon, 2006). The environmental aspect in this process is something more actors should consider (Schiller & Merhout, 2011). It is critical to effectively treat servers at their end-of-life, to avoid environmental harm involved in improper disposal, to prevent wasting of scarce resources and to conserve potential value embodied in the servers (Peagam et al., 2013). The process of recovery is crucial in reversing the one-way production and helps us move closer to a sustainable system (Gungor & Gupta, 1999).

The European Union has acted on the problems of WEEE through creating the WEEE Directive, where the concept of extended producer responsibility is enforced (Huisman, Stevels, Marinelli, & Magalini, 2006; Krikke, van Harten, & Schuur, 1999). The processing of end-of-life servers is perceived as a responsibility of the producers and through this directive, this responsibility established for processing of all the servers they sell (Corsini, Rizzi, Gusmerotti, & Frey, 2015). This responsibility works through one or multiple producer responsibility organisations, financed by the producers of EEE to recycle WEEE (Sander et al., 2007). However, the WEEE Directive is focused mainly on disposal of consumer electronics, while data centre servers are business-to-business (B2B) waste (Huisman et al., 2006). For B2B waste the WEEE only partly applies, and the products are not collected at producer responsibility organisations, but are processed in a separate treatment network of contractors and informal agreements (Peagam et al., 2013). The consequence is that the B2B waste is not reported on, and thus is hard to track or to control (Ylä-Mella et al., 2014; Zoeteman, Krikke, & Venselaar, 2010).

Usually in looking into the WEEE recycling flows, only the flows through producer responsibility organisations are taken into account. Huisman et al. (2012) looked into the complementary flows of B2B as well in the case study of WEEE flows in the Netherlands. From this it can be concluded that the B2B complementary flow is almost half the size of the WEEE coming through the producer responsibility organisations, 2.7 kg/inh for businesses versus 7.5 kg/inh for producer responsibility organisations. Of this 2.7 kg/inh, 0.41 kg/h (approximately 15%) comes from the IT sector, to which data centres belong. It is unclear however what happens to this hardware, and thus unclear whether this is processed environmentally sound.

The approach of introducing EPR to the B2B has not yet been successful in making recovery of disposed IT hardware more environmentally friendly. The EPR approach has had critique in other respects as well. It is questioned whether it was sufficiently analysed beforehand to intervene with introducing EPR by policy makers (Zoeteman et al., 2010). It is also debated what the impacts of EPR policies have been on regional skills and capacities in handling of WEEE (Corsini et al., 2015). The goal of EPR policies is to create a closed-loop reverse supply chain, where products or materials return to the original producer (Fleischmann et al., 1997). It is considered more sustainable compared to the alternative, an open-loop system, where products are recovered by other parties outside the original supply chain who will reuse or repurpose the product or materials (Gou, Liang, Huang, & Xu, 2008; Hammond & Beullens, 2007). In a closed-loop supply chain, the original equipment manufacturers (OEMs) are given a key role in the sustainable disposal of their products (Geyer & Jackson, 2004; Toffel, 2003; Zoeteman et al., 2010). Producers are made economically and/or physically responsible for disposal of their products at end-of-life, through the extended producer responsibility (Bufardi, Gheorghe, Kiritsis, & Xirouchakis, 2004; Walther et al., 2010). The closed-loop supply chains are considered more sustainable, as the producer pays for disposal of their product, incentivising the producer to take a life cycle approach to designing products, in which the environment is considered. Research has focused on reaching closed-loops in production chains (Rubio, Chamorro, & Miranda, 2008), but whether a closed or an open-loop reverse supply chain should be preferred is still an open question (Gobbi, 2011). The reaching of a closed-loop supply chain can be seen as an idyllic goal for WEEE, due to complexity in this goal and the technological and economic constraints present (Corsini et al., 2015). Especially for servers this is difficult as the fact that servers have a high obsolescence rates, has the consequence that new production cannot be substituted with recovery (Zoeteman et al., 2010).

The question remains how sustainability can be achieved in the reverse supply chain for servers. In achieving an environmentally and financially sustainable supply chain, synergy between economic and environmental goals or incentives is a sought for situation (Zoeteman et al., 2010). In supply chain literature economic goals are set on maximum value recovery, but this is not necessarily the best outcome for sustainability of the entire supply chain (Govindan, Soleimani, & Kannan, 2015). Occurrence of trade-offs is possible in the often complex reverse supply chain models (Quariguasi Frota Neto, Walther, Bloemhof, van Nunen, & Spengler, 2010). Therefore the goal should be to not only create economic value, but also create environmental value (Geyer & Jackson, 2004). An opportunity towards this reverse supply chain should not only be economically viable, but also better for the environment and thus a 'win-win' situation (Geyer & Jackson, 2004).

Research into reverse supply chains has been mainly focussing on creating a closed-loop supply chain (Govindan et al., 2015). The goal of a closed-loop supply chain is to be able to substitute new production with recovery of old equipment, in order to retain maximum value, environmentally speaking as well economically speaking. For datacentre servers, which are complicated technical products with high obsolescence rates, substitution with new products seems farfetched. Additionally, a closed-loop is completely different from the current situation where equipment is often contracted to specialised companies, unrelated to the producer responsibility organisations managing waste of EEE for OEMs. Therefore here the disposal is analysed from the perspective of companies using the servers and the contractors involved in disposal of the servers, as their practice dictates how servers are processed when they become end-of-life (Peagam et al., 2013). An improved economic and environmental performance of the open-loop system is needed, in order to recover resources, maximise value creation and prevent environmental damage. The research question therefore is:

> *How to improve on the current open-loop reverse supply chain for data centre servers, to come to a more environmentally friendly and economically viable reverse supply chain for data centre servers, when a closed-loop supply chain is not an option?*

Information on the waste stream of data centre servers specifically is not present. In order to assess how waste is handled, it first should be known what the characteristics of the stream are. The steps in the recovery process as developed by Zoeteman et al. (2010) can be used to structure these waste flows.

> *SQ1*
> *How is the waste stream of data centre servers currently organised, and what steps are involved in processing disposed servers?*

Next to maximising economic value and reducing environmental impact, different incentive might be crucial in disposing of data centre servers. It should therefore by analysed what the incentives are in the business, in order to be able to influence the reverse supply chain.

> *SQ2*
> *What are the incentives of actors involved in the different steps of the waste recovery process?*

By getting insight into the value chain of disposing servers, possibilities become apparent to change the way servers are disposed. It makes it possible to get grip on the disposal strategies. This leads to the third research question:

> *SQ3*
> *What can the involved parties change, to move towards a more environmental friendly and financially advantage reverse supply chain for data centre servers?*

These research questions will be answered by doing a case study research. A possible way to approach a case study would be to look at cases for specific data centres and compare the results for these data centres. Data centres are often clustered as in operating a data centre geographical establishment factors are of importance. It is therefore more interesting to look at a region of data centres. These factors are for example being close to an internet exchange point, having a reliable internet connection, having fibre and telecom connections, being close to other data centres for connections between data centres, and being close to physical infrastructure and an international airport (le Fèvre & Leclercq, 2013). In the study by Zoeteman et al. (2010), companies where the main influencers in reaching these win-win situations. The critical success factor is to achieve regional on a regional basis, which is why here a regional approach to investigating is chosen. As the data centres are clustered geographically, looking at a cluster of data centres gives the possibility to analyse problems on this regional level. The conditions for the different server owners are similar and differences and similarities can be spotted for the different data centres. This makes for a more interesting case than looking at a specific data centre. In the Netherlands a cluster is present around the AMS-IX internet exchange, which is chosen as the case to be studied.

The Amsterdam Metropolitan Area is the third strategic data centre hub in Europe (le Fèvre & Leclercq, 2013). The municipality of Amsterdam is also promoting its region as the Green Data Port. This heading is supported by a collaboration of the Dutch government, the City of Amsterdam, and the ICT sector in Amsterdam through Green IT Amsterdam. The sector has committed itself through a voluntary agreement to become more energy efficient (Nederland ICT, 2013). The region is not only actively pursuing data centres becoming more energy efficient, but also promotes innovation, technological development, and efficiency in the ICT supply chain to become more environmentally friendly (le Fèvre & Leclercq, 2013). The Amsterdam Metropolitan Area, another governmental body in Amsterdam, has initiated a programme where regionally waste streams will be pushed to become circular (Cramer, 2014). As clear ambition and goals to become more sustainable are present, the Amsterdam Metropolitan Area makes for a unique and compelling case to move towards an economically and environmentally aligned reverse supply chain.

In the following section, the case study will be described. This is followed with an explanation of the theoretical background. Here literature on B2B WEEE, green IT and open-loop supply chains is discussed. The third section will discuss the methods used. Subsequently the results will be presented. These results will be used to reflect on the theory in the analysis section. The research will be completed with the conclusions, the discussion and the advice for the business involved in this research. The business involved in this research is EvoSwitch, a data centre colocation provider in the Amsterdam Metropolitan Area.

Case description

A data centre is a purpose-built facility to house computer systems and the accompanying connectivity and storage systems. It is a complex technical facility, designed to function without interruptions (Vermeulen & Patel, 2016). In the Netherlands, 64% of all data centres is located in the Amsterdam Metropolitan Area. The sector is actively pursuing energy efficiency, because of environmental reasons, but also as it makes business sense (Vermeulen & Patel, 2016). Data centres in the Netherlands committed themselves to reducing energy use by 2% every year from 2005-2020, as agreed upon in the MJA-3 agreement (Nederland ICT, 2013). Other sustainable initiatives in the sector include the increased use of green energy, research into the possibilities of smart grids and the stimulation of sustainable building through BREEAM and LEED certificates (Nederland ICT, 2013). In the data centre establishment policy for Amsterdam, focus is similarly on reducing energy use and using green energy for data centres. Attention is broadening to include further corporate social responsibility initiatives and supply chain management initiatives, for example influencing data centres by demanding sustainable ICT processing in procurement processes (le Fèvre & Leclercq, 2013).

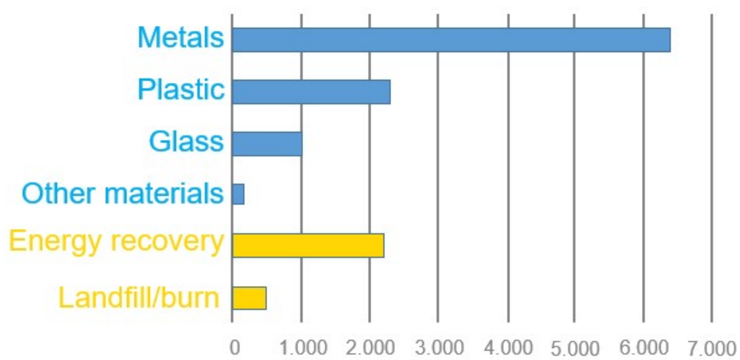

Figure 1 Recovered materials in the Netherlands (x1.000 kg) (ICT Milieu, 2014)

Managing WEEE for the data centre sector in the Amsterdam Metropole Region is currently not an issue. When taking the data centre approach companies and the government are mainly aiming at reducing energy use. The Dutch data centre sector however does want to become green and is looking into managing the supply chain for ICT processing and WEEE in general is getting increased intention. In the Netherlands increased attention is being given to the collection of end-of-life electronics. From the electronics ending up at the responsible actors ICT Milieu and Wecycle, 79% of the weight at collection is recycled to recover the raw materials, which are metals, plastics and glass (ICT Milieu, 2014). For 18% of the weight of collected waste is used for energy recovery. The remaining 3% is either landfilled or burned. Figure 1 provides a graphical overview of what happens to the materials in WEEE in the Netherlands. EEE producer responsibility is implemented by the producer responsibility organisations Wecycle and ICT Milieu in the Netherlands. Extensive studies have been done into the flows of WEEE in the Netherlands, amongst others the study by Huisman et al. (2012). This study has shown that in the Netherlands B2B waste does not flow through Wecycle and ICT milieu, but through a complementary processing system. For this complementary processing system, it is not known what happens to waste, making it clear that attention here is focused more on consumer waste than on assets disposed in the B2B sector. In the B2B sector the extended producer responsibility does apply, but with less strict regulations, for example leaving out the financial guarantee system (Sander et al., 2007). This financial guarantee system pays the producer responsibility organisations, which is why the B2B sector does not take part in this system. In what way the relevant companies in the data centre sector deal with this responsibility is analysed in this research.

IT asset disposition

A server can be returned for a variety of reasons, but here only end-of-use and end-of-life returns are considered. When a product is functioning but replaced by a technological upgrade, it is considered end-of-use (Guide & Van Wassenhove, 2009). When a product has become technologically obsolete or no longer contains utility for the user it has become end-of-life (Guide & Van Wassenhove, 2009). IT asset disposition (ITAD) is employed to address proper disposal of these end-of-use and end-of-life IT assets, while maximising value and minimising risks (Schiller & Merhout, 2011). The correct disposition of servers is often perceived by organisations as a challenge (Schiller & Merhout, 2011). For a corporation it is essential that WEEE is disposed of responsibly and that private data is destroyed in the process. Responsible disposal is necessary to reduce the risk of harming the environment through toxics present in electronic equipment (D'Amico & White, 2012). When disposal is not organised properly, organisations can be subject to fines and bad press (Brannon, 2006). To make sure environmental harm is prevented, a range of regulations apply on the disposal of IT. This makes it difficult for organisations to make sure all the applicable regulations are accounted for, especially when an organisation has servers in different countries or continents (Schiller & Merhout, 2011). Other challenges with disposing servers can be the fact that equipment is heavy and disposed of in large quantities, the fact that it can be located in multiple locations, the fact that assets must be packaged and palletised, and the fact that serial numbers must be captured for reverse logistics which is cumbersome and costly (Brannon, 2006).

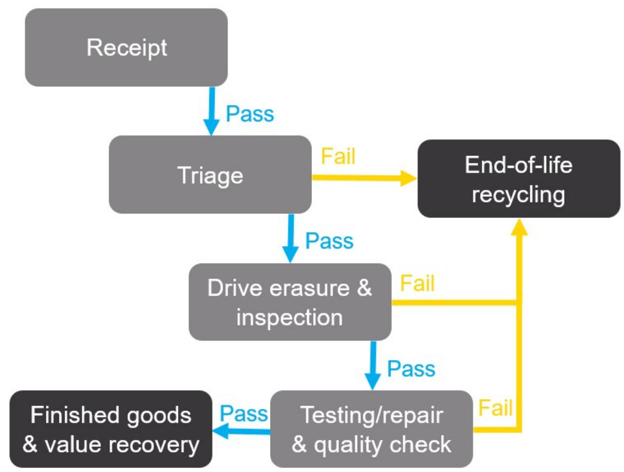

Figure 2 Typical ITAD process (Schiller & Merhout, 2011)

In order to properly manage confidential data and the legal and environmental risks of ITAD, organisations often hire ITAD solution providers to for example erase hard drives, clean and remarket assets, manage charitable donations and recycle assets with no value on the secondary market (Brannon, 2006). For these services a typical process has been illustrated by Schiller & Merhout (2011), see Figure 2. In the receipt and triage steps, the equipment is identified and inspected and it receives a unique tracking code to be able to trace it back to the originator. The equipment can now be followed using a sticker, barcode, or RFID-tag. In the inspection it is decided whether or not the equipment has enough value for the secondary market. This decision is made based on technical, functional and cosmetic aspects. When failed the product ends up at end-of-life recycling, with a pass it continues on to drive erasure and inspection. Drives are erased with specialist software and the equipment is inspected for other media that may contain data, like CDs or USB flash memory drives for example. It is made sure all the relevant data is removed, either by software erasing or destruction of the data carrier. The final step is testing, where equipment is tested and minor repairs can be made to make equipment ready for sale and thus value recovery. A fail here again leads to end-of-life recycling.

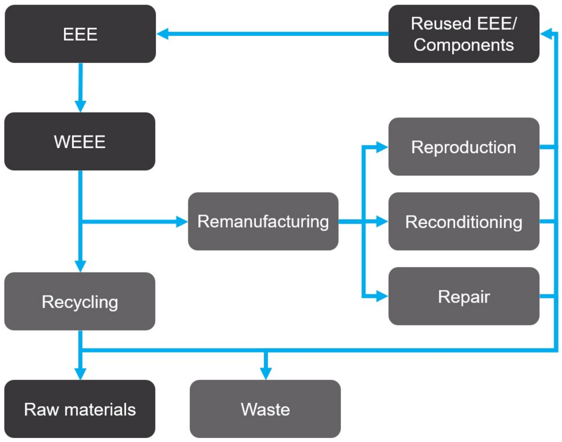

Figure 3 Generalised WEEE recovery flow (Wang et al., 2014)

This way of processing WEEE, leads to a general model with two broad categories, namely recovery of materials and reusing of products (Wang, Wang, Gao, & Vánczac, 2014). When products are reused, they are remanufactured and end up on the secondary market. In the route for material recovery parts are not suitable for the secondary market and are therefore recycled, with the goal to recover materials used to manufacture the equipment (Schiller & Merhout, 2011). Recycling partners will perform initial disassembly and extraction of usable components. These are put into large containers which will eventually be sent to smelting partners who will further process or refine materials and convert them into new products (Schiller & Merhout, 2011). Figure 3 gives an overview of the two routes for WEEE.

Theory

Supply chain management

In disposing data centre servers through one of the options present, a range of actors are involved. Supply chain research helps structure the way in which the actors are influenced by each other. In supply chain management, concerns influencing the flow of raw materials and information from the point of extraction, to the end user and possibly back (Seuring & Müller, 2008). Traditionally supply chains are organised in a linear fashion, but according to the circular economy supply chains should also consider recovery of materials through a reverse track (Cramer, 2014). Through re-entry the value of the materials can be recaptured or the materials can be disposed of in a proper way (Govindan et al., 2015). With the recovery of materials incorporated, two different routes can be identified. Recovered products, either end-of-use or end-of-life, can either return to the original producer or reused by a different party in or outside the original supply chain (Schenkel, Krikke, Caniëls, & Van der Laan, 2015). When the product is returned to the original supply chain, it is often returned to the original producer, making it a closed-loop supply chain (Fleischmann et al., 1997). A closed-loop consists of a traditional forward supply chain and a reverse supply chain where products re-enter the forward chain, through various options (Govindan et al., 2015; Wells & Seitz, 2005). When products end up at an actor different from the forward supply chain, an open-loop reverse supply chain is formed (Gou et al., 2008).

In general a closed-loop supply chain is preferred, to create a EPR-based system where the OEM accepts the responsibility for processing their products that have become end-of-life (Zoeteman et al., 2010). The open-loop supply chain structure though, has several advantages over a closed-loop supply chain, as discussed in the introduction. Integrating the reverse supply chain into a forward supply chain is a difficult process, as reverse supply chains can differ dramatically from their forward counterparts (Defee, Esper, & Mollenkopf, 2009; Gobbi, 2011). As in data centre server disposal is organised through specialised ITAD solution providers, the forward and reverse chains clearly differ. As the parties are different from the forward supply chain, the potential integration of the forward and reverse supply chain is constrained (Fleischmann et al., 1997). For data centres it is also a different situation than in the typical open-loop situation, where producer responsibility organisations manage processing of WEEE on behalf of producers. Below it is explained how steps are identified as relevant by earlier research, in sustainably disposing of servers in open-loop supply chains.

In analysing steps for recycling and reuse, the following literature is used. The article by Zoeteman et al. (2010) is used, as here ways of handling WEEE waste flows are compared, which is unique in reverse supply chain management literature. Reverse supply chain for the IT sector in the B2B is a subject that has until now only been researched by Peagam et al. (2013), who describe how users of B2B IT EEE dispose of their equipment at end-of-life. Another relevant literature section is that on company decisions in greening it, green IT literature (Murugesan, 2008). One element of green IT is green disposal, concerned with environmentally and economically viable disposal of IT equipment (Murugesan, 2008).

The first topic in disposal of servers is the decision to replace a server (Peagam et al., 2013). To make an environmentally friendly disposal decision for IT hardware, embodied and operational impacts of servers should be considered (Vereecken et al., 2012; Whitehead, Andrews, & Shah, 2015). The operational impact concerns impact made during the use phase of a server, while the embodied impact concerns the impact made during manufacturing, the embodied impact. The ratio of the embodied impact compared to the operational impact, influences whether the lifespan should be extended or focus should be on purchasing products with a more energy efficient product design (Chang, Meza, Ranganathan, Bash, & Shah, 2010; Daoud, 2008; Quariguasi Frota Neto et al., 2010). As older servers especially have a high energy use, they are unsuitable for a lengthened lifecycle (Wagner et al., 2014). The majority of companies in the survey recycle their equipment after 2-4 years (Peagam et al., 2013). These lifecycles are shorter than generally found in consumer electronics (Peagam et al., 2013). It is unknown though whether these short lifecycles are caused by the will to reduce embodied and operational impacts or by different factors.

The equipment, can thus be concluded, is often still functioning and holds significant value to be used in a second lifecycle (Peagam et al., 2013). Consequently, the majority of the responding companies in the research, did recycle or reuse their equipment. A problem identified for IT equipment in reuse is that it cannot be assured that the materials are recycled at the end of the second lifecycle (Wagner et al., 2014). Zoeteman et al. (2010) identify a related problem of illegal exporting of waste, to developing countries as China and India. These countries are developing and have strong need for materials, which is why they value these waste streams. A consequence is that large parts of WEEE flows travel long distances before being processed. This leads to increasing energy use and thus environmental emissions. Zoeteman et al. (2010) here are argue for regionalised recovery of value through recycling or reuse, to prevent unnecessary transportation and remain in control over the materials. From the results of the survey by Peagam et al. (2013) it can be concluded that other options than the reuse or recycle route were employed, but it is not possible from the survey to identify what that was. Another option next to reuse and recycling identified by (2010), is reusing of parts. These parts of discarded products are often undervalued and can be a valuable source of spare parts and parts for assembly of new products.

In the research by Zoeteman et al. (2010), it can be identified from the flow scheme of the WEEE generation process, that after the user of EEE has made a decision what to do with the waste, more decisions are made. Decisions are made between recycling and exporting, and between reusing regionally and exporting for reuse. When these steps are aggregated, Zoeteman et al (2010) identify four scenarios. First is landfilling/incineration. Second the export to low-cost regions like Africa and Asia. Third regional material recycling and fourth direct reuse, domestically or abroad.

The larger organisations dispose equipment through contractors, while the smaller organisations dispose units through formal arrangements (Peagam et al., 2013). The decisions made in the disposal of IT were often made by a single party, namely the IT manager or the IT technician, making decision making a straightforward process. What is not known however, is what incentives are behind these decisions. And even less known is about the decisions taken further down the material flow of servers, for example to either reuse regionally or to export for reuse. It is unclear who takes these decisions and with what incentive. No literature has researched what the preferred way for data centres is to dispose of their waste. It is not known what considerations are made to distinguish between reusing or recycling and whether for example operational or embodied impacts are considered is unknown.

Incentive alignment

Not only knowledge on how an environmentally friendly and economically viable supply chain can look like is necessary, it is also a question of how this situation is reached. For an effective move towards a sustainable regional reverse supply chain, it is necessary that there is environmental as well as economic incentive towards this move (Geyer & Jackson, 2004; Whitehead, Andrews, & Shah, 2015). In these cases, the environmental gains are aligned with the economic incentive (Guide, Harrison, & Wassenhove, 2003; Quariguasi Frota Neto et al., 2010). In other situations trade-offs occur between economic and environmental rational (Quariguasi Frota Neto et al., 2010). In trade-off situations obstacles or constraints are present, which need to be overcome or removed (Geyer & Jackson, 2004). Next to the economic incentive, namely maximising value recovery, and the environmental incentive, namely reduced resource extraction, reduced energy use and reduced leakage of harmful toxins, also a transportation incentive is identified by Zoeteman et al. (2010). Due to constraints on international shipping, increased global competition for raw materials and increasing pollution problems in the Far East, it has become more advantageous to keep disposed products in the region, instead of exporting used products globally. With exporting end-of-life equipment to the Far East, resources and knowledge that are crucial for sustained competitive advantage of local firms are also exported (Corsini et al., 2015). This research will look into whether these incentives are present in data centres and what constraints are present in aligning these incentives.

Conceptual model

First the flow of materials is identified from the decision a product becomes end-of-life to the point a product or the materials go back into a forward supply chain. The model of Zoeteman et al. (2010) is used to see which of the possible flows of materials are present in the recovery of data centre servers. When the material flows are described, it becomes possible check whether the problems discussed above are present in these flows. Through the classification of incentives into economic, environmental, and transportation incentive, structure is given to reasons for data centre server disposers to choose a certain route for material flow.

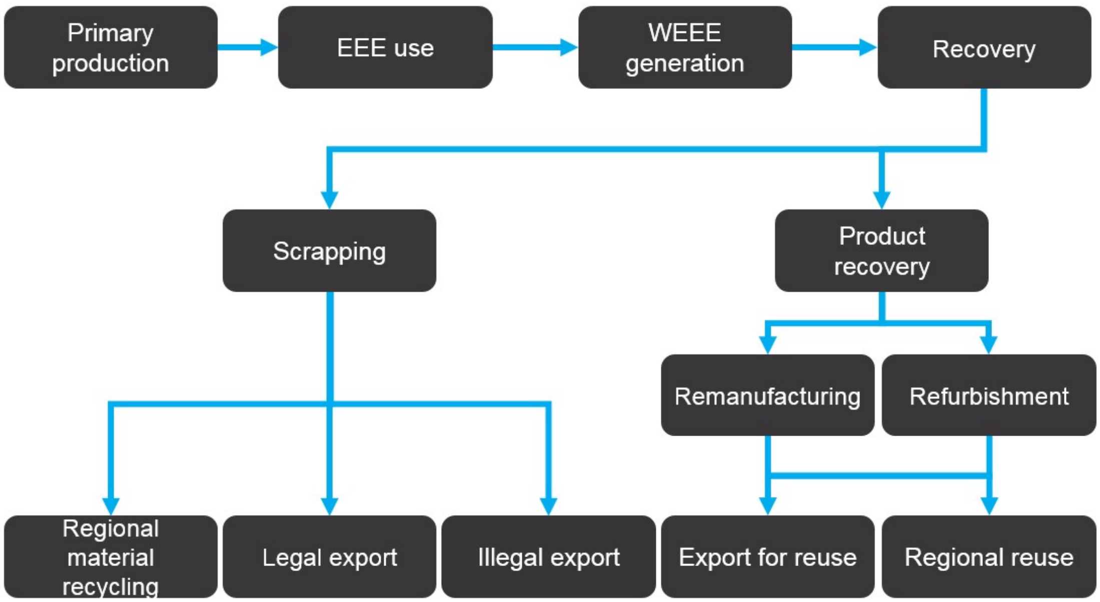

Figure 4 Simplified version of flow scheme of regional WEEE generation and processing by Zoeteman et al. (2010), *edited for B2B WEEE using Peagam et al.* (2013)

Methods

Research design

The disposal of data centre servers was researched through doing qualitative research on a case study. The case research performed in this research is approached inductively. The disposal of B2B WEEE, to which data centre servers belong, is a subject that little research has been performed on. An exploratory research is thus appropriate. This research uniquely investigates the possible WEEE flows for data centre servers, through qualitative analysis of interviews with relevant actors in this disposal chain. The relevant actors are identified are identified from the case study description and ITAD research. The relevant actors reach from the OEMs, to the server users through to the relevant steps in disposal of servers. As in the case study description it became clear that the services associated with disposal are an important aspect of disposing for server users, these are identified as well. With this information on actors and services, it can be identified how materials flow back to a forward supply chain. The information on the flows is used as a basis to identify possibilities of improving through the approach by Zoeteman et al. (2010) of improving the effectiveness of WEEE processing. The incentives of actors to dispose of the material in the way they do, is also questioned in the interviews. These incentives are classified into the three factors as described by Zoeteman et al. (2010). These steps make it answer to answer the research question to come to improvement on the open-loop way of disposal as it is currently organised. In answering this research question, doing a case study is a fitting strategy. It allows for an intensive analysis of a single case (Bryman, 2012). This case is a unique case, of which the features are elucidated, which is known as taking an idiographic approach (Bryman, 2012). Through doing a case study a precise description or reconstruction can be made, making most of the qualitative approach of doing interviews chosen. Another reason for doing a case study is the fact that a how or why question is proposed, related to a contemporary set of events, over which the researcher has limited to no control, which are criteria for doing a case study (Yin, 2009). A drawback of this research design is difficulty of extrapolation of results. As this research is meant to give an exploration in the new field of data centre server recycling this is not really a problem.

Data collection

Data was primarily collected from interviews in this research, supported with collection of secondary data. The secondary data consisted of official documents by public parties, and company publications. The interviews were conducted in a semi-structured way. This way relevant topics were discussed but room was allowed for new or hidden themes. As it was semi-structured, these new and hidden themes were deepened by asking follow-up questions (Bryman, 2012). To get as close as possible to answering the research question with the interview questions, the questions were structured according to the sub-questions. Theoretical concepts were used to make sure all relevant information was touched upon in the interview question. The interviews thus were divided in three part and for every part the relevant theory was used to form the interview questions. The interview questions were updated and improved after the first interviews done, as through doing the interview it became more clear what questions worked and what questions could be improved upon. Also new information learned in these interviews could be adopted to in the interview questions to check against the other interviewees.

The questions were open ended and as general as possible, to allow for the opinion of the interviewee. When further specification was needed, this was provided through follow-up questions. The interview questions were structured using the three sub-questions, as shown below.

> *SQ1*
> *How is the waste stream of data centre servers currently organised, and what steps are involved in processing disposed servers?*

Questions in this part investigated the way data centres currently dispose of servers, by looking into the parties involved and the recycle/reuse option chosen. The interviewees were asked open questions on what actors and disposal ways they identify, and what services they associate with these actors.

SQ2
What are the incentives of actors involved in the different steps of the waste recovery process?

In the way the disposal of data centre servers is organised, inherently choices are made. Knowing what the incentives behind these choices are, is the first step to knowing how to make sure choices are made that improve on economic, ecological and transportation aspects of the reverse supply chain. In the interviews it was asked which incentive actors have for making certain choices in the supply chain. It was made sure the results were not steered with questions, by not making suggestions for incentives in the initial question. Only when an interviewee is missing a certain issue, a follow-up question might be asked to check something found in literature or in earlier interviews. The incentives given could later be organised according to theory.

SQ3
What can the involved parties change, to move towards a more environmental friendly and financially advantage reverse supply chain for data centre servers?

The parties involved were asked directly what they believed that should be changed and what is needed to come to this change. This was a general question, as well as a more direct question what they believed to be in their reach to change. Based on these answers a shortlist of recommendations could be formed to come to a regional reverse supply chain for data centre servers.

Sampling

Case selection

In the Amsterdam Metropolitan Area support for an environmentally and economically driven reversed server supply chain seems to be apparent. This is shown through support from governmental bodies specifically concerned with creating a server recycling community (Cramer & Nederstigt, 2015; Cramer, 2014). The companies in the region are also active themselves in becoming more sustainable, which is defined in a voluntary multi-year agreement (MJA-3) between a large portion of companies and the Dutch government (Nederland ICT, 2013). In this drive to be more sustainable the inclusion of care for WEEE can become the next target. Support is at least present for this move. WEEE in general is getting increased intention on a Dutch and on European level (Huisman et al., 2015). In addition to the focus on properly recycling WEEE, the Netherlands is also proactively being promoted as a hotspot for the circular economy, through ambassadorship by a very diverse array of companies and governmental organisations (Douma, 2016). The Netherlands is also a clear case where the WEEE B2B waste is organised separately from the consumer waste which is collected by producer responsibility organisations (Huisman et al., 2012) The combination of the separately organised waste stream within a country with positive preconditions towards sustainably managing data centre server disposal makes for a unique case to analyse the possibilities of making the data centre server disposal more sustainable, and thus can be classified as a critical case (Yin, 2009).

Interview sampling

A generic purposive sampling strategy was used, to select actors most relevant for answering the research question. Sampling was thus performed fixed and a priori to the research, according to a set of criteria. An important notion is that this research was performed at EvoSwitch, a colocation provider in Haarlem. To make most of the research, the network of EvoSwitch was used in approaching interviewees. This made it possible to interview parties, which otherwise would have been difficult to reach. To be able to answer the research question it was of importance that as much parties in as much different positions as possible were interviewed. This meant interviewing OEMs, users of servers, ITAD solution providers, remanufacturers, and recyclers. Also a NGO promoting sustainability in the sector was interviewed to give sector wide information. In sampling it was attempted to pick actors who actively portrait themselves as sustainable and actors who have less feeling with this subject, as interviewing sustainable parties only could have skewed the results. At every actor at least one employee was interviewed. As most connections into a company came through the EvoSwitch network, it was not possible to steer who was interviewed or what responsibilities on server disposal the interviewed actor had. In some cases, multiple employees were interviewed, but only when the possibility presented itself and when it was deemed useful. To make sure the Amsterdam Metropolitan Area was represented, a prerequisite was that companies had operations in the region. To be able to talk to enough parties for (near) saturation, but considering the limited time available, a total of eighteen interviews were performed. The interviews were recorded and transcribed in order to be analysed thoroughly. An overview of interviewees can be found in 'Appendix – Interviewees' and is depicted in Figure 5. In summary the following actor types were interviewed: five employees working at three different OEMs, by which a large majority of servers produced for the region is covered; six employees of three server users; two recyclers, a recycler/refurbisher and a refurbisher; two ITAD solution providers; one NGO involved the greening of the IT sector. An overview of all the interviewees and the role of the interviewee in their company can be found in the appendix.

Figure 5 Overview of actors interviewed

Data analysis

The available data was analysed through qualitative content analysis. In qualitative content analysis, categories, which are derived from theoretical models, are used, as is the case here (Flick, 2009). Different from other techniques like grounded theory, the theory is brought to the empirical material, through the categories. For the main structure of the categories the research sub-questions were used. Within these categories the theories that belong to the sub-questions were used to further categorise. In order to come to an organisation of the waste stream, concerned with the first research question, the conceptual model of the theory section was used. Every step in the conceptual model was incorporated as a category below the research question. When possible, sub-categories were created by using concepts identified in B2B WEEE, green IT or open-loop supply chain literature. For sub question two, the same steps where used, together with incentives provided by open-loop supply chain management literature. In answering the third sub-questions open ended questions where used. This is an exploratory part of the research, and builds on the results from the first sub-questions. By asking open-ended questions on how to improve the supply chain, some useful starting points might arise. The coding tree that was created with help of literature and the research questions was improved on by notes made during the interviews. For the actual coding the software package NVivo was used. In the actual coding, the relevant pieces of interview text were encapsulated in the corresponding defined codes. When no fitting code was present, new codes were developed or lower level codes were made. After all the interviews were coded, the text encapsulated in the codes code was read code-by-code. During reading it was checked whether it should not belong to a different code. It was also analysed whether codes should be merged to other similar codes or whether the text in a code should be split into multiple different codes when information was too diverse. This way the final coding structure was formed by a combination of literature, research questions and qualitative empirical data. The results were written based on the resulting coding tree. Because of this process, the results are a summary of the interviews, based on the structure created by sub-questions and the conceptual model. The analysis is then a comparison between the theory and the results, based upon which the final conclusions are drawn. Because the codes are organised according the sub-questions, an answer can be given to the sub-questions. Through answering the sub-questions, an answer to the research question can be given.

Results

Below the results from coding are described. Here the order of the sub-questions will be followed. The conceptual model is used to display the results.

SQ1 – Organisation of server disposal

Here firstly the codes concerning actors involved are summarised. It is explained shortly what their role is. Subsequently it is explained what servers are performed in the supply chain, and what these services comprehend.

Server procurement

The main role for OEMs in the supply chain is producing servers. In the Netherlands the market for servers is dominated by two producers, Hewlett Packard Enterprise and Dell. Other computer producing enterprises are active on this market as well, like for example Lenovo and Huawei. The focus of the producers is to produce servers and gain market share. The procuring of servers works through procurement processes, where certain demands can be set for OEMs to apply to or score on. In producing servers, an aspect is the design of servers, although here the OEM is dependent on the involved suppliers. A producer of servers makes a housing in which different computing components are combined, like the processor, memory and hard disk. These components are produced by different companies (Intel, Kingston and Western Digital for example). When pursuing recyclability of their servers for example, the OEM, is very dependent on the suppliers to change their components. Influencing these suppliers goes through for example demanding certain aspects in the procurement process or through auditing. The design influences the recyclability of a server at one end of the chain and influences the upgradeability at the other end of the chain. When servers are harder to take apart, more costs are made at the recycling facility and/or less material can be recovered.

Decision to dispose

The managing and disposing of servers is a role that is filled in by the server user. Users of servers are very diverse. Companies operating in different sectors can operate their own servers, in their offices, or in datacentres. Here a single IT department is responsible for managing the servers. In other cases, servers or IT services are hired from specialised companies. These parties provide entire servers, processing capacity on servers or specific IT services. In this route multiple actors are involved in the management of a server. In such a case the company owning the server, can be different from the company maintaining the server and again different from the company using the server. On top of that, the parties involved can also change over time. Even though the same IT provider owns a server, a server can have many different users and also ways in which the server is used.

The decision-making in server assets is a role that can be dispersed over different departments and companies. The IT department for example might be responsible for managing servers, but a specific facility services department might be in place to manage disposal of assets. Or a company might manage a range of servers, but pay for these through a leasing structure, where the lease provider is owner of the assets and therefor responsible for disposal of the assets.

When a server becomes end-of-use, the actual disposal of a server is not a given. Disposal can also be prevented. An organisation might for example use an old server for a different purpose, which is less demanding and thus does not need a state of the art server instead of disposing of the server. Organisations interviewed tend to use the servers as long as possible, before disposing. In order to get to a longer lifecycle, also upgrading the server by placing extra memory is possible. Only marginal gains are possible here however, as new generations are often not backwards compatible to older generations.

Services

In disposing of servers, it is not only about the service of waste disposal, other services are relevant as well. The following services are offered by actors active in service disposal.

Collection

Often servers are collected at the user's location. For the user it is important to know which servers have been taken away, while for the disposal party it is important know what types of server are involved. They need to be identified, then they can be tracked by the server user. Often at this point also the components that are present in the server are identified, as this can be different for two servers who look similar on the outside.

Data security

Before anything else happens, it has to be made sure that the data on the drive cannot be leaked. To make sure no data is left on the server, different processes can be performed. The first option is to shred the entire server. The downside to shredding servers and hard drives is that they cannot be reused, but also that it is more difficult to identify the different materials. The different materials become tiny hard to recognise nuggets, making it costlier to sort the materials. The goal of shredding is to make nuggets, in order to make sure the drive cannot be reconstructed. In the process however, a lot of dust is created as well. Some parts will be so tiny, that they cannot be identified anymore and have to be disposed of as waste. Shredding more, inherently means more dust and powder which has to be send off to waste treatment facilities. To prevent valuable material of being shredded, the hard drives can be separated from the server so only the hard drives have to be shredded. And even the hard drives themselves can be dismantled. By separating the physical drive, the rest of the hard drive can be left intact. Then only the physical drives have to be shredded. Consequently, the circuit boards in the hard drives can be brought to the smelter in one piece, leading to a higher revenue.

Another technique is degaussing, which removes the data and makes the drives useless, but does leave the hard drive physically intact. It is also possible to erase the drives while keeping them working. A special software package is used for this: 'Blancco'. This is a time consuming process where the program is run up to seven times to ensure the data is wiped properly. Often the service is offered to erase the data on the location of the customer, to reduce risks of leaks even further.

Certification and reporting

When servers have been erased, clients are provided with the information what servers have been shredded, but also give out a certificate of destruction, so the client can prove they made sure no data was leaked. This is not only about producing a certificate of destruction, but it also needed to report what happened with what server. As an end result the client receives a total report on what has happened to every piece of equipment, accompanied by the aforementioned certification. This service is often an audited process, to show the quality of it. In software wiping running the 'Blancco' program more times is a higher certification level.

Recovery

When it has been made sure data is securely destructed, hardware is inspected and tested. Here it is identified whether a server is fully functioning or if possibly components need to be replaced. When inspected and tested it is decided whether servers are suitable for refurbishment or if servers should be recycled. The actual repair or refurbishment mostly involves cleaning, removing of dust and replacing broken parts. Sometimes servers are also upgraded with spare parts, as for example extra memory if possible. Components are highly complex and are usually replaced instead of repaired when broken. Some servers cannot be repaired or do not have enough value to justify refurbishment, these go on to be recycled. After refurbishment the servers are booked into stock to be sold again.

Regional reuse versus export

When servers are refurbished, they are generally not directly sold to a new end user, but one or more brokers are present in between. Broker parties only buy and sell equipment, and do not add value other than that. This process of buying and selling often happens quickly with small margins. In multiple interviews it became apparent that it is common for multiple brokers to be present between the reseller and the new customer: *"Before such a server ends up at a new end customer two, three or even four actors might have had the server in its possession. That is a real possibility. […] When we sell* *a server, we do not know what happens to it"*. It is often a company secret to whom servers are sold, in order to protect the client database. And even when this would be accessible information, it is very likely the next party is a broker who directly sells the server again, without disclosing to whom. This makes it impossible to trace what happens to the servers. Thus from the interview data it was not possible to give a clear answer to where the servers are given a second life, geographically speaking. Different interviewees gave very different answers to where they thought servers would end up, though. Some interviewees thought servers are hardly ever refurbished and reused, and thus a reuse market for servers was not present. Others spoke of a lively second hand server market, where most older servers end up outside the region and outside the Netherlands. Guesses here vary widely, servers can be freely traded and thus might end up in all kinds of European or even non-European countries.

Shredding and dismantling

The recycler will take the server apart to separate the different materials. It is the final step before factories who actually make raw materials of it again. Recyclers sort the server into different materials. This can be done by manually dismantling server by server or by shredding. Materials are separated as much as possible and sorted. When aiming for getting the most value out of the server materials, it is better to take the servers apart manually. The circuit boards can then by separated and carefully sorted on quality to go to a smelter company. These circuit boards are the most valuable part of the server and also contain all the precious and rare metals. The value of the circuit boards is increased further by removing pieces that lower the quality, for example the cooling fins. The value of different circuit boards can differ a lot, which makes it important to sort them on quality. Circuit boards are offered to the smelters by the container and are tested for quality in batches of 5kg. A couple of circuit boards in lower quality can make a big difference, if they are part of the batch. The servers are sold to specialised smelter companies, because they are too complex to split for the recyclers. These specialised smelters separate the materials in circuit boards to come to raw materials again, which can be used for production of new products in all kinds of supply chains. Next to circuit boards, servers mostly consist of plastics and metals. These can be separated by the recyclers and are sold to smelters. These smelters can process the resources into materials useable in all kinds of supply chains to produce new products.

What percentage of the material of which the server is composed can be recycled in this entire process is not very clear. Different interviewees gave different answers on what percentage they expected to be recyclable. A majority mentioned numbers between 90% and 99% can be recycled, others answered numbers as low as 40%. Some interviewees also pointed out, that more information is relevant here. The most valuable part of the servers, circuit boards, only make up about 6-7% of the weight of the servers. When 90% of a server is recycled, nothing can be concluded on whether the circuit boards are recycled properly or not. So it is also important to know how much of the materials in these circuit boards is recovered. Here more information by the smelters is needed.

Regional recycling versus export

Further down the supply chain, when a server is recycled, the different sorted materials go to smelters. These smelters smelt it back to a new resource. The recycling of WEEE is regulated, amongst other regulations, through the WEEE label of excellence (WEEELABEX). Through this regulation it is stated how materials should be treated, but also to which parties the material is can be sold. Selling the waste from broker to broker like in the market for second hand servers is therefore not possible. The only thing that ends up as waste, and even that might be used as filler material, is the powder that comes from shredding and cannot be retraced or sorted as a certain material. This is only a very small fraction of the total server. This goes to waste treatment facilities and is there either used for energy recovery or landfilled.

The smelters parties are often situated outside the region and outside the Netherlands as well. This is especially true for the circuit boards, the high value part of the server. Companies capable to recycle these circuit boards are scarce, only 8-10 exist worldwide. For the Netherlands the closest is Umicore in Hoboken, Belgium. Smelters of the other materials in servers are more common than smelters of circuit boards and can be situated in the region, like for example Tata Steel for the Amsterdam Metropolitan Area. These materials are also sold to smelter factories outside the Netherlands or outside the European Union. Turkey for example is a popular country to export metals to, as here a big shortage is present.

SQ2 – Incentives in the reverse supply chain

In answering the second sub-question, the model made in the first sub question will be used. The first sub question describes what choices are made in the supply chain. This does not show however, why choices for different actors or ways of disposal are made. To fully understand the reverse supply chain, the incentives in choosing for specific services will be explained here.

Server procurement

Economic viability

The sale of servers often involves a procurement process. In order to win such a process, price is an important factor. However, it is possible to distinguish in other factors, like for example recyclability, but then the customer needs to demand for it. When the customer, in this case the server user, demands for a certain design value, a higher price can be justified. Currently design values as recyclability and reduced energy use for servers are often not items discussed in the procurement process.

When a server is bought, it is also planned in what amount of time a server is deprecated. This influences the moment of replacement. When sale of a server is contemplated, the book value can be an important tool to decide whether to sell the server or to keep it in operation. A strong categorisation can be made here. Some companies buy servers and deprecate them over a certain time-period and do not plan the moment that they are going to deprecate the server, but take it year by year for example. Other companies have a more elaborate strategy for server replacement. They may even take into account the full cost of ownership of a server and plan for replacement through this calculation. Another planning option is signing a lease-contract, making the lease provider responsible for disposal of the server when the lease contract ends.

An upcoming item some parties are starting to consider is the energy use of the server. This is not out of environmental concerns, but because they have calculated the energy a server uses over its lifetime, costs more than a new server. When a new server generation is more energy efficient, especially when also considering processing power in the calculation, it can be interesting to replace a server sooner rather than later. However not all parties are convinced energy consumption has such an influence on the total cost of ownership. Another critique is that it is hard to predict what the energy consumption of a server is; as the way a server is used can differ a lot over the lifetime of a server.

Decision to dispose

When deciding to dispose or use a server longer, a decisive factor can be the amount of energy a server uses. The energy use and its impact is discussed above in the section on the sale of a new server from OEM to user. The same applies here, some actors are starting to identify the importance of considering energy use in the decision to dispose of a server of keep it in use. Deciding whether to keep or to dispose of a server is often a complex financial decision, where it is difficult to assess what the most optimal solution is. Another complicating financial aspect is the associated support contract and warranty a server has.

When a server is bought, often a support contract is also agreed on. After this support contract has ran out, the costs of lengthening it are often higher than the initial costs. The risks of breakdown increase over time, making it more expensive to support the server. Also the availability of replacement servers can be a reason to upgrade (when a server is no longer in production), or the technical support of certain applications or operating systems.

Services

Data security

The first priority in disposal by users is what happens to the data on the server. That has two reasons. Firstly, the data can contain business secrets or other sensitive data, of which the user and owner of the data do not want others gain access to. The second is that it is very important to remove the identity of the servers. By erasing the data on the server, the product cannot be traced back to its first owner. After servers are sold, the user does not have control over them anymore. By making sure nobody can who previously owned the servers, the previous owners cannot be held responsible over what the consecutive owners do with the servers.

In disposing the server, the reason to choose for a certain way of disposal the possibilities of data destruction are important. The way the data is destructed is steered by the provided sense of security. For software wipe, even when performed seven times, it could be possible that data is recovered with very intensive research. For companies it is a consideration between recovery of financial value through sale using software wipe or the decreased risk in knowledge that data cannot be recovered after the various other methods for data destruction, like for example degaussing, shredding and shredding of only the drives. The more sense of security, the less value can be recovered.

This focus on data security has become more intensive in recent years as regulation became in place on this subject. With regulation on data leaks, the possible penalties for leaking data are very high. For a lot of businesses this means they are focussed on ensuring that data is erased. Dealing with a certified company that can provide with certificates of disposal is a must for most interviewees.

Responsible disposal

When data security is made sure of, the second priority is that the materials are disposed of in a responsible way. The specific way the material is disposed of is not always important, as long it happens responsibly. Companies do not want to be liable through violating environmental legislation. Therefore, it is not a factor to distinguish upon, but often more a like a minimum requirement. A way to check this requirement for actors is to through demonstrating a range of certifications. For material recycling, WEEELABEX is obliged by legislation. For refurbishment and resale however, there is not such a specific certification. Other relevant certifications can be different environmental management systems like ISO14001 and Dutch specific certification like 'MVO' (a label for corporate social responsibility).

These certificates are not the only argument to let actors believe that the disposed servers are handled in an environmentally responsible way. This is also enacted by relationships of trust. The trust can off course be strengthened by the presence of appropriate certificates. It is relevant for a user of servers to know that the servers are disposed in an environmentally friendly way, but the exact way the disposal party takes care of this is usually a matter of trust. As user of servers do not have a lot of knowledge on the possibilities and the positive or negative impacts associated, relying on trust is necessary to be able to come to a decision. This also makes that parties are not eager to switch to a new party, when they are convinced their current partner in server disposal is doing their job responsibly.

Convenience

For server users, making sure servers are disposed of is generally a low priority issue. It is important that space is made for new equipment so the old equipment needs to be taken care of. It can be very time consuming to separate for different disposal facilities and to transport it. The owners of servers want to invest as less time as possible in removal of these hardware. If a company can come in and take care of all the necessary services, like collection, identification, drive erasure and separation of recycling and refurbishment, that saves a lot of time and energy. Especially international for bigger companies, operating in large volumes and maybe even in multiple countries, it is simpler to deal with one company who can manage the entire stream of waste in all different locations.

For smaller business, the servers to be disposed might be mixed in a stream of the WEEE of a business combined. This might be a container or storage unit that fills up over time and at some point needs emptying. Here the most convenient option for such a company is to have a company take care of all the electronics in one go.

Economic value

When a server user disposes servers, the price given for second hand servers might be a reason to choose for a refurbisher instead of a recycler, or the other way around. Also different refurbishers and recyclers may give different prices for a server, making the price the deciding factor for a certain actor. It can also be a motivation to either sell the server or use it longer. When the market value of a server is higher than the book value, it is easier to decide to sell a server. A complicating factor in the economic value, is that users often do not know the exact value of their servers. Especially the reselling market can be very nontransparent, making it difficult to know the value of a product.

When server users are more interested in the service provided, and not so much in the value of the materials, a revenue share model is used. The service provider, refurbisher or recycler takes care of the logistics, drive erasure and other required services. They sell the separate materials or the product and the user gets a part of the profit when the costs of service are deducted from the revenue made.

Recovery

Server generations

When deciding whether to refurbish a server or not, one of the leading questions is what generation a server is. Servers are produced in a certain generation, say for example generation six. Within that generation upgrades can be done, but only with components for that generation. So when generation seven components are launched, they are inherently better than the generation six server, and it is not possible to upgrade it to generation seven. This means that servers lose their value quickly. The current and more recent generations are often used in the Netherlands. However older generations can be exported to other countries where these are still used. Within a generation however, there can also be differences in servers. The low-range servers have less value for resell, than the top of the line high-end servers. It is possible to upgrade these low-range servers, but some actors say this is very time consuming and therefore not financially viable. Another important point is the brand of the server, the popular brands are easier to sell than the unknown brands.

Parts

At the point that a server of a certain generation is not valuable enough for sale, or when it is not functioning, often the valuable parts are removed from a server. These can be used as spare parts for organisations that still use this generation of servers. They are either sold to organisation where the server originates from, or to the OEM, or to a broker.

Costs of handling

In the situation that a server is going to be refurbished as a piece, as well as in the situation where a server is going to be sold in parts, there has to be decided beforehand if it is worth it. A server might have a certain value, but the costs of handling the server can be easily just as much or more. In the deliberation whether to recycle or refurbish or use in parts, this is always a consideration. Refurbishers and ITAD service providers often know beforehand what certain servers and certain components are worth. They can then decide whether it is worth it to invest the man hours to go through the refurbishing process. Often databases are used, which includes the prices of all kinds of different hardware. These databases tell employees whether they should refurbish, use for parts or recycle a certain server.

When disposed goods are delivered to refurbishers in a mix of electronic equipment. The costs of handling increase, as the different electronics need to be sorted. Also these collections of electronic equipment may be collected over a longer period of time, thus the oldest equipment in it is not worth refurbishing anymore. As the amount of dated equipment in a batch is bigger, the time that needs to be invested to sort the valuable equipment out, gets less worth it.

Scrap value

When refurbishing or using parts is not a viable option, servers will always be sold for scrap value. The upside for servers is that even when scrapped it is a relatively valuable product. It consists of materials that are generally recyclable, like metals and plastic, and has high value parts, namely the circuit boards.

Regional reuse versus export

Here servers are sold to the company paying the best price. The companies spoken to stated that they sold their products to somewhere in Europe often. But it is, as explained before, uncontrollable what happens after that. Some refurbishers are considering to only sell servers in certain countries, or to stop reselling of equipment with very low values, as with these low value servers, the chances are they end up in countries without proper waste treatment is higher. However, this is not common practice yet, and also not a priority as this is not something clients demand.

Dismantling and shredding

Shredding

In the recycling of materials, the first question is whether servers should be shredded or not. When this is not a demand, materials can be separated more easily and there is less loss through material turning in to dust or powder. The less of the material is shredded, the more that goes to the smelters, and thus more value can be recovered.

Scrap value

A small difficulty in the process from recycler to smelter, is that the recycler only learns what was exactly the amount of materials in a batch, after they are sold to a smelter and tested by the smelter. That may be long after the material was first received by the recycler. Therefore, the recycler needs to make an estimation of the worth of materials he buys. This works by making a mass balance of what masses are in a certain product. This is not the same for all servers, so is estimated as much as possible on historical data recyclers have collected over time.

Regional recycling versus export

Materials are sold to the actors that offer the best price for the materials. Side note here is that smelters close to home are often preferred, as transportation costs are lower here. A lot depends on the quality of the materials however; different smelters are interested in different qualities.

SQ3 - Change in the supply chain

For sub question three, the interviewees where asked what they thought was currently wrong in the supply chain and how thought to come to a more environmentally friendly and economically viable reverse supply chain. Very different answers where given, and here everything is collected that was identified as a problem by multiple interviewees.

Nothing is going wrong

A minority of interviewees was convinced nothing is wrong with the way disposal of servers is currently organised. They could only think in secondary sources of pollution, like transport of the servers to and from customers, which might be organised more efficiently.

Barrier

The fact that some parties do not think something is going wrong, might be because there is no specific actor in the chain who owns the problem. The problem with an imperfect disposal chain is with the society as a whole. This is exactly why some actors are not aware that there are imperfections. The fact that there is no actor who is experiencing problems, makes it difficult to motivate actors to change.

Awareness

That there is no problem owner, can be related to a problem of awareness, which is the most often mentioned problem. A lot of companies do not know what the value is of servers. They do not know even the oldest servers have value in terms of scrap value. This means they might leave it at a storage facility, of throw it in with the wrong kind of trash. Another problem is that they do not realise the value of slightly dated servers in reuse value. When collecting electronics waste over a longer time before disposing, the older electronics have lost value. In the server market value is lost quickly, as new generations follow themselves up quickly. A crucial point here is that server owners might not know about the different options for data destruction, and are afraid of running the risk of a data leak. Informing them on this might help in making the decision to dispose of their unused equipment sooner. Here also awareness is necessary. Actors should know that it is not always necessary to shred entire servers, but that other options are available too, where less value is lost.

Suggested change

To motivate actors in the chain to make better decisions on disposal, informing them is a suggested way of coming to this change. Actors need to be informed of the value of the materials they dispose and the revenue they can make by properly disposing. This will create a financial incentive to think through the way in which they handle their old equipment. Electronic waste should be separated more at the source and disposed of more quickly, preventing that it is stored until most reuse value is gone.

Another subject parties should be informed on, is on data security. There are many different ways of data destruction for servers in which value of the entire server or the hard drive can be retained. By highlighting this and the safety of the process, actors will hopefully dispose of their servers easier and with more value conservation.

In investing in server materials, asset lifecycle management could be a useful way to make efficient use of servers. The lifecycle of a server should be a more planned and thought about process, incorporating energy use, book value, resale value and other relevant factors. A server is bought and planned for a certain amount of time, and over the life it is checked if it is still needed, if it would be more economically advantageous to replace it, or if it should be upgraded. This would make for a more environmentally friendly server lifecycle as well as a more economically advantageous lifecycle.

Supply chain cooperation

One of the most fundamental issues with recycling and reuse of servers is the way in which they are designed. An often mentioned problem is that producers mainly focus on selling as much servers as possible. In this production cycle, the fact that servers are not upgradeable and generations follow each up quickly is in their advantage. Because upgrading is only marginally possible, it is currently better to replace servers instead of upgrading. With replacing a server, it becomes more energy efficient and more powerful. If a server could be upgraded, certain parts could be conserved, instead of having to replace the entire server. On the recycling side there are still materials which cannot be recovered through recycling. But also the way the parts are connected in a server is not yet optimal. When it becomes easier to dismantle a server into different parts, it becomes to cheaper to do it as well. This means the value of a server for recycling is higher and recyclers manual dismantling becomes more favourable over shredding.

Suggested change

There is currently not much communication or collaboration between OEMs, recyclers and refurbishers. While with more collaboration maybe servers might be designed in such a way that servers are produced so materials can be won back easily after their short life, or so that they can be upgraded and used longer. Two aspects could be changed, the recyclability and the upgradability of servers. For OEMs to change this, they are very dependent on their suppliers. From their perspective it is very important that these changes are asked for by the customers. Improvements in this area often means extra revenue for downstream parties and not for the OEMs. Therefor changes should be asked for in procurement processes, making recyclability and upgradability distinguishing factors in these processes.

Regional reuse

When servers are sold for reuse, there is no way to control where they end up. When a server is sold, the next owner can use it wherever he wants, but can also sell it again. It is not traceable what happens to servers and where they end up. This means it cannot be guaranteed that the servers are recycled when they are truly end-of-life. This is problematic as a server contains resources, which should be recovered. The resources in servers are valuable, and should preferably be kept in the region. This is especially true for the materials which are becoming increasingly scarce, the rare earth materials. By keeping them in the region it can be made sure that they are recycled, and control is kept over these valuable resources.

Suggested change

The crucial factor is the ownership of the servers. By changing the way business model of server reuse, control might be kept over the materials. Different business models like leasing or renting out servers might help, as here ownership is kept over the physical materials. Leasing already is a popular business model for servers, however this is mostly used for leasing new servers. For older servers, success has yet to be shown with employing business models like leasing.

For the reuse chain, it is problematic that it is very unclear where servers go and what amount of servers is concerned. Quantitative data is needed on how the disposal chain of server looks like. This makes it clear something should change, and can give actors who do it differently a benchmark they can improve on. It quantifies server resale in what streams are present and what costs are incurred for companies but also for the society as a whole. The potential impacts that can be prevented become clear through more availability of data.

Analysis

The results per sub question will here be linked back to the theory section.

SQ1 – Organisation of waste stream for data centre servers

In the results the different steps of disposing data centres were described. Based on these results a model can be made, as depicted in Figure 6. This model has some slight differences to the model presented in the theory section. Some steps are added and others that were not found in the results were removed.

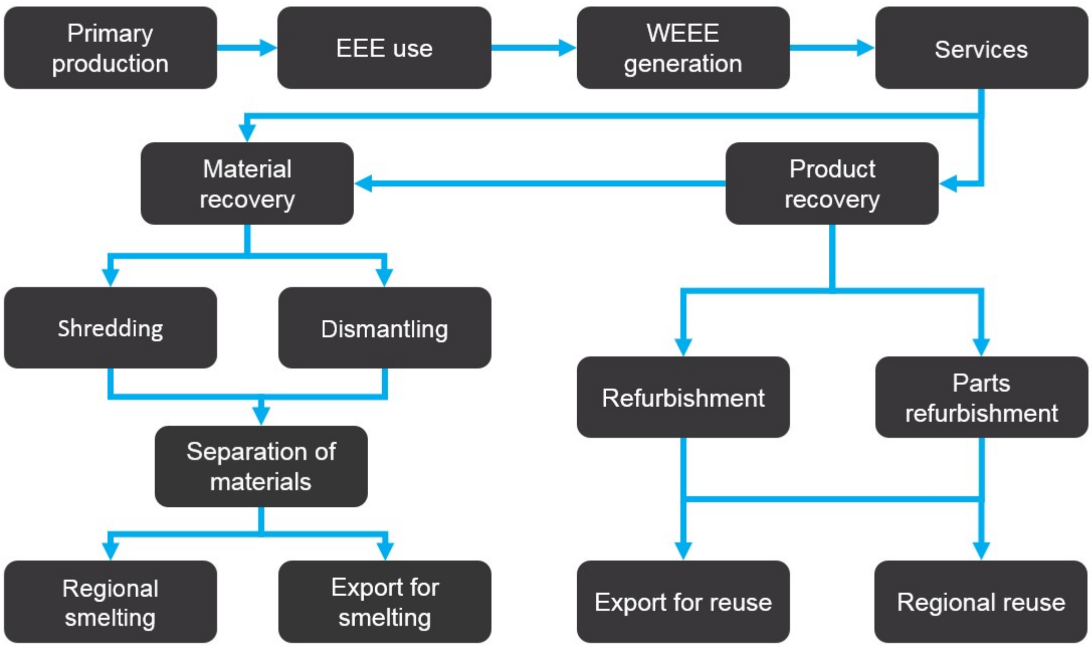

Figure 6 Flow scheme for data centre server disposal

Different from disposal of consumer waste, is that contractors are hired to take care of waste disposal. In hiring contractors to take care of the correct disposal of servers, not only the processing of waste is important, but also the services accompanying the disposal are important. Servers are collected from the user's location, are identified and data is destructed. This comes before any other action and sometimes happens already at the location of the client. The importance of data destruction is also confirmed in the ITAD disposal information in the case description. An addition to the information mentioned in ITAD texts is reporting on which hardware was erased or destructed and giving out certificates of destruction. This certificate of destruction is needed for owners of hardware in order to prove that a data leak was not possible.

Following the services, which are provided by either a recycler, a refurbisher, or an ITAD solution provider, different routes are identified. As established by Peagam et al. (2013), two main routes can be distinguished, reuse and recycling. These routes however can be differentiated however, into a total of four general routes. More combinations are possible, but less relevant for the economic and environmental values in the chain.

Shredding

In the data destruction directly a choice is made that influences the rest of the flow scheme. Simplifying the situation, a server can be shredded or data can be deleted through another method. When a server is shredded the only option is following the route to the far left and thus shredding and either recycle materials regionally or export them for recycling. With shredding of servers economic and environmental is lost. Firstly, material is lost because of dust and powder created. This means less materials is available for selling to smelters. Less financial value is recovered and also resources are wasted. More value is wasted as investments are needed in machines to separate the material, on the upside though less manual labour is needed in dismantling equipment.

When materials are separated, materials are either brought to a regional smelter or are (legally) exported to foreign countries. Here for less transportation and keeping the materials local, regional smelting is favourable over exporting. However, as this market is become increasingly regulated, making the trading of endless trading of materials difficult and forcing recycling companies to directly sell their materials to smelters. As transportation costs can be a big factor and enough demand for materials is present in Europe, materials are often not exported outside the EU.

Dismantling

A more sustainable alternative to shredding materials is by dismantling them. This way the different materials can be sorted more easily before they are brought to the associated smelter parties. The most interesting parts of the server in terms of value and resources incorporated, are the circuit boards. The specialised smelters involved in smelting circuit boards, are not local parties. Only 8-10 smelters of circuit boards are present in the world and they control how much of the rare earth materials in servers are recovered. For the Amsterdam Metropolitan Area, the facility in Hoboken, Belgium is the closest. This means for the most valuable part of the servers, currently exporting is necessary, as no facilities are present in the Netherlands.

Export for reuse

A generally more sustainable alternative to recycling, is refurbishing and reusing a product. More value is retained and the process of refurbishing is often less polluting and cheaper than virgin production. In the reuse part of the reverse supply chain the first distinction to be made is between reuse of parts and reuse of the entire server. It is hard to favour one or the other in environmental and financial values however. For older servers, refurbishment is too costly due to handling costs. Refurbishment of parts to use as spare parts for example might be a good alternative. Both the refurbishment of servers and the refurbishment of parts however do retain a lot of production value. In these steps not a lot of energy is expanded, as the products are often only tested and cleaned.

A more crucial step, is whether the services are exported or reused regionally. A refurbished server is not a waste product, is it a product which can be traded freely. The market onto which it is sold is very broad. Here it is unknown what current practice is, as parties would like to keep their clients, to which they sell servers, a secret to protect their client database. Also servers are resold often, so chances are a server is exported. With often several parties being present between a user and a next user, it might be expected that a server is exported. This means increased transportation, especially when many different brokers are present in between. It also means that resources are exported, although they are also needed in the region.

Regional reuse

As also explained above, exporting servers is unsustainable and reuse in the region should be preferred, to guarantee material recycling and reduce transportation. However, this is more difficult than it sounds. When a server is sold to the next actor, the next actor has the ownership and therefore the possibilities to do with the server what he wants. So although ideally servers would be reused in the region, the way the reverse supply chain is currently organised, this is difficult to reach.

The fact that with reuse, control over the product and whether it is exported or not, makes it very difficult to assess environmental and economic benefits. It is therefore also difficult to determine if it is generally speaking better to refurbish or recycle a server. With recycling it is easier to control what happens to materials, while with reuse more value might be recovered.

SQ2 - Incentives in the reverse supply chain

Server procurement

Green IT literature prescribes environmental targets as a tool to prevent environmental harm in server disposal. From the results it is clear that these targets are often not set in practice. In buying servers price is an important driver, together with specific demands in procurement processes. In demands targets in product selection could be included, which are energy consumption, design for the environment and design for recycling. Currently however, this is not the case. The server as well as the OEM have not made this a topic for discussion in the procurement process.

Decision to dispose

In using servers, optimized utilisation and minimised energy consumption is prescribed by literature. Here some companies have identified the financial merit of optimized utilisation and minimised energy consumption. Through analysing the total cost of ownership of servers it is possible to monitor what the optimal moment is to replace a server and opt for a new server. The energy consumption is a factor that is starting to be recognised as an important factor in the total cost of ownership, and therefore is being considered in servers. It is a difficult factor to calculate, as the energy consumption can differ on any moment based on the processing power that is needed at that moment. The more of a server's capacity is used, the more energy it uses. With less energy capacity used, the potential gains by replacing a server with a more energy efficient server also becomes smaller. So the energy use is different and the savings by replacing it with a new server are also different.

When the energy consumption of equipment is considered however, it becomes possible to better calculate the most sustainable moment for replacing a server. In theory this has shown to be related with the energy use that is needed in production of a server. This can be compared to the financial factors of the price of buying a server and the price of using a server, the energy consumption in use. The price of buying a server is already a decisive component through the deprecation of equipment over time. It is thus expected here that the environmental and economic incentives are mostly aligned.

Services

In server retirement, the most important factor for all users is data security. This is not necessarily aligned with environmentally sound retirement of assets. The most comprehensive data security solution is shredding an entire server and it gives the best sense of security. However also a part of the low and high value materials is lost, as they are turned into dust. With less intrusive methods, like software wipe, more materials can be recovered, and the reuse scenarios stay a possibility. It also is a way in which refurbishment is still a possibility. The less intrusive methods, provide more material value, and thus also a higher sale value for the user. The economic and environmental values here are thus mostly aligned. However, the sense of security is perceived by most users as more important. Another value that is often rated as more important is that a server is disposed of environmentally responsibly. This is also a sense of trust, exerted through certification or the name of a company in the market. A third important consideration in hardware disposal, is convenience for the disposing company. Hardware to be disposed is only of marginal importance, and the less time needed to dispose of it, the better. After data security, responsible disposal and convenience comes the price of the disposal. For most companies this is of minor importance but it can be a deciding factor to choose a certain way of disposal or a company. In general servers have higher value in reuse than in recycling. If costs are considered reselling will thus often will be chosen before recycling, unless the server is too old. The value of servers drops quickly over time.

Recovery

When a refurbisher receives a server, the main question is whether to recycle it or to refurbish and sell it. Here three options are present. A server can be reused, it can be used for parts and it can be recycled for scrap value. Reusing a server as a whole has the highest possible value. If the server is too old, the investment of refurbishing is not worth the revenue of sale. Secondly selling in parts is considered and when this is also not viable a server is brought to the recycler. The choice to recycle a server can thus be made twice in this flow of scheme. Once at the user, which mainly looks at the services incorporated and once at the refurbisher, in which case the economic output is the only and deciding factor.

Regional reuse versus export

For refurbishers it is very difficult to control what happens to servers. When they are incentivised by clients to make sure data centre servers are reused regionally only, they might try new things in making sure only regional reuse is possible. At this moment in time this is not the case, and limiting to only reuse in the region is a complicated issue, as well as a big limitation on the possible resell market for refurbishers. The refurbishers thus have a strong economic incentive to keep the resale as it is and set no limitations on where the server is going to be reused.

Dismantling versus shredding

For the recycler, just as with the refurbisher, the economic incentive is mostly aligned with the environmental value. For a recycler the goal is to recover as much value from the materials present in a server. For the environment, recovering as much material as possible material should be recovered to be used. When the recycler has the choice, it would be best environmentally as well as financially to dismantle servers instead of shredding them. Through customer it is sometimes demanded servers are shredded however, for data security reasons for example.

Regional smelting versus export for smelting

Exporting smelter materials means more transportation is introduced into the server. For recyclers however, the incentive is firstly to keep materials as close as possible to reduce transportation costs. This aligns the incentive not to transport, which is good for the supply chain, with the economic incentive. A crucial factor here though is that the recyclers are dependent on what the different smelters offer for a certain quality of material. Getting the best price for a batch of materials is also a strong economic incentive.

SQ3 – Change in the supply chain

The results of sub-question three give an overview of what the interviewees believe should change. The answers given will be related to what is learned from theory and the rest of the results.

The problem of awareness identified by interviewees, is reflected in the research area. B2B WEEE waste disposal is a subject not researched often, and for servers, focus has mostly been on energy use. Here especially the fact that users trust that servers are disposed correctly is relevant. Contractors like recyclers, refurbishers or ITAD solution providers are hired and that was a convenient and way to solve the problem. Maybe when the actors gain more insight in problems that are present in the disposal chain, they also get motivated to solve the problems. And some parts, like for example preventing shredding, are pieces of advice that are better for the environment and help regain more value.

Another suggestion is to create more cooperation in the supply chain. The goal here is to motivate the OEM to design their product in such a way that they are more recyclable and upgradeable. The problem is that it is not financially advantageous for OEMs to produce servers in a more recyclable or upgradeable way. In both cases the financial benefits go to other actors in the supply chain. The only way to change this is for the server users to demand a change. In this case it becomes financially advantageous for producers to change the server designs. For the users of servers, it might be beneficial refurbish and scrap values will as a result will probably increase.

A change in the business model for reuse is suggested, as it is very difficult to track the resources present in servers after they have been sold. This is related a statement made by Wagner et al (2014): as correct disposal of the materials in the servers is the most important, lengthening the lifecycle of servers is not a sustainable option. Even more so because old servers use more energy compared to new servers. The interviewees confirm that through the current way server are refurbished and resold, it is unclear where servers end up. Correct recycling of the materials a servers consist of can therefore not be ensured.

Conclusion

To tackle the societal problem of environmentally friendly disposal of data centre servers, the research question '*How to improve on the current open-loop reverse supply chain for data centre servers, to come to a more environmentally friendly, resource efficient and economically viable reverse supply chain for data centre servers, when a closed-loop supply chain is not an option?'* was posed. To answer this question a case study was performed on data centres in the Amsterdam Metropolitan Area. Literature on B2B WEEE, green IT and open-loop supply chains was used to produce a conceptual framework. Using the conceptual framework, relevant actors were identified to be interviewed. Of the interviews with different actors throughout the supply chain, transcripts were made. These transcripts were coded using the conceptual model and notes made during the interviews. Through this coding process it was possible to summarise results, which were analysed against the theory. In this entire process, the data was structured using the sub questions. Below the results are displayed per sub question.

First it should be known how the disposal is currently organised. In the open-loop reverse supply chain, the following steps are identified. First servers are procured from the OEMs. Then these servers are used, until a decision is made to dispose the servers. Both for environmental and economic reasons, the optimal moment needs to be carefully chosen. Not all crucial factors are taken into account yet. To dispose of the servers, a service is contracted from a recycling company, a refurbisher or an ITAD solution provider. The servers are collected, identified, data is destructed, and finally a report and certificate of destruction is given out. In the choice for way of data destruction, the rest of the flow is influenced. Currently servers are sometimes shredded to safely destruct data, while other options are available, which retain more environmental and economic value. Following these services, four scenarios emerge. When servers are shredded for data security, refurbishing of servers has become impossible, as well as the material recycling route were servers are dismantled manually. Instead the shredded server parts need to be sorted on the different materials. The materials are than sold to smelter factories per specific material. The second scenario is also material recycling, but now the products are dismantled instead of shredded. More value is recovered, but also more costs are made through manually dismantling the server. Through manual dismantling it becomes possible to separate the circuit boards, which are sold to a separate specialised smelter, located outside the region. This is currently the best way to recycle the circuit boards on material level.

The third scenario is in the route for refurbishing servers, either as a whole or in parts. At product recovery it is decided whether materials are worth the costs of handling to refurbishment, or if they should go to material recycling. Based on the value of the server it is decided whether a server is recycled, refurbished in parts or as refurbished as a whole. The crucial part is what happens when servers are sold. Currently they are sold to brokers, and it is uncontrollable where they end up. It is environmentally advantageous that they are reused, as more value is recovered. But control over the resources is lost. Valuable resources for the region are lost and it cannot be made sure that the materials are recovered. A preferable situation is one where refurbished servers and refurbished server parts are reused in the region. This is currently however not a real option, as no successful business model for reusing servers, whilst making sure they are not exported.

The second part in answering the research question is investigating what the incentives are to choose certain routes of server disposal. The route starts at the purchase as a server. Currently this is mostly based on price, but here an opportunity is present for server users. When they start demanding more energy efficient and upgradable servers, they have less costs over the lifetime of the server and in disposing of the server. When demands are set, it becomes financially necessary for the OEMs to act on them in order to be competitive.

In managing servers, the decision to dispose has to be made at some point. Here the economic incentive is to take as much variables in consideration as possible, in deciding what the equilibrium point is to disposing a server. Often only depreciation and hardware support contract costs are taken into account, but it would be more favourable and sustainable to include embodied impact and operational impact of the servers and a possible replacement server as well.

In the actual disposal of a server the data security is an important aspect. Here the environmental aspect is aligned with the financial aspect; less shredding means more value will be retained and less resources will be lost. But fear of data leakage is strong and shredding feels as the safest option. The incentive to secure data is stronger than the environmental and economic incentive.

In refurbishment of servers, the refurbishing parties are incentivised to refurbish a product as long as the product has market value. The market is not limited to the region but is global. It is also very difficult to control, as servers are often resold again and again until they end up at the next end-user. For refurbishers it is economically most advantageous to not limit sales to the region, as often parties from foreign countries are interested. And even if they would limit sales to the region, it is very likely servers end up outside the region in resale. Here the economic incentive and transportation/environmental incentive are clearly not aligned.

Two scenarios are clearly more advantageous, namely the server dismantling scenario and the regional reuse scenario. Especially the regional reuse scenario is difficult to reach, as here the economic incentive is to follow the export for reuse scenario. It is difficult however to make a decision between the regional reuse and the server dismantling scenario. With reuse more value is retained, where this value would be lost with dismantling and recycling a server. Old servers however consume more energy, and as operational impact for servers is bigger than embodied impact, replacement for a new and more energy efficient is more environmentally friendly than keeping an old server in use. It depends on the situation whether a server should be reused regionally or should be dismantled and recycled.

The third sub question was what involved actors can change in developing a regional reverse supply chain. Firstly, the procurement process of servers can motivate OEMs to produce servers from which more value is recovered through recycling, and which are more upgradable. A current problem in upgradability is that only marginal upgrades are possible, this makes it difficult to lengthen the lifecycle. When more drastic upgrades become possible, it can become possible to improve energy efficiency of existing servers, making it environmentally desirable to lengthen server lifecycles. Upgrades in energy efficiency are environmentally desirable as the operational impact is lowered, while only a small embodied impact is made. When users demand upgradability and recyclability, it becomes interesting for the OEM to collaborate with recyclers, smelters and refurbishers to improve on the current way of working.

A second possible action is informing server users on the possibilities in server management and disposal. With more information more informed decisions can be made. Possible improvements are less loss of value due to dismantling of servers instead of shredding. By informing users on the possible ways of securing data destruction, without shredding servers, the environmental impact of server disposal would be lowered. It would mean more parties will choose the dismantling scenario over the shredding scenario. In server management users should consider the impact of operational and embodied energy use more. This is a financial consideration which is currently not well employed. By informing users on the way to manage all the relevant costs, which thus includes the cost of energy use and possible reduced costs when servers are replaced for more energy efficient servers, more environmentally advantageous decisions will be made.

In the reuse scenarios, the regional reuse scenario is more environmentally friendly, but currently not realistic. It is not yet possible to refurbish servers and sell them for reuse in such a way that the materials stay in the region, which is preferable over exporting. The interviewees rightly stated that new business models are needed to solve this problem. Leasing second hand servers might be solution for example, as when leasing is the case ownership is retained by the refurbishing party. Problematic however, is that the economic incentive for refurbishers is to export servers, as in the region demand for older servers is low. A solution might be that users of servers demand that servers stay in the region after refurbishment, when the contract refurbishers. Problematic however is that for them the incentive is also not in favour of limiting sale to the region. Here a clear trade-off in incentives is present to which no solution is present at this moment.

In coming to a more environmentally friendly, resource efficient and economically viable reverse supply chain for data centre servers, the two scenarios dismantling servers and regional reuse are more sustainable than the two scenarios of shredding servers and exporting for reuse. Changing towards dismantling for reuse is the easier of the two changes here. To motivate actors to dismantle servers, the server users should be informed on the possibilities in data destruction, which do not involve shredding, but do provide adequate data destruction. In order for servers to be reused regionally, a new business model is needed that guarantees materials will stay in the region, instead of entering the uncontrollable global second hand server market. The difficulty here is that the economic incentive is currently towards the global export route. When comparing which is more environmentally friendly, resource efficient and economically viable, dismantling or regional reuse, it is difficult to come to a conclusion. More information is necessary to be able to conclude on that choice.

Discussion

In order to come to a truly environmentally friendly, resource efficient and economically viable reverse supply chain for servers, some issues need to be resolved. In some cases, more research is necessary to come to a solid conclusion.

Reuse is in the circular economy traditionally more sustainable than recycling, as more value is retained. However, for the reverse supply chain for servers, trade-offs occur in reusing servers. Here a consideration has to be made between using servers with less energy efficiency longer, while having no control over resource recycling, or directly recycling servers and losing potential reuse value. Daoud (2008) for example says that in managing servers optimising energy consumption is a target for an environmental friendly operation of IT, but on the other hand also the lifecycle of a server should be as long as possible. This can be seen as a contradiction. Newer servers are more energy efficient, making it possible to have a lower energy use. Newer servers are needed to optimise energy consumption while also lifecycles should be elongated. Wagner (2014) reasons that servers should always be recycled, to make sure the resources are recovered. Here the focus should be on improving the product design, instead of lengthening the lifecycle of the product (Quariguasi Frota Neto et al., 2010). Following this reasoning, servers should not be reused, but always recycled. Because of these contradictions, it remains unclear when to replace servers and whether to recycle or reuse them. With more research into the decision-making whether a server lifecycle should be elongated, and when it is better to recycle a server, it can become more clear when to recycle versus reuse a server.

Another issue in the reverse supply chain for servers, which has not received much attention in this research, but should be investigated further, is the smelting of circuit boards. This is a process where not much is known about and where only very few actors are active in. Only one specific smelter party for circuit boards, was mentioned and was mentioned often, namely Umicore in Belgium. Circuit board smelters are the only actors who are involved in physically dismantling the circuit boards, but they are also the group of actors the least is known about. They are relatively closed, whereby it is unknown what challenges are in recycling of circuit boards, what amount of the resources invested in a server can be recovered, and what materials are lost in this process. More information on this process is needed, in order to be able to make solid conclusions of the sustainability of the recycle process. This research has also focused much on the circuit boards in the recycling process, as these are the most valuable parts. The rest of the materials have received limited attention in comparison, also as interviewees did not focus on the other materials. But although these materials contain less value, still the resources should be recovered. Investigating these materials and the sustainability of recycling these is therefore an interesting subject for further research.

Another gap identified in the literature, was a lack of focus on sustainability in open-loop reverse supply chains. Often it is assumed closed-loop models offer more environmental value, and thus should be preferred over open-loop models. For some supply chains however, these closed-loop models are unrealistic and idyllic visions. This research can serve as an example of what environmental goals should be set in such situations. Other supply chains possibly have similar issues however, which deserve attention.

This research has provided in bringing insight in the material flows of B2B WEEE, specifically for data centre servers. Research by Peagam et al. (2013) has shown that this is relevant subject with different variables than are apparent for WEEE from the consumer market. This research confirms that also for data centre servers these differences hold. More research in the B2B reverse supply chain is necessary, for example so that policy makers can make appropriate policies which better account for the B2B market.

Being a case study, with only one case, not being able to extrapolate results to other cases of server disposal in different regions is a limitation. As an explorative case study however, results of this case study could be used in further investigating disposal of servers. Reliability in the case study itself however, is a different situation. Here it is important to interview as much actors in different roles in the supply chain as possible. A lot of different actors were spoken, working in different positions in the server supply chain. For some actors a good overview of the market was gained, for example with OEMs and with recyclers. However, for users of servers it was more difficult to get access. Here also a wide array of actors is involved on different levels, where for OEMs only a couple of parties control the market. Big hosting firms operate in data centres, but also small companies are present. In this research it was tried to speak to as many different type of actors as possible, but unfortunately only three server users were interviewed. In all three of these companies two different employees were interviewed however, increasing the quality of information. This was directly also a problem in some of the other interviews. In most interviews only one actor was interviewed, who did not always have a complete knowledge on the relevant subjects for the interviews. The lack of interviews and constrained knowledge of some interviewees limit the reliability of the case study. Speaking to different people in the same organisation and all the different actors identified beforehand guarantees however most viewpoints are covered. Also the fact a lot of the same remarks were made by different actors shows the research came close to saturation of viewpoints.

In the content validity of the research, the main limitation was in the third sub question. In the first and second sub question the operationalisation was clear through the indicators set by theory. This helped in finding a clear overview of current actors as well as their incentive in the supply chain. In the third sub question however it was asked really openly what actors would change or improve in the supply chain. The answers here were really diverse and not always as focused on the core of the problem. Here more theoretical basis could have been sought or the question could have been better operationalised. The construct validity, the research design to test the research question thus was not perfect, but the content validity was good. The answers that were given, when focused on the core problems did provide correct indicators for the identified problem. Further research might use the conclusions of this research to better operationalise the changes needed to come to a regional reverse supply chain.

Advice for EvoSwitch

EvoSwitch is a supplier of carrier neutral colocation services. They own and operate data centres where they rent conditioned space to clients and provide supporting services. They do not actually own servers but they provide server space, cooling, power, redundant power, carrier connection and security. In the supply chain as illustrated in this research the colocation providers like EvoSwitch are not represented as an actor type. They are in close connection to the server users however, as these are their direct customers. In this sense no direct role in the supply chain is taken, but they are a closely involved with the core of the supply chain, namely the actual users of servers. For EvoSwitch sustainability is a core value. This is expressed through the use of 100% green electricity and through efficient cooling of the servers. Innovative techniques were adopted to reduce the power usage effectiveness (PUE). In data centres a lot of extra equipment, like cooling and backup power, is present to make sure the servers run continually, even in case of for example power outages. The PUE is a measure where the total power use of the servers and the equipment together is set off against the power use of the servers alone (Vereecken et al., 2012). As a colocation provider is the owner of the supporting equipment, this is a measure they have influence on. In recent years this PUE for the EvoSwitch data centre was improved, capturing the majority of low-hanging fruit in cooling effectiveness. EvoSwitch is now looking for further ways of portraying their sustainability. In this enacting this intention, they initiated this research, to look into ways to help in making the disposal of servers more environmentally friendly and resource efficient.

What EvoSwitch is looking for is a way to take a role in the correct disposal of servers, where servers are disposed more environmentally friendly on the one hand, and on the other more value is created for the server users. The first opportunity is simply informing customers on the possibilities in server disposal. By explaining the major impact of server energy use in the total cost of ownership, it becomes possible for clients to take more informed decisions on when to replace servers. Another important distinction EvoSwitch can inform server users on, is the preferable scenarios of disposal to be followed, namely dismantling of servers and regional reuse of servers. With knowing what scenarios to follow, it becomes possible to dispose servers in a way that more value is recovered, while data security, responsible disposal and convenience are ensured. Actors can be informed on the crucial steps in reaching the desired scenarios. To prevent servers ending up in the shredding scenario, data destruction services can be demanded where a server and its hard drive stay physically intact, for example. A recycling party can be sought who is active in reaching the best possible sorting on quality of circuit boards, while invaluable easy to remove parts are stripped, for example the cooling fins. These actors recover more value, meaning more value for the actor disposing the server as well. Another thing important is that the correct regulations are followed. Most important here is the WEEELABEX certification, but other quality labels are possible too. Additionally, it can be checked to what countries materials are exported to, and whether keeping materials as close as possible is really a goal for the recycler, as predicted in this research.

The main problem with reusing servers is the question what happens with the resources, when the server life ends at the next server user. This is something that no real solution has been found for yet. Some new business models are being developed, like for example leasing second hand servers, but this has yet to prove itself as being successful. In procuring disposal at a refurbishing party, this is an important subject. When it cannot be made certain materials stay close to home and are recycled at end-of-life, recycling is a more sustainable option for servers, especially when older servers are considered. The older a server is, the bigger the chance is the server is exported to other continents where recycling facilities might not be in place. It is also important to know to what recycler servers are brought that are not refurbished, and what policies are in place to ensure proper recycling of the servers.

Another possibility is starting a partnership with a recycler or refurbisher in order to bring more convenience to data centre clients. Convenience in server disposal is a sought after aspect by server users and choosing the correct partner for the data centre clients might be an extra step in this convenience. The choice of partner is crucial though. Data security and responsible disposal are most important in choosing a partner, as these are critical factors for the clients in the data centre. Partnership could be sought with actors willing to improve on the current situation in recycling and willing to innovate in reuse of servers. For a partner it might for example be interesting to provide data destruction servers on site, so EvoSwitch client can make sure data is safely and conveniently deleted, after which transportation for various clients might be combined. By talking with actors active in disposing electronics, opportunities for similar win-win situations might arise.

To conclude, the core of the advice for EvoSwitch is to start the conversation on proper disposal of data centre servers. Servers are often replaced, but what exactly happens to servers is something not a lot of actors are totally aware of. Here a lot of servers might end up in the environmentally less desirable scenarios of export for reuse and shredding, while more economic and environmental value would have been gained by dismantling and regionally reusing servers. Start by organising an event and invite someone who has experience in aiming for environmental disposal of servers and start the discussion on what actors perceive as sustainable in data centre server disposal.

References

Alsheyab, M. (2014). WEEE Recycling: Analysis of Materials Potential Recovery from High-Grade WEEE. *Journal of Civil & Environmental Engineering*, *04*(03), 1–5. http://doi.org/10.4172/2165-784X.1000143

Bigum, M., Brogaard, L., & Christensen, T. H. (2012). Metal recovery from high-grade WEEE: A life cycle assessment. *Journal of Hazardous Materials*, *207-208*, 8–14. http://doi.org/10.1016/j.jhazmat.2011.10.001

Brannon, C. (2006). Unique Reverse Logistics Challenges of IT Asset Disposition. *Reverse Logistics Magazine*, *Summer 200*.

Bryman, A. (2012). *Social research methods* (Fourth edi). New York: Oxford University Press Inc.

Bufardi, A., Gheorghe, R., Kiritsis, D., & Xirouchakis, P. (2004). Multicriteria decision-aid approach for product end-of-life alternative selection. *International Journal of Production Research*, *42*(16), 3139–3157. http://doi.org/10.1080/00207540410001699192

Chang, J., Meza, J., Ranganathan, P., Bash, C., & Shah, A. (2010). Green Server Design: Beyond Operational Energy to Sustainability. *The 2010 Workshop on Power Aware Computing and Systems (HotPower)*, (1), 1–5. Retrieved from http://www.usenix.org/events/hotpower10/tech/full_papers/Chang.pdf

Corsini, F., Rizzi, F., Gusmerotti, N. M., & Frey, M. (2015). Extended Producer Responsibility and the Evolution of Sustainable Specializations: Evidences From the e-Waste Sector. *Business Strategy and the Environment*, *24*(6), 466–476. http://doi.org/10.1002/bse.1831

Cramer, J. (2014). *Moving Towards a Circular Economy in the Netheralnds: Challenges and Directions*.

Cramer, J., & Nederstigt, J. (2015). *De Metropoolregio Amsterdam als Circulaire Grondstoffen Hub*.

D'Amico, C. D., & White, B. (2012). IT Asset Disposition. *Communications of the IIMA*, *12*(1), 34–46.

Dao, V., Langella, I., & Carbo, J. (2011). From green to sustainability: Information Technology and an integrated sustainability framework. *The Journal of Strategic Information Systems*, *20*, 63–79. http://doi.org/10.1016/j.jsis.2011.01.002

Daoud, D. (2008). *White Paper - Beyond Power : IT ' s Roadmap to Sustainable Computing*. Framingham, MA, USA.

Defee, C. C., Esper, T., & Mollenkopf, D. (2009). Leveraging closed-loop orientation and leadership for environmental sustainability. *Supply Chain Management: An International Journal*, *14*(2), 87–98. http://doi.org/10.1108/13598540910941957

Deshpande, B. A., & Kuware, R. (2015). Green Computing : The approaches to Go Green. *International Journal on Recent and Innovation Trends in Computing and Communication*, *3*(2), 93–95.

Douma, A. (2016). *Netherlands Circular Hotspot - Sharing Innovation*.

Elliot, S. (2007). Environmentally Sustainable ICT : A Critical Topic for IS Research ? *Pacific Asia Conference on Information Systems (PACIS, 2007)*, *Paper 114*, 100–112.

Fleischmann, M., Bloemhof-Ruwaard, J. M., Dekker, R., van der Laan, E., van Nunen, J. a. E. E., & Van Wassenhove, L. N. (1997). Quantitative models for reverse logistics: A review. *European Journal* *of Operational Research*, *103*, 1–17. http://doi.org/10.1016/S0377-2217(97)00230-0

Flick, U. (2009). *An Introduction to Qualitative Research* (Fourth Edi). London: SAGE Publications.

Forge, S. (2007). Powering down: remedies for unsustainable ICT. *Foresight*, *9*(4), 3–21. http://doi.org/10.1108/14636680710773795

Georgiadis, P., & Besiou, M. (2010). Environmental and economical sustainability of WEEE closed-loop supply chains with recycling: A system dynamics analysis. *International Journal of Advanced Manufacturing Technology*, *47*, 475–493. http://doi.org/10.1007/s00170-009-2362-7

Geyer, R., & Jackson, T. (2004). Supply loops and their constraints: The Industrial ecology of recycling and reuse. *California Management Review*, *46*(2), 55–73. http://doi.org/10.1016/S0161-6420(98)96023-7

Gobbi, C. (2011). Designing the reverse supply chain: the impact of the product residual value. *International Journal of Physical Distribution & Logistics Management*, *41*(8), 768–796. http://doi.org/10.1108/09600031111166429

Gou, Q., Liang, L., Huang, Z., & Xu, C. (2008). A joint inventory model for an open-loop reverse supply chain. *International Journal of Production Economics*, *116*(1), 28–42. http://doi.org/10.1016/j.ijpe.2008.07.009

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, *240*, 603–626. http://doi.org/10.1016/j.ejor.2014.07.012

Graedel, T. E. (2010). *Metal Stocks in Society - Scientific Synthesis*. (International Panel for Sustainable Resource Management, Ed.). Paris.

Guide, V. D. R., Harrison, T. P., & Wassenhove, L. N. Van. (2003). The Challenge of Closed-Loop Supply Chains. *Interfaces*, *33*(6), 3–6.

Guide, V. D. R., & Van Wassenhove, L. N. (2009). The Evolution of Closed-Loop Supply Chain Research. *Operations Research*, *57*(1), 10–18. http://doi.org/10.1287/opre.1080.0628

Gungor, A., & Gupta, S. M. (1999). Issues in environmentally conscious manufacturing and product recovery: A survey. *Computers and Industrial Engineering*, *36*, 811–853. http://doi.org/10.1016/S0360-8352(99)00167-9

Hammond, D., & Beullens, P. (2007). Closed-loop supply chain network equilibrium under legislation. *European Journal of Operational Research*, *183*(2), 895–908. http://doi.org/10.1016/j.ejor.2006.10.033

Hanselman, S. E., & Pegah, M. (2007). The Wild Wild Waste : e-Waste. *SIGUCCS ' 07 Proceedings of the 35th Annual ACM SIGUCCS Fall Conference*, 157–162. http://doi.org/10.1145/1294046.1294083

Harmon, R. R., Demirkan, H., & Raffo, D. (2012). The next wave of sustainable IT. *Foresight*, *14*(2), 121–138. http://doi.org/10.1109/MITP.2010.140

Huisman, J., Botezatu, I., Herreras, L., Liddane, M., Hintsa, J., Luda di Cortemiglia, V., … Bonzio, A. (2015). *Countering WEEE Illegal Trade (CWIT) Summary Report, Market Assessment, Legal Analysis, Crime Analysis and Recommendations Roadmap,*. Lyon, France.

Huisman, J., Stevels, A., Marinelli, T., & Magalini, F. (2006). Where did WEEE go wrong in Europe? Practical and academic lessons for the US. *IEEE International Symposium on Electronics and the Environment*, *2006*, 83–88. http://doi.org/10.1109/ISEE.2006.1650039

Huisman, J., van der Maesen, M., Eijsbouts, R. J. J., Wang., F., Baldé, C. P., & Wielenga, C. A. (2012). *The Dutch WEEE Flows*. Bonn, Germany: United Nations University.

ICT Milieu. (2014). *ICT Milieumonitor 2014*.

Krikke, H. R., van Harten, A., & Schuur, P. C. (1999). Business case Océ : Reverse logistic network re-design for copiers. *OR Spektrum*, *21*, 381–409.

le Fèvre, S., & Leclercq, M. (2013). *Data centres establishment policy: The Amsterdam region as Green Data Port*. Amsterdam.

Murugesan, S. (2008). Harnessing Green IT: Principles and Practices. *IT Pro*, (January/February), 24–33. http://doi.org/10.1002/9781118305393

Nederland ICT. (2013). *Meerjarenplan Energie Efficiency - ICT-sector 2013-2016*. Woerden.

Pazowski, P. (2015). Green Computing: Latest practices and technologies for ICT sustainability. *Managing Intellectual Capital and Innovation for Sustainable and Inclusive Society; Management, Knowledge and Learning; Joint International Conference 2015*, 1853–1860.

Peagam, R., McIntyre, K., Basson, L., & France, C. (2013). Business-to-Business Information Technology User Practices at End of Life in the United Kingdom, Germany, and France. *Journal of Industrial Ecology*, *17*(2), 224–237. http://doi.org/10.1111/jiec.12017

Quariguasi Frota Neto, J., Walther, G., Bloemhof, J., van Nunen, J. a. E. ., & Spengler, T. (2010). From closed-loop to sustainable supply chains: the WEEE case. *International Journal of Production Research*, *48*(15), 4463–4481. http://doi.org/10.1080/00207540902906151

Rubio, S., Chamorro, A., & Miranda, F. J. (2008). Characteristics of the research on reverse logistics (1995–2005). *International Journal of Production Research*, *46*(4), 1099–1120. http://doi.org/10.1080/00207540600943977

Sander, K., Schilling, S., Naoko, T., Rossem, C. Van, Vernon, J., & George, C. (2007). The Producer Responsibility Principle of the WEEE Directive. *DG ENV. Study Contract N° 07010401/2006/449269/MAR/G4*, 319. Retrieved from http://ec.europa.eu/environment/waste/weee/pdf/final_rep_okopol.pdf

Schenkel, M., Krikke, H., Caniëls, M., & Van der Laan, E. (2015). Creating integral value for stakeholders in closed loop supply chains. *Journal of Purchasing and Supply Management*, *21*, 155–166. http://doi.org/10.1016/j.pursup.2015.04.003

Schiller, S., & Merhout, J. W. (2011). IT Asset Disposition Services: A Green Solution for the Enterprise. *17th Americas Conference on Information Systems (AMCIS)*, 1–6.

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, *16*, 1699–1710. http://doi.org/10.1016/j.jclepro.2008.04.020

Toffel, M. W. (2003). The growing strategic importance of end-of-life product management. *California Managemnt Review*, *45*(3), 102–129. http://doi.org/10.1109/EMR.2003.24907

Vanner, R., Bicket, M., Withana, S., Brink, P. Ten, Razzini, P., Dijl, E. Van, … Hudson, C. (2014). *Scoping study to identify potential circular economy actions , priority sectors, material flows and value chains*.

Vereecken, W., Vanheddeghem, W., Colle, D., Pickavet, M., Dhoedt, B., & Demeester, P. (2012). The environmental footprint of data centers: The influence of server renewal rates on the overall footprint. In *Lecture Notes in Electrical Engineering* (Vol. 113, pp. 823–831). Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84855698448&partnerID=40&md5=742cbf1f71f8010c8b09ee49a978ded2

Vermeulen, P., & Patel, M. (2016). *2016 Report State of the Dutch Data Centers - The new foundation*.

Wagner, M., Feldhaus, C., Fox, P., Li, F., Milford, K., Little-wiles, J., & Hundley, S. (2014). Exploring the Sustainability Life Cycle of Enterprise Computers in Higher Education. *2014 Proceedings of PICMET '14: Infrastructure and Service Integration*, 1523–1533.

Walther, G., Steinborn, J., Spengler, T. S., Luger, T., & Herrmann, C. (2010). Implementation of the WEEE-directive-economic effects and improvement potentials for reuse and recycling in Germany. *International Journal of Advanced Manufacturing Technology*, *47*, 461–474. http://doi.org/10.1007/s00170-009-2243-0

Wang, L., Wang, X. V., Gao, L., & Vánczac, J. (2014). A cloud-based approach for WEEE remanufacturing. *CIRP Annals - Manufacturing Technology*, *63*(1), 409–412. http://doi.org/10.1016/j.cirp.2014.03.114

Wells, P. E., & Seitz, M. (2005). Business models and closed-loop supply chains: a typology. *Supply Chain Management: An International Journal*, *10*(4), 249–251. http://doi.org/10.1108/13598540510612712

Whitehead, B., Andrews, D., & Shah, A. (2015). The life cycle assessment of a UK data centre. *International Journal of Life Cycle Assesment*, *20*, 332–349. http://doi.org/10.1007/s11367-014-0838-7

Whitehead, B., Andrews, D., Shah, A., & Maidment, G. (2014). Assessing the environmental impact of data centres part 1: Background, energy use and metrics. *Building and Environment*, *82*, 151–159. http://doi.org/10.1016/j.buildenv.2014.08.021

Whitehead, B., Andrews, D., Shah, A., & Maidment, G. (2015). Assessing the environmental impact of data centres part 2: Building environmental assessment methods and life cycle assessment. *Building and Environment*, *93*, 395–405. http://doi.org/10.1016/j.buildenv.2014.08.015

Yin, R. K. (2009). *Case Study Research: Design and Methods* (Fourth Edi). Thousand Oaks, California: SAGE Inc.

Ylä-Mella, J., Poikela, K., Lehtinen, U., Tanskanen, P., Román, E., Keiski, R. L., & Pongrácz, E. (2014). Overview of the WEEE Directive and Its Implementation in the Nordic Countries : National Realisations and Best Practices. *Journal of Waste Management*, *2014*, 18.

Zoeteman, B. C. J., Krikke, H. R., & Venselaar, J. (2010). Handling WEEE waste flows: On the effectiveness of producer responsibility in a globalizing world. *International Journal of Advanced Manufacturing Technology*, *47*(5), 415–436. http://doi.org/10.1007/s00170-009-2358-3

Appendix – Interviewees

#	Firm	Actor type	Role interviewee
1	Leaseweb	User	Logistics
2	HKS Metals	Recycler	Sales
3	Parnassia	User	Procurement
4	Parnassia	User	IT management
5	KPN International	User	IT management
6	Hewlett Packard Enterprise	OEM	Sales
7	Hewlett Packard Enterprise	OEM	Sales
8	Infotheek	Refurbisher	Sales
9	Sims	Recycler/refurbisher	Sales
10	Nijssen recycling	ITAD solution provider	Sales
11	Dell	OEM	Sales
12	Siso	ITAD solution provider/refurbisher	Director business development
13	KPN International	User	IT Disposal
14	Lenovo	OEM	Sales
15	Lenovo	OEM	Sales
16	Coolrec	Recycler	Marketing
17	GreenIT	NGO	Communication
18	Leaseweb	User	Supply chain manager